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Hydrological similarity approach and rainfall satellite utilization for mini hydro power dam basic design (case study on the ungauged catchment at West Borneo, Indonesia)

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Hydrological similarity approach and rainfall satellite utilization for mini hydro power dam basic design (case study on the ungauged catchment at West Borneo, Indonesia)

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Abstract. An approach on flow duration and flood design estimation on the ungauged catchment with no rainfall and discharge data availability was been being develop with hydrological modelling including rainfall run off model implemented with watershed characteristic dataset. Near real time Rainfall data from multi satellite platform e.g. TRMM can be utilized for regionalization approach on the ungauged catchment. Watershed hydrologically similarity analysis were conducted including all of the major watershed in Borneo which was predicted to be similar with the Nanga Raun Watershed. It was found that a satisfactory hydrological model calibration could be achieved using catchment weighted time series of TRMM daily rainfall data, performed on nearby catchment deemed to be sufficiently similar to Nanga Raun catchment in hydrological terms. Based on this calibration, rainfall runoff parameters were then transferred to a model. Relatively reliable flow duration curve and extreme discharge value estimation 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 analysis, especially to give prolongation to the availability of the rainfall and climate data with some novel approach like downscaling of global climate model.

1. Introduction

Hydroelectricity potential in Indonesia reaches approximately 22 GW, however, the power utilization from hydroelectricity still as low as 6 % from it's potential in 2012. Hydroelectricity as renewable energy power source in Indonesia facing challenging condition from the design stage, e.g. causing by unavailable of critical data for design parameterization including rainfall, discharge and sedimentation at many region of Indonesia. Even when it's available usually not in well distributed condition, not long enough period, and or with lower reliability and quality.

Approach on Flow duration and flood design estimation on the ungauged catchment with no rainfall and discharge data availability are been being develop by researchers. In this case, approach which are used in the research with following some of the publication [1];[2];[3];[4]. Generally, discharge characteristic of ungauged watershed can be estimated by extrapolating and transferring discharge characteristic from hydrologically similar gauged watershed with regionalization process[5];[6];[7].

Further approach can by develop with hydrological model including rainfall run off model implemented with watershed characteristic dataset. Near real time Rainfall data from multi satellite platform e.g. TRMM, APHRODITE, and CMORPH can be utilized for regionalization approach on the ungauged catchment [8];[9];[10];[11];[12];[13];[14] .

The primary objective of this study are :
a. Determine / making Flow duration curve estimation for mini hydro power plant design on ungauged catchment
b. Determine/ making Design Flood estimation for mini hydro power plant design on ungauged catchment

Scope of works during this study are limited to :
a. Hydrologically similarity analysis for the ungagged- gauged watershed
b. Setup Model, Calibration, and validation for gauged watershed model (donor watershed)
c. Setup Model, FDC analysis and Flood Design estimation for ungauged watershed (target watershed) using transferred parameters from gauged donor watershed model.
d. TRMM Rainfall Satellite Data

2. Methods

2.1. Location
Mini hydro power site located on the Nanga Raun Watershed, upper Kapuas, West Borneo Indonesia

2.2. Data and Software
Data and Software which are used in the study

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	2010
Discharge	BWS			
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
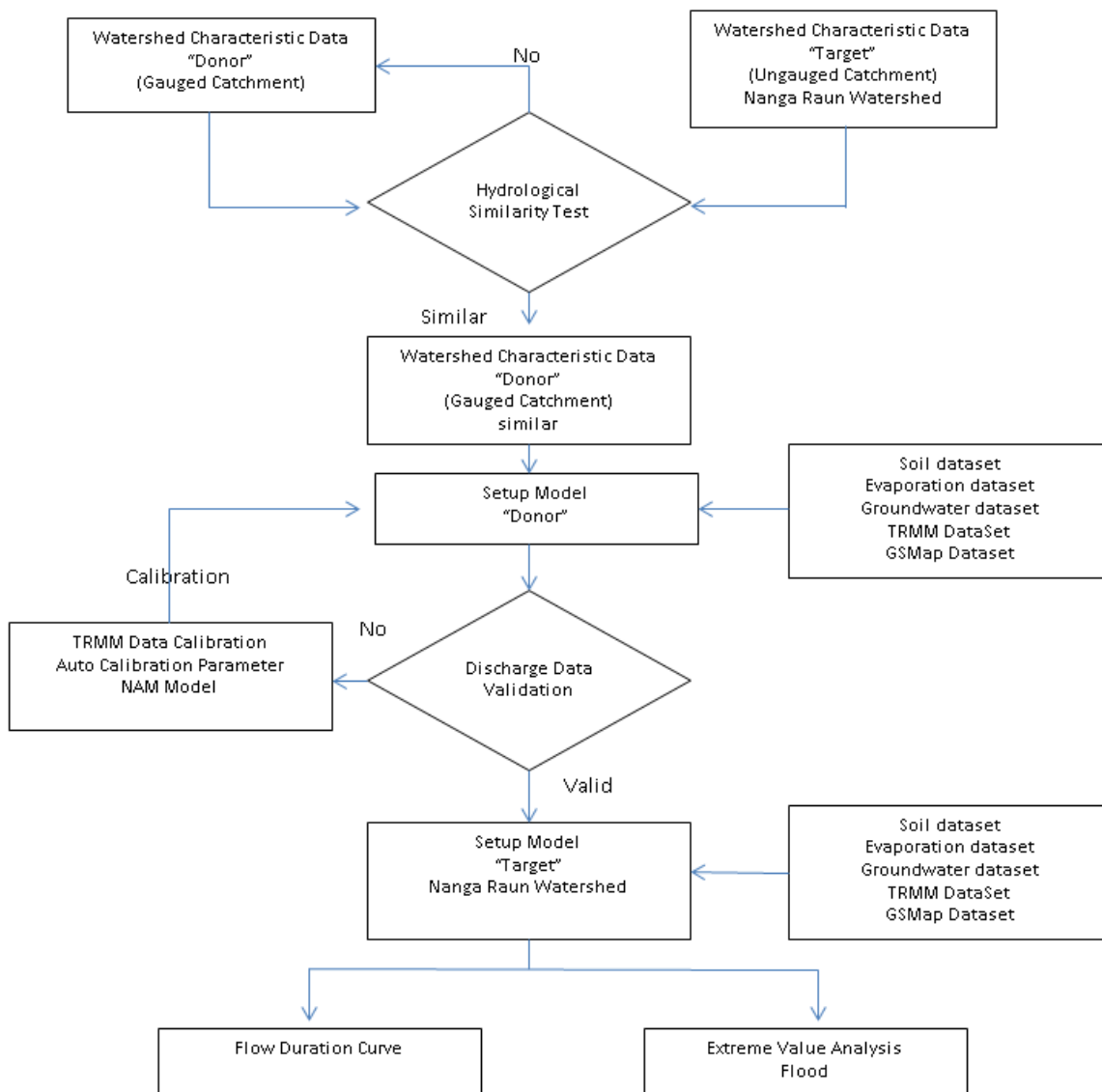
Figure 1. Research Flow Chart

3. Results/Discussion

3.1. Watershed Hydrologically Similarity

Watershed hydrologically analysis are including all of the major watershed in Indonesian Borneo Region which predicted to be similar to the Nanga Raun Watershed. Hydrologically similarity criteria are used in this study following the catchment similarity analysis protocol proposed by previous researcher [15];[16];[17];[18];[19];[20];[21]. Including :

a. Watershed area
b. GSMap Rainfall
c. Median TRMM Daily Rainfall
d. 95th percentile

e. Average TRMM Daily Rainfall
f. Percentage of TRMM Rainy days (percentage of rainy day TRMM, TRMM Rainfall > 0)
g. Available Water Content
h. Years of Data
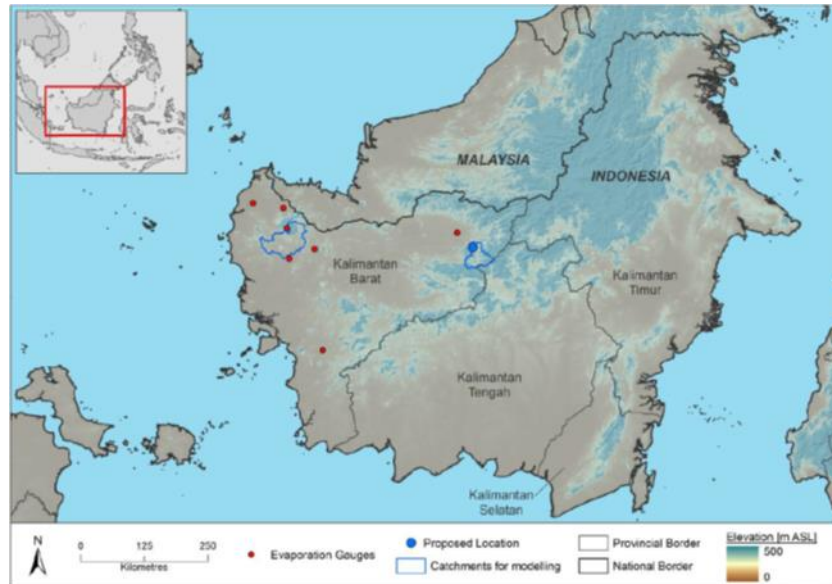
Figure 2. Similar Donor Watershed Gauge No. 03-044-01-04

3.2. Setup Model, calibration , and Validation Donor Watershed Model
Based on the hydrologically similar donor watershed, setup parameter in the NAM Mike 11 model are transferred to the target watershed (Nanga Raun Watershed) with replacing the watershed characteristic dataset, including :
a. DEM and Watershed boundary
b. Evaporation data set
c. Soil dataset
d. Groundwater dataset
e. TRMM Rainfall dataset

   Running NAM – MIKE 11 Model are used for simulated discharge. Discharge data then will be calibrated using the observed discharge data from the automatic water level recorder available on donor watershed.
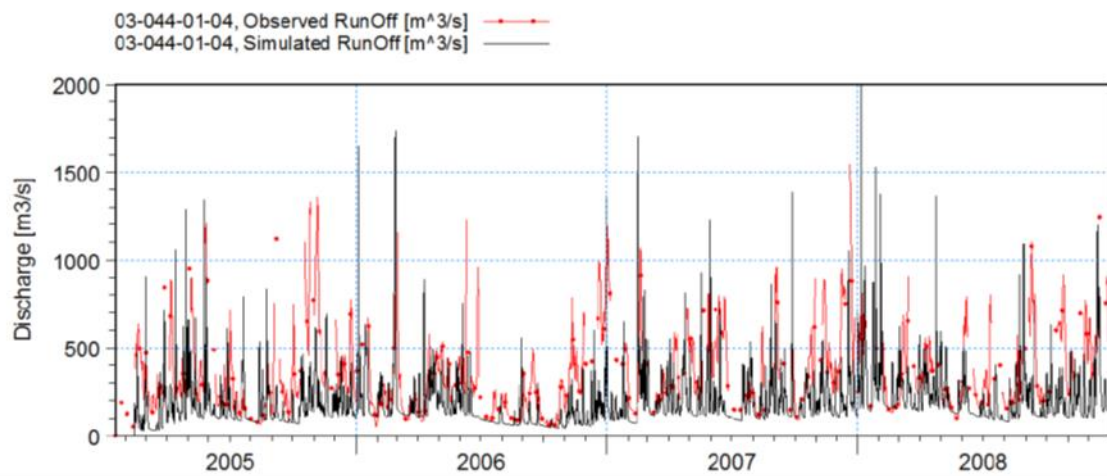
Figure 3. Comparison of observed (red) and simulated (black) discharge at 03-044-01-04, based on TRMM Rainfall Data
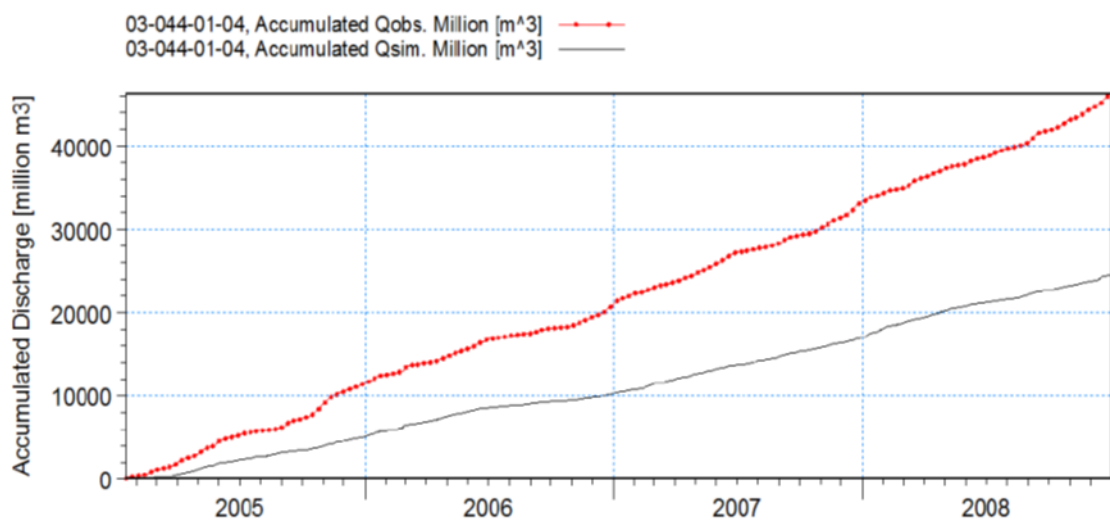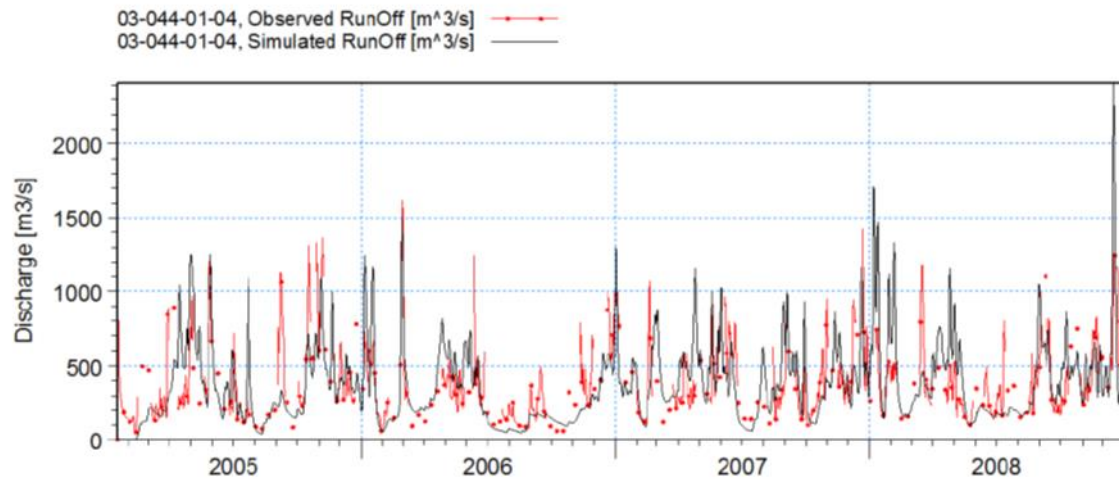

Figure 4. Comparison of observed (red) and Simulated (black) accumulated discharge, based on TRMM Rainfall Data

The simulated runoff does appear to be too low, as is confirmed by a comparison of the accumulated discharges, in Figure 4. This may indicate that the TRMM data underestimate the actual rainfall over the catchment. The TRMM rainfall data were increased by a factor of 1.4 (with trial-error process in order to match the observed water balance based on discharge data), and a series of auto-calibration routines was run in order to optimize the model parameters. Following this, the comparison of simulated discharge with the observed data is as shown below Figure 5. And Figure 6 Show the simulated versus observed discharge time-series, which indicates that a much closer fit has been achieved than previously. The difference in water volumes at the end of the simulation is approximately 2 %. Auto calibration NAM MIKE 11 Rainfall Runoff Model Parameters are including :

a. Maximum water content in surface storage (Umax)
b. Maximum water content in root zone storage (Lmax)
c. Overland Flow Runoff Coefficient (CQOF)
d. Time constants for Interflow (CKIF)
e. Time constants for Routing Overland flow (CK1,2)

f. Root zone Threshold value for overland flow (TOF)
g. Root zone Threshold Value for interflow (TIF)
h. Time constants for routing base flow (CKBF)
i. Root Zone Threshold value for Groundwater Recharge (Tg)

Figure 5. Comparison of Observed (red) and Simulated (black) discharge at 03-044-01-04, after a number of auto-calibrations have been run (using scaled TRMM Data)
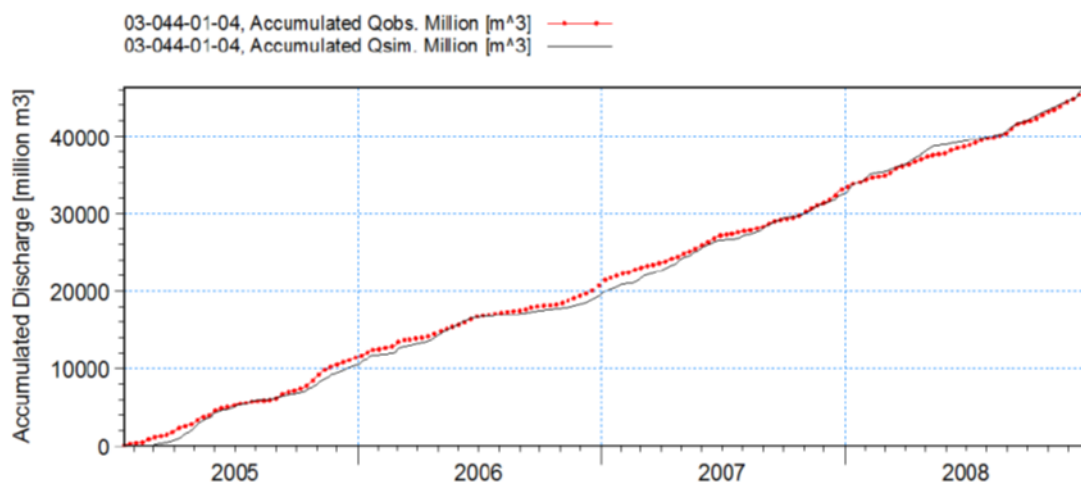
Figure 6. Comparison of Observed (red) and simulated (black) accumulated discharge, after a number of auto calibrations have been run (using scaled TRMM data)

While the time series shown above does not indicate a very close match between observed and simulated discharge for specific events. Instead, it is most important that the model be shown to capable of representing the basic hydrological regime of the river at the site location. For this reason, it is most interesting to calibrate the model based on comparison of Flow duration Curve (observed FDC Vs simulated FDC), this approach has previously been used by another researchers [14].

As shown in Figure 7, the final calibrated simulation appears to be capable of representing the observed Flow Duration Curve at 03-044-01-04 relatively close (with deviation below 5 %). This provide some confidence that the calibrated parameter set may be reasonably transferred to a model of the proposed site on the ungauged catchment like in Nanga Raun Catchment, West Borneo in order to simulate the hydrological regime at that location too.
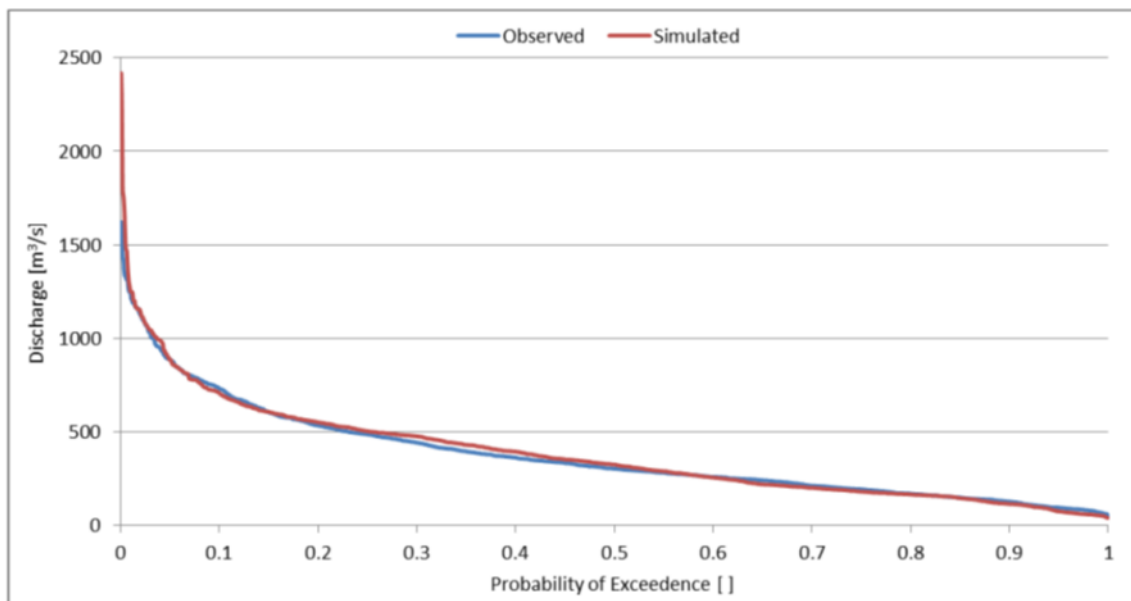
Figure 7. Comparison of observed (blue) and Simulated (red) Flow Duration Curve at Gauging Station 03-044-01-04, Based on TRMM Rainfall Data

3.3. Simulation of Nanga Raun Catchment (target/ site ungauged watershed) based on Calibrated parameters

Following on from the hydrological model calibrations presented in section b, the calibrated rainfall-runoff model parameters were then transferred to the models of the proposed site's catchment in Nanga Raun. It is assumed that these parameters will provide a reasonable assumption for the project catchment too, based on the hydrological similarity. The catchment averaged TRMM rainfall data were scaled up by a factor of 1,4 and used to run simulation from 2/3/2000 to 1/1/2013 (based on the availability of rainfall data). Note that evaporation data were only available from 1/1/2002 to 31/12/2008, with the period before and after that filled in based on the monthly averages of the available data. The flow duration curve and Extreme Value estimation (Design Flood) produce from these simulation result are presented in Figure 8, Figure 9 and Figure 10.

The extreme value analysis (Design Flood Estimation) processing was performed using simulated discharge data, from March 2000 – December 2012, based on scaled TRMM rainfall data from the nearest climatological station. Given that almost 13 years of data are available, this suggests that extreme events up to 30 year may be reliably predicted, with larger events becoming less and less reliable.
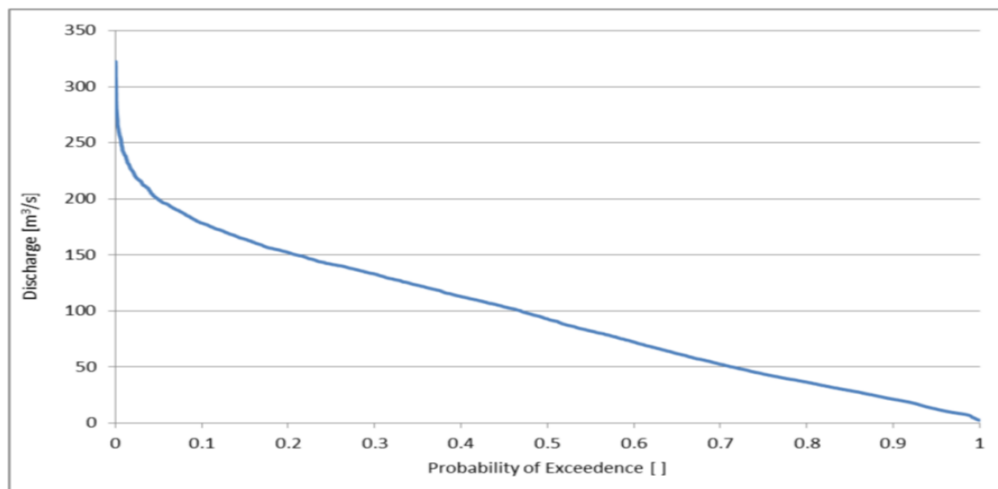
Figure 8. Flow Duration Curve for Proposed Mini hydro Power Site At Nanga Raun, Based on TRMM Rainfall Data
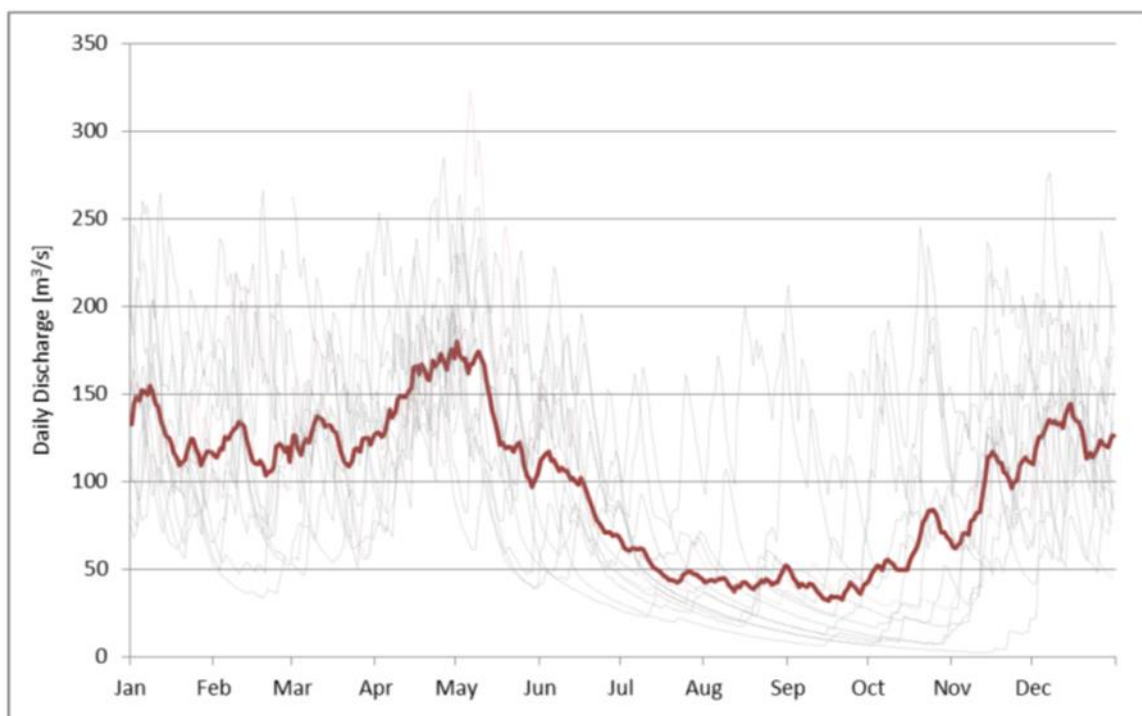

Figure 9. Average Daily Discharge Over the Calendar Year (red line), with individual years simulated shown by light grey lines.

Given the relatively short period of historical discharge data available (less than 13 years), the partial duration series (PDS) method of extracting extreme values was used, instead of annual maxima. It was found that PDS threshold value of 180 m3/s, slightly higher than 90th percentile of simulated discharge values, provided good results. In other words, measured discharge values greater than this value were considered to be extreme events and included in subsequent analysis. In addition, an inter event time of 15 days was used as independence criterion to ensure that the same extreme flood event was not counted more than once. A variety of extreme value distributions types were trialed in order to select that which

appeared to fit the data best. It was found that a Log-normal distributions, using the method of moments for estimation Lower bound quantile method II provided the best fit.

The extreme value probability distribution fitted to the simulated discharge data sets is presented in Figure 10, showing a relatively close fit. While the fit is not as close for the larger flood events, this result is considered acceptably conservative. As noted previously, the limited data available only allow prediction of extreme events with return periods of up to approximately 30 years. However, it is possible to estimate the extreme events of return period 1,5,10,25,50,100, and 200 years with less and less reliable. Thus, the extreme value distributions fitted to the available data have been extended to allow predictions of these events. It should be stated very clearly that these predictions are based on insufficient data.
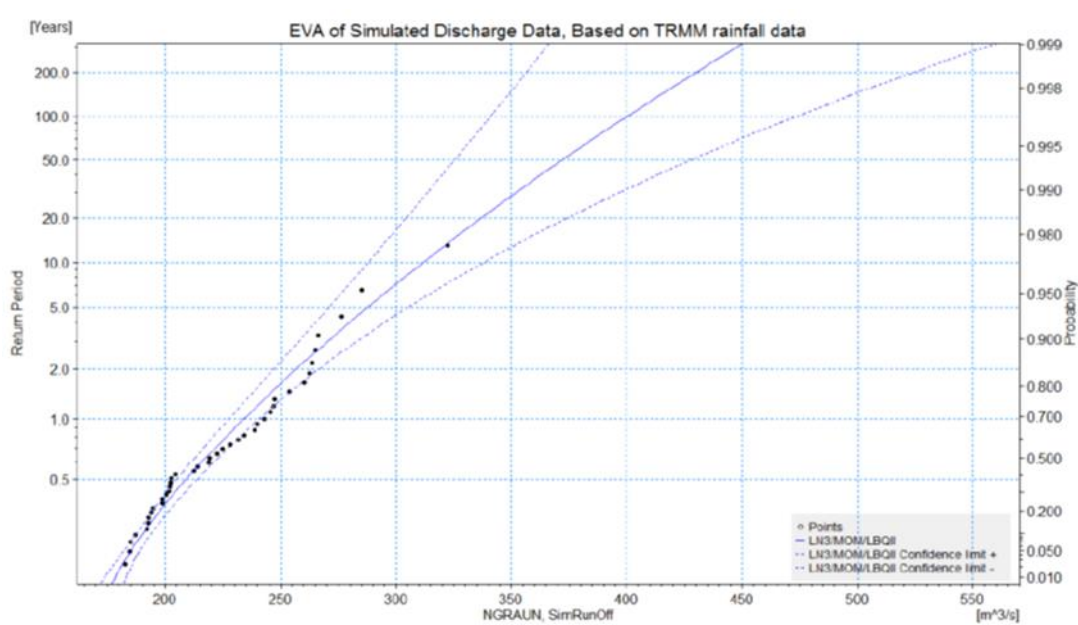
Figure 10. Probability distribution (Full Line) fitted to simulated discharge data (confidence intervals as dashed lines), assuming Log-normal distribution and method of moments for estimations

4. Conclusion

In conclusion, it was found that a satisfactory hydrological model calibration could be achieved using catchment weighted time series of TRMM daily rainfall data (after scaling), performed on nearby catchment deemed to be sufficiently similar to the proposed ungauged catchment in hydrological terms. Based on this calibration, rainfall runoff parameters were then transferred to a model of Nanga Raun catchment (as target ungauged catchment proposed as mini hydro site) and run to obtain a time series of simulated discharge. Relatively reliable flow duration curve and 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, especially to give prolongation to the availability of the rainfall and climate data with some novel approach like downscaling of global climate model to obtain either historical and future rainfall and climate data on the ungauged catchment.

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