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Streamflow extreme value analysis using correlation of streamflow data with TRMM derivatives at Bone Watershed Gorontalo, Indonesia

W G Prakoso[1], K Murtilaksono[2], S D Tarigan[2],Y J Purwanto[3]
[1]Graduate School Bogor Agricultural University, Jl. Raya Darmaga, Gedung Sekolah Pascasarjana IPB, Kampus IPB Darmaga Bogor 16680 - Jawa Barat, Indonesia
[2]Watershed Management, Departement Of Soil Science and Land Resources, Jl. Meranti Kampus IPB Darmaga, Bogor 16680
[3]Department Of Civil and Environmental Engineering, Gedung FATETA Jl. Lingkar Akademik, Jawa Barat 16680, Indonesia

E-mail: wahyu_prakoso@apps.ipb.ac.id

Abstract. Most recent studies that have attempted to use rainfall dataset for continuous modelling of rainfall-runoff have found that, without detailed local calibration against traditional rain-gauge measurements, the TRMM data is simply not accurate enough for that purpose. This is partly a result of the coarse spatial resolution of the dataset, with each grid cell being 0.25° x 0.25°, and partly to do with the inherent difficulty in remotely sensing rainfall intensity. For this study, however, it was decided to derive a more general rainfall parameter, the total amount of rainfall calculated to have fallen on each of the delineated catchments, processed as a mean annual total, (in m^3), and to see how closely that was correlated with the streamflow data. Considering that most of the streamflow data available is from 2007 – 2010, TRMM V6 3B42 3 hourly data covering this four year period were used.Given the lack of long-term data both discharge and rainfall, at Bone Watershed, Gorontalo Province, Indonesia), the limitations of an Extreme Value Analysis using such a short data set must be stressed from the outset. Most data sets available comprise approximately 3 – 4 years of data, which are insufficient to provide reliable predictions of discharge events with large return periods. A satisfactory hidrological correlation could be achieved using catchments weighted time series of TRMM daily rainfall data after scaling, with streamflow data from Bone River (Alale and Tulabolo) to obtain a time series of simulated discharge. Realatively reliable extrema value estimation on the design flood parameter were produced with resasonable several limitation.

1. Introduction

Natural adverse events such as floods from high precipitation and floods from upstream dam failures, earthquakes, landslides and sedimentation are also important contributors to risk to the dam safety. In the case of hydrologic loads the development of flood frequency relationships and reservoir inflow hydrographs are important inputs to the risk analysis process. For risk analysis, the focus of flood evaluations shifts from a single maximum event, like the probable maximum flood, to describing a range of plausible inflow flood events. Extreme Value Analysis (EVA) of rainfall events and flood play vital role in the design process of dams. Floods from high precipitation are the most significant natural events that can impact dams and pose a hazard to people and property. Failure to account for these events has been costly both to dam owners and the public in general. Flash floods can happen anywhere, even in small watersheds. Therefore, flood potentials must be included in risk analyses for dam failure.

Dams are, without doubt, among the safest structures constructed by man. Indeed, dam engineers spare no effort in order to ensure that every dam is conceived, built and maintained according to the best experience, the most exacting criteria and the most advanced knowledge. And these efforts are, by and large, extremely successful.

Extreme value analysis on flood discharge that are generally used divided into three category based on data availability: first when time series of the discharge are available, statistical and distribution analysis will be used, second when rainfall data available in the region, rainfall-runoff model approach will be used, and third if relatively there is no data available, regionalization approach will be used. Those approach and techniques inherent a high degree of uncertainty and weakness.

Most recent studies that have attempted to use this rainfall dataset for continuous modelling of rainfall-runoff have found that, without detailed local calibration against traditional rain-gauge measurements, the TRMM data is simply not accurate enough for that purpose[1-3].This is a result of the coarse spatial resolution of the dataset, with each grid cell being 0.25° x 0.25°), and partly also causing by the inherent difficulty in remotely sensing rainfall intensity.

In general, the approach to estimating reliable flow characteristics for ungauged catchments (or catchments with limited/unreliable streamflow data) is some form of transference or extrapolation of information from gauged catchments to ungauged sites, in a process known as regionalisation [4-6].

1.1. Objective

The primary objective of this study are:

a. Correlation analysis of Streamflow Data With TRMM Derivatives
b. Determine/ making Design Flood estimation with extreme value analysis (precipitation, and flood) on ungauged catchment.

1.2. Scope of Works

Scope of works during this study are limited to:

a. TRMM Rainfall Satellite Data Analysis
b. Regionalization Streamflow Data Analysis on Minahasa Peninsula
c. Rainfall- Run off Modelling.

2. Methods

2.1. Location

This study is located in the Indonesian province of Gorontalo, found midway along the northern arm of Sulawesi (known as the Minahassa Peninsula). The province's mainland is dominated by hills and mountains, with elevations ranging from 0 – 2,060 m above sea level and slopes generally between 0 – 40° [7]. This study will evaluate Bone Watershed representing one ot the biggest watersheds in the region.

2.2. Data and Software

Data and Software which are used in the study is shown in table 1.

Table 1. Data and software

Data	Source	Note	Software	Version
DEM	SRTM		ArcGIS	10.1
River Polyline	SRTM, RBI		SAGA	
Rainfall Satellite Data	TRMM, GSMap	TRMM 3B42 Ver.7	DHI MIKE	11
Evaporation	BMKG		SMADA	
Raingauge	BWS, BMKG		MS Excell	2007-2010
Discharge	BWS			2008-2014
Landsystem	BIG	1: 250,000		
Land Unit	BBSDLP			
Groundwater	BGL ESDM	1: 250,000		

2.3. Flow Chart
Working flow of the study are as follows (figure 1).

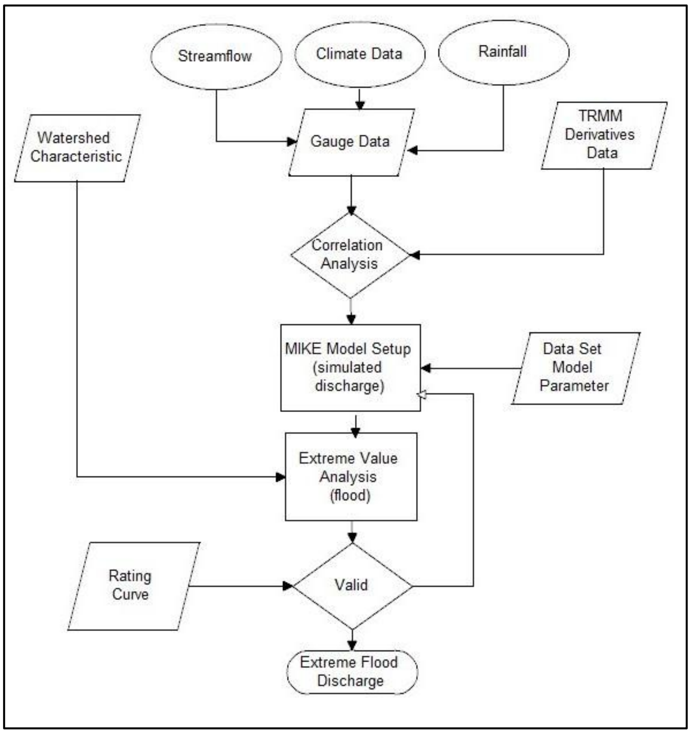


Figure 1. Research flow chart.

3. Results/Discussion

3.1. Watershed Characteristic
Bone watershed located at Minahasa Peninsula, it's covers both part of Gorontalo Province and North Sulawesi Province, Indonesia (figure 2). Based on spatial analysis, watershed area of study ± 1,000 km^2 (table 2). The province's mainland is dominated by hills and mountains, with elevations ranging from 0 – 2,060 m above sea level and slopes generally between 0 – 40° [7]. Gorontalo experiences a fairly typical equatorial climate with two main seasons: rainy and dry. Throughout the province,

average annual rainfall is approximately 1,500 mm, with December typically being the wettest month of all. Mean temperatures are relatively uniform at sea level (around 25 – 28°C), although can be lower in the highlands.

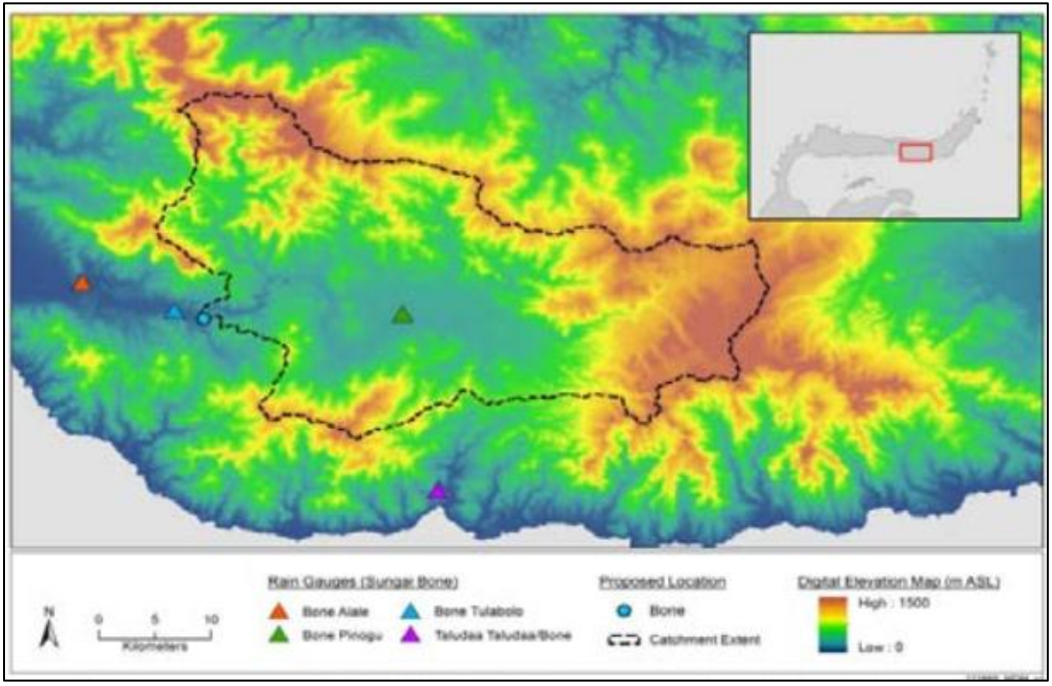


Figure 2. Bone Watershed and Catchment area of study.

Bone watershed is radial type watershed where the watershed forms resembling a fan, creeks concentrate to a point radially, generally relatively large floods occur at the confluence of tributaries. Flow pattern the river in the Bone River follows a dendritic pattern, meaning the river flow pattern forms like tree branching, irregular branching with direction and various angle, with small river branches coming from various directions on the steep slopes of the hill then fused in the main river. Based on the consistency test conducted on three stations, it was found that the consistent stations were Bone Tulabolo, and Bone Alale, while Bone Talumolo was not consistent so it was not used further in this study.

Table 2. Summary of catchment parameters.

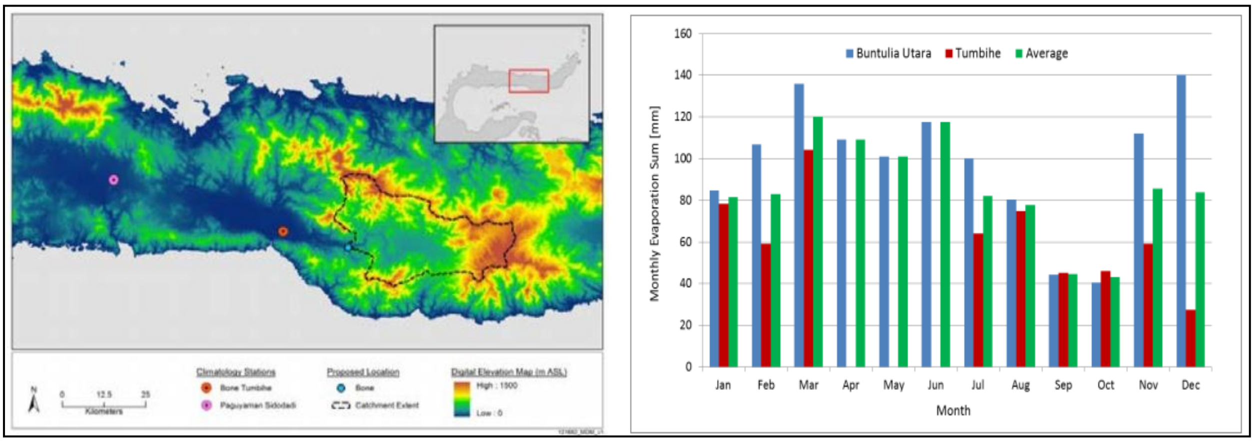
Parameter	Unit	Bone River Catchment
Catchment Area	(km^2)	1,000.9
Dominant Soil Group		Acrisols
Minimum elevation	(m ASL)	94
Mean Elevation	(m ASL)	803
Maximum Elevation	(m ASL)	1,941
Mean Slope	(%)	28.5

The following is the numerical summary of discharge data available from gauge station at Bone watershed (table 3).

Table 3. Numerical summary of discharge data available from gauge station at Bone Watershed.

Parameter	Unit	04 2 20 03 04 Bone Tulabolo	04 2 20 03 02 Bone Alale	04 2 20 03 03 Bone Talumolo
Catchment Area	(km^2)	1,003	1,192	2,727
Longitude	(decimal degrees)	123.267	123.171	123.063
Latitude	(decimal degrees)	0.499	0.531	0.5156
Data Used		2010-2011	2008-2011	Not Used
Median Discharge	(m^3/s)	150.3	176.4	
Mean Discharge	(m^3/s)	154.4	176.8	
No of Records		1612	1612	911

Another meteorological parameter potentially of relevance to the current study is evaporation, data for which were sourced by the BMKG, with daily values available from two primary locations in Gorontalo (Tumbihe and Buntulia Utara). These values are Pan 'A' Evaporation data, available for a period of four years (2007 -2010) (Buntulia Utara), and two years (2009 – 2011) (Tumbihe). The locations of these climatological stations are shown in figure 3. Although neither station is actually within the catchment boundary of the site. Evaporation is generally less spatially-variable than parameters such as rainfall.



(a) (b)

Figure 3. Evaporation stations available on catchments (a), Mothlyevaporation values from Buntulia Utara and Tumbihe as well as an average of two station's data (b).

Evaporation is frequently represented in terms of monthly totals. Figure 3 (b) presents three time-series of monthly evaporation totals: from Buntulia Utara and Tumbihestations, as well as an average of the two. This average may be considered a reasonable estimation during periods for which no local data are available.

3.2. Correlation Analysis

A great number of plots were drawn to investigate potential correlations between the discharge data descriptives and the individual catchment characteristics. Correlation assessment was primarily visual and qualitative, in order toidentify the catchment parameters of relevance (i.e. those that appeared to have some correlation with the streamflow data). These parameters were then analysed using software based on genetic programming – an evolutionary algorithm-based methodology that mimics biological evolution to test and constantly refine possible relationships between the data [8], the specific discharge data characteristics which were consideredincluding:

a. Median discharge
b. Mean discharge
c. Interquartile Range (IQR)
d. Quartile Skew Coefficient (QSC)
e. Discharge percentiles, (1%, 5%, 10%, 25%, 75%, 90%, 95%, 99%).

In terms of the catchment characteristics derived for correlation tests, they included thefollowing:
a. Delineated Catchment Area
b. Catchment Elevation Derivatives
c. Drainage Class of Soil Type
d. TRMM Rainfall data Derivatives.

Perhaps the most significant catchment parameter for which data are available is the catchment area. The distribution and catchment extent of the streamflow gauges sourced for the current study is shown in figure 4.

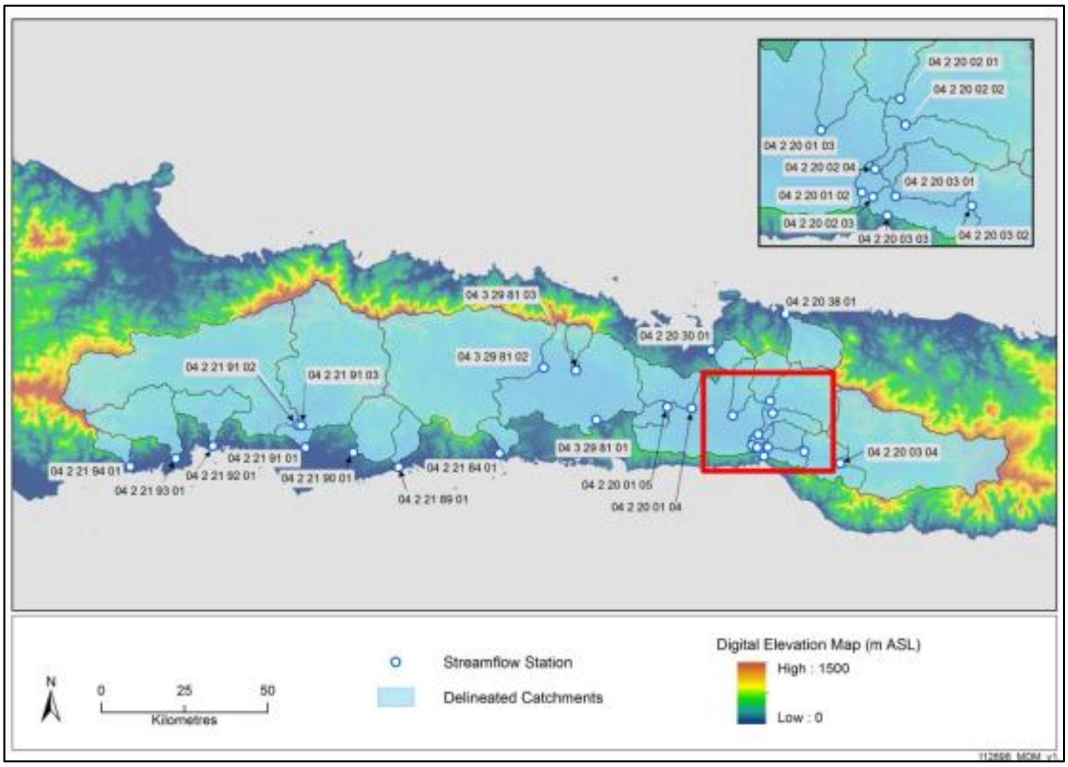
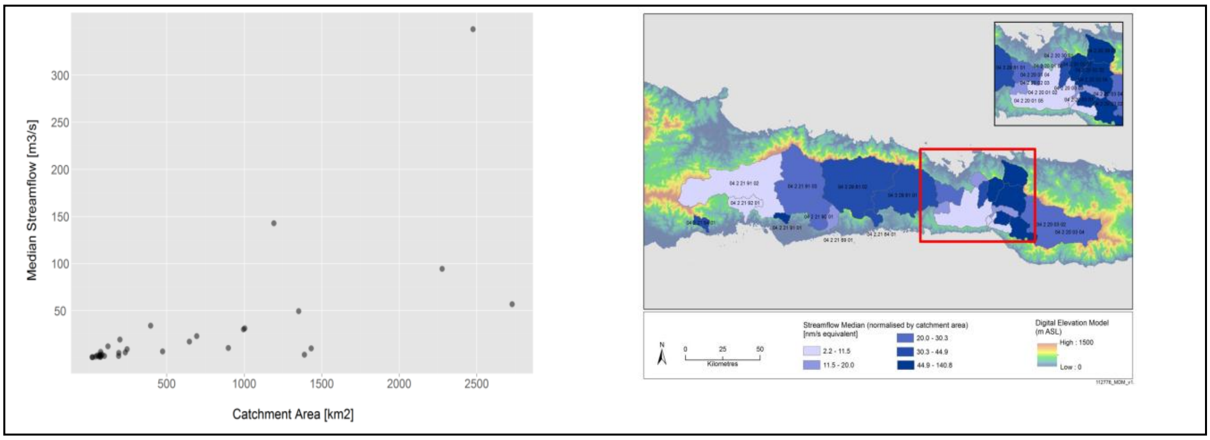


Figure 4. The location and extent of delineated catchment for the streamflow gauges used for the study.

As shown in figure 5 (a), there is a clear correlation between catchment area and median streamflow values, with a general trend of increasing medians with increasing catchment areas. However, there is still a great deal of variation unaccounted for based on this relationship alone, suggesting that median streamflow depends on other parameters as well. In order to begin considering what other factors might be significant in explaining this variation, figure 5 (b) presents a plot showing the variation in median streamflows for the different gauging station data sourced for the study.

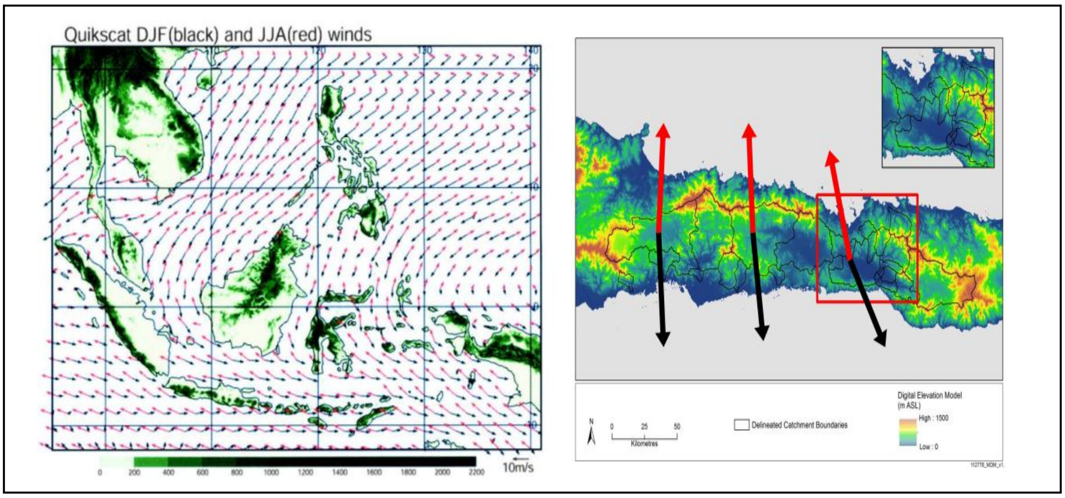


(a) (b)

Figure 5. Correlation between catchment area (a) and median streamflow (b); representation of streamflow medians (normalised by catchment area) calculated for the gauging station data sourced for the study.

Note that median streamflow values have been normalised by the catchment area (i.e.the value shown is equal to the median streamflow divided by the catchment area). It has already been established that the median streamflow may depend primarily on catchment area, but that this parameter alone does not explain all of the variation in streamflow values. Therefore, by normalising the medians against area, the area-dependency factor may be remove and can begin to investigate other factors that might also influence streamflow medians. Further comparison of the area-normalised streamflow medians to an outline of these catchment superimposed over the region's topography may also be performed, to see if any correlation between streamflow medians and catchment elevation/topography is apparent.

This comparison does seem to indicate a connection between the two, most likely due to the importance of orographic (or relief) rainfall in mountainous regions such as Gorontalo. This is the name given to rainfall that results when a flow of warm, moist air is forced upwards over a mountain range, cooling as it rises until it condenses and fall as rain (generally on the windward side of the mountain).



(a) (b)

Figure 6. QuickSAT data for Dec-Jan-Feb (black arrows) and Jun-Jul-Aug (red arrows) (a); Prevailing winds over the catchment on Jun-Jul-Aug (red arrows) and Dec-Jan-Feb (black arrows) (b).

In order to determine whether this may be the case in Gorontalo, it is necessary to understand the region's wind patterns on the seasonal scale. Figure 6 presents a regional plot of the prevailing winds in South East Asia for two main seasons (the December-January-February season winds as black arrows, and the June-July-August winds as red arrows). This plot is based on QuikSCAT scatterometer windsat the sea surface, covering the period from January 1999 to December 2002 [9]. Although the spatial resolution of this dataset is medium (25km x 25 km grid cells), the data clearly reveal a predominantly north-south axis to the prevailing winds around Gorontalo (south during the DJF season and north during the JJA season). It is speculated that a significant proportion of the rainfall experienced in this area is of the orographic type, as these warm, moist air currents (coming in from over the ocean), are forced up over the Minahassa Peninsula's mountain ranges.

One of the most obvious catchment parameters that may be expected to relate strongly to streamflow is rainfall. However, the available rain-gauge data is insufficient to cover the entire domain of interest. For this study a novel approach has been employed, using the Tropical Rainfall Measuring Mission (TRMM) dataset, which comprises remotely-sensed rainfall estimates (based on cloud cover analysis) from a joint space mission between the National Aeronautics and Space Administration and the Japanese Aerospace Exploration Agency. For this study, general rainfall parameter, the total amount of rainfall calculated to have fallen on each of the delineated catchments, processed as a mean annual total (in m^3), and to see how closely that was correlated with the streamflow data. Considering that most of the streamflow data available is from 2007 – 2010, TRMM data covering this four year (2007-2010) period were used.

When each catchment's median streamflow value is plotted against this TRMM-derived mean annual total rainfall amount, it is clear that there is a strong correlation between the two (figure7). However, it is noted that this volume is based on the catchment area as well, and so this correlation is at least partially a result of the area-dependency. Despite this, it is proposed that accounting for rainfall variation in this way may help explain some of the variation that the area-dependency didn't account for.

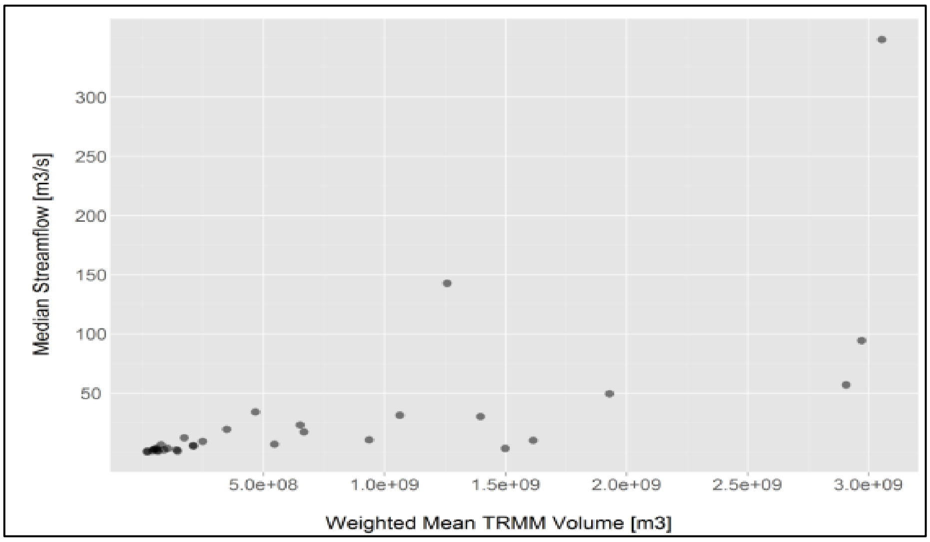


Figure 7. Correlation between mean annual rainfall (TRMM data) and Median Streamflow.

Other potentially significant TRMM data derivatives were investigated (such as the 95th percentile intensity values, longer-term rainfall totals, etc), but no other strong relationships were found.

3.3. Extreme Value Analysis for Flood Discharge

The EVA processing was performed using simulated discharge data (Mar 2007 – Dec 2014),based on scaled TRMM rainfall data and evaporation data from the nearest climatological station. Given that

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almost 7 years of data are available, this suggests that extreme events up tothe 25-year-event may be reliably predicted (with larger events becoming less and less reliable). Note that evaporation data were only available from 1/1/2009 to 31/12/2012, with the period before and after that filled in based on the monthly averages of the available data. Extreme value estimation (Design Flood) produce from these simulation result are presented in table 4.

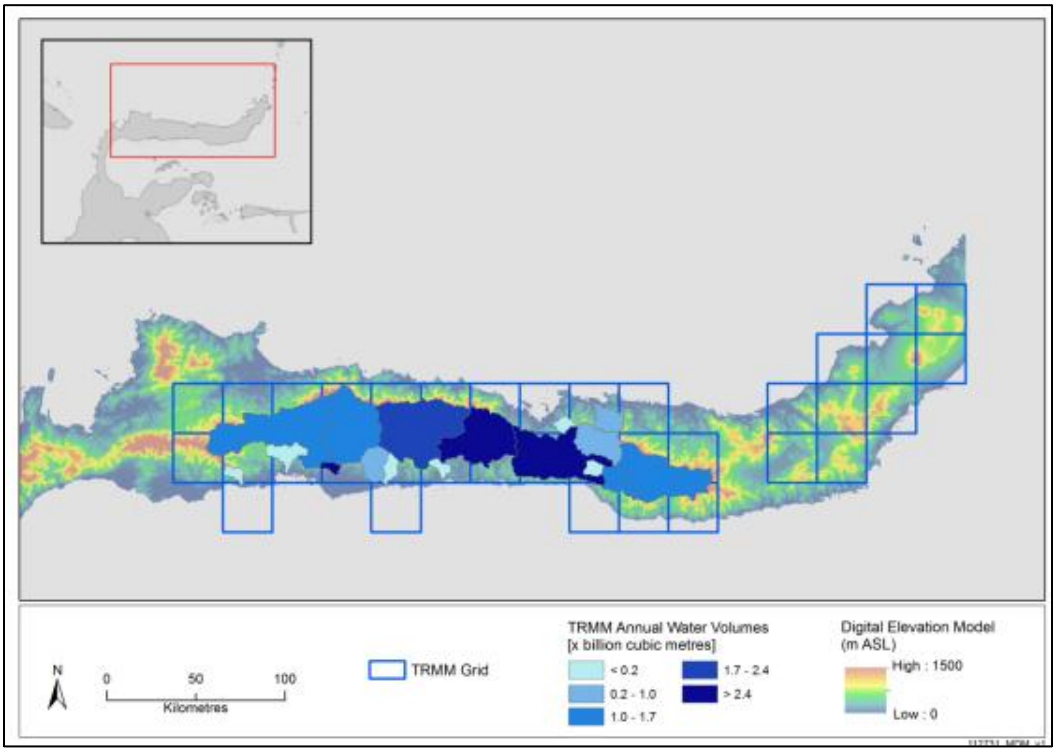

Figure 8. Tropical Rainfall Measuring Mission (TRMM) grid illustrating time series downloaded and processed, as well as weighted mean annual rainfall volume per catchment.

Table 4. Numerical Summary Of extreme discharge on Bone Watershed at certain return period.

Return Period	Predicted Discharge (m^3/s)		
	Alale (Scaled Data)	Tulabolo (Scaled Data)	Average
1	234	252	243
2	312	346	329
5	372	411	392
10	422	464	443
25	498	541	520
50	566	607	587
100	644	682	663
200	733	765	749

4. Conclusion

In conclusion, it was found that there is strong correlation between TRMM rainfall data, median streamflow, monthly mean streamflow and cathment area. The relationship between catchment area and the interquartile range (IQR) of each streamflow dataset was also found to be quite significant. However, no correlation was found between catchment area and Quartile Skew Coefficient, it is clear that the majority of the streamflow datasets have a positive QSC. There does not appear to be any strong relationship between drainage class and median streamflow. This would appear to make sense, in that rain falling on well-drained soils would be more likely to infiltrate below the surface, contributing to interflow and baseflow into the rivers over the long-term (thus reducing the proportion of No Flow Days that one would expect). On the other hand, rain falling on catchments composed of poorly drained soils would be more likely to run off, resulting in higher hydrograph peaks after storms but lower stream flows during drought periods.

A satisfactory hydrological correlation could be achieved using catchment weighted time series of TRMM daily rainfall data (after scaling), with streamflow data from Bone river (Alale and Tulabolo) to obtain a time series of simulated discharge. Relatively reliable extreme value estimation (design flood) were produced with reasonable several limitation.

Further approach may be performed in order to deal with the primary limitations inherent in the hydrological and statistical analyses, and also by comparing with conventional method using unit hydrograph and or synthetic hydrograph such as Nakayashu, Gama-1 and other well known hydrograph used in the region.

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