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Article *in* Procedia Engineering · December 2017
DOI: 10.1016/j.proeng.2017.01.480

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ScienceDirect

Procedia Engineering 171 (2017) 1495 – 1504

Procedia Engineering

www.elsevier.com/locate/procedia

Sustainable Civil Engineering Structures and Construction Materials, SCESCM 2016

Proposed method to determine the potential location of hydropower plant: application at Rawatamtu watershed, East Java

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Abstract

Potential of hydroelectric plants depend on the availability of discharge and head flow. The steep slope of rivers and the abundant of water flow in rural areas are as potential locations of hydroelectric power plant site (HPPS). The lack of discharge data measurements on the tributaries are the main obstacles to determining the potential sites. This paper proposed a method to identify the potential sites for HPPS. The method based on two main information: (1) location of the steepest slope, and (2) discharge generation of tributaries. In this case, ASTER GDEM 2 was used to: delineate watershed boundary, determine river network, and derive slope. Then, long section of the selected tributaries was analyzed to obtain the location the steepest slope potentially to HPPS. Furthermore, generated discharges for selected sites were calculated using Clark UH running under HEC-HMS program. The model was calibrated using daily discharge data observed at the watershed outlet. The time series period used for calibration process is range from 2002 to 2014. Simulation model of rainfall-runoff at a variety of outlets were selected to obtain the dependable discharge assisted with hydro-office program. This result show that total potential of hydroelectric plants can reach up to 653 kW.

Peer-review under responsibility of the organizing committee of SCESCM 2016.

Keywords: hydrology; spatial; FDC; HPPS

1. Introduction

The electrical energy is currently the most urgent needs correspond with current developments in both urban and rural areas. In urban areas, the electric energy supply is still constrained by the rotation outages. While in rural areas,

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Peer-review under responsibility of the organizing committee of SCESCM 2016.
doi:10.1016/j.proeng.2017.01.480

the electricity supplies have not yet to serve entirely. Lack of sources of electrical energy is an issue that must be resolved in all regions. Various alternative energy sources such as PLTH, power plant, etc. have been developed. However, the electricity crisis is still unresolved.

Hydroelectricity is a small-scale alternative energy source which has the advantage to replace greenhouse gas emissions, which can contribute to sustainable rural development [1]. According to [2] where hydroelectric plants provide an important contribution to environmental protection of the local communities, and social cohesion (reduction of migration, etc.), because the method of run-off river does not require a large reservoir, so that the issue of the environmental impacts of dams was not feasible in this system. Run-off river systems provide an alternative power generation, and can be financed and owned by the local communities. The positive effect of these hydropower plants, the presence of potential sources should be sought as a power generator.

Potential source of Hydrolelectric affected by discharge availability and head flow that capable to change kinetical energy to become potential energy or power. Power, P, (kW) formulated by equation (1) [3] was influenced by the flow rate, Q, (m^3/s); effective height, h, (m); the density of the fluid, ρ, (kg/m^3); acceleration of gravity, g, (m^3/s).

$$P= Q.h. \rho.g.\eta \quad (1)$$

Based on these variables, Jember regency has the potential to build hydropower plants, because the area is mountainous and impassable by many tributaries that have a source of water with a fairly steep slope area. However, these potential locations are generally located in areas that are difficult to reach, thereby determining the location of optimal hydropower plants is hard to do in a conventional manner. Thus, the potential water resources are not fully utilized. Therefore a method for determining the potential of hydroelectric power plants efficiently and effectively in remote areas is needed.

Some researchers have determined the potential of hydropower plants to locate remote areas who generally have limited means of measuring discharge by using hydro-spatial approach. As performed, [4] are identifying potential hydropower plant in Uganda with spatial analysis found 250 potential locations, and once selected 14 locations turned out to only three locations available water discharge. [5] in Pohnpei, Federated States of Micronesia (FSM) determine the flow duration curve (FDC) using parametric curves of flow versus the average annual discharge selected for specific conditions on the percent exceedance. [6] is determining the height difference with the neighborhood and the statistical method in river discharge using SCS-CN equation in Kapuas upstream resulting in able to identify 18 sites with electric power of 100 kW to 5.2 MW.

Based on the success of the method in previous studies, the potential for hydroelectric power plants in the Rowotamtu watershed need to be developed. This paper integrates spatial analysis to determine the location of the height difference using Geographic information system (GIS), with rainfall-runoff modeling to generate a flow of data in locations that are not available discharge measuring tool to determine its FDC. The method used in the generation of discharge data differ from previous methods [6], Clark unit hydrograph is used due to a lack of land use recording data.

GIS is very supportive in hydrological modeling to facilitate the processing, management, and interpretation of hydrological data. One of the most useful capabilities of a GIS is the ability to describe the topography of the area [7]. This capability is used to develop a Digital Elevation Model (DEM). DEM is a digital representation of ground surface elevation. It is used for processing ground elevation values measured at the intersection of the horizontal grid lines [8]. Elevation data grid is a type of raster data, which is an array of values measured at uneven locations spatially across the region. DEM is required to generate a current, flow direction, flow accumulation, flow length, steepness of the slope and watershed [9]. DEM is the essential tool needed to research the hydrology and water resources.

HEC-HMS is a hydrological model that is able to model the rainfall data into the stream for single or continuous produced by the US Army Corps of Engineers hydrologic Engineering Center [10]. Rainfall runoff modeling process with HEC-HMS in a watershed can describe the loss of water when it precipitation (loss method comprises 4 methods), transformation of rainfall into streams (there are 6 unit hydrograph models include: Clark, ModClark, SCS, Snyder, User- specified S-graph, and User-specified), routing the flow in the river (there are 5 methods include: lag, Muskingum, Muskingum cunge, modifield puls, kinematic wave and straddle stagger), and baseflow (methods include constant, monthly-varying value models, exponential recession-linear models and reservoir volume accounting model)

The Clark unit-hydrograph (UH) is the transformation of rainfall into runoff models that exist in the watershed that represent two important processes. Movement of runoff water from the channel to the outlets, and the loss of the existing amount of discharge in the watershed. The principle of this model is similar to the linear reservoir models that have the continuity equation [10]. The model is a function watershed linear reservoir storage, S_t, watershed storage coefficient, R, and outflow, O_t, formulated in the equation:

$$St = R\,O_t \qquad (2)$$

Clark UH method using the time of concentration (T_c) and storage coefficient (R) to build the shape function of time-area. This method is quite flexible and able to connect geomorphology in the form of hydrograph [11]. Therefore Clark UH has the advantage that it can performed to a watersheds that do not have AWLR. Time of concentration equation (3) is a function of the length of the main river (miles), L, and the slope of the river S (ft / mile).

$$Tc = 1{,}54 L^{0{,}875} S^{-0{,}181} \qquad (3)$$

Storage coefficient (R) equation (4) is function of main river length (mil), L, and river slope (ft/mil), S, formulated as below:

$$R = 16{,}4 L^{0{,}342} S^{-0{,}790} \qquad (4)$$

Muskingum method is performed for river routing. This method has been successfully applied by [12],[13], and [14] for river routing. This method is based on the assumption that there are linier relationship on channel storage, inflow and outflow discharge with all consequently introduced. This method is suitable for the channel-shaped prism with the high enough reservoirs. Towards the river downstream, the outflow can be calculated using equation (5) representing the mass balance, and the equation (6) expresses reservoirs volume (W) on the channel, which is a simple linear combination of discharge at upstream inflow (I) and outflow (Q) at downstream. The required parameters in Muskingum method is x and K. K is travel time (T) of flow through the entire channel and is called coefficient of reservoirs. x represents the weighting factor with a value ranging between 0-0.5 range depends on channel cross-sectional shape.

$$\frac{dW}{dt} = 1 - 0 \qquad (5)$$

$$W = K[xI + (1 - x)Q] \qquad (6)$$

2. Methodology

2.1. Data

The data used in this research is hydroclimatological and spatial data. Climatological data in the form of daily rainfall and discharge data. Rainfall data were obtained from the Department of Water Resources Jember for 12 years (2002-2014) from 20 rain stations include Dam Makam, Dam Pecoro, Rambipuji, Rowotamtu, Dam Sembah, Bintoro, Dam Arjasa, Kopang, Dam Pono, Tamanan, Sukokerto, Sukowono, Sumber Kalong, Sukorejo, Sumberjambe, Cempedak, Kotok, Jember, Ajung and Renes. While discharge data that used are from the Rawatamtu AWLR station result of 12 years records (2002-2014) obtained from UPT Bondoyudo-Mayang.

ASTER GDM 30 data (a spatial resolution of 30m x 30m) performed by Arc Gis 10 and ArcHydro 9 is used to generate the river network and create sub-watershed and watershed delineation accessed from the characteristics of the topography. Based on the GIS layer can be obtained length of the river, watershed area, and the slope is input from UH Clark. Layer land use is needed to determine its impervious value.

2.2. Rainfall-runoff modelling

Rainfall-runoff modeling process is intended to generate the long term discharge in the location of the planned hydropower plants. This generation process using two approaches aided by HEC-HMS 3.5 software. Model calibration is performed in the downstream Rowotamtu discharge station. The results of the calibration parameters on the tributaries is used to generate models of the long term discharge. Rainfall-runoff modeling process in the Rowotamtu Watershed for loss rate using initial loss, constant rate, and impervious transformation of rainfall into streams (direct runoff) using method of Clark unit-hydrograph, baseflow using bounded recession and for the search of flooding on the river using the Muskingum and gain / loss of his using constant. The sub watershed scheme with the required parameters in the model of HMS HEC program is shown in Fig 1.

2.3. Model evaluation

The evaluation process model is performed by calibrating the entire modeling on Rowotamtu AWLR station. Calibration is performed automatically by minimizing the objective function peak weight RMSE. Goodness of fit from model calibration is shown based on the efficiency of the resulting model (EEF) as performed by Ibbitt and O'Dannell, [15] and Nash - Sutcliffe [16]. EEF value is affected by observation discharge (Q_{oi} m^3/det); average observation discharge ($\overline{Q_o}$ m^3/det); and discharge simulation results (Q_{si} m^3/det). If the total of observations discharge are similar to discharge simulation results, the EFF value equal to 1. The equation to evaluate the EEF is as follows:

$$EEF = \frac{\sum_{i=1}^{n}(Q_{oi}-\overline{Q_o})^2-\sum_{i=1}^{n}(Q_{oi}-Q_{si})^2}{\sum_{i=1}^{n}(Q_{oi}-\overline{Q_o})^2} \tag{7}$$

The calibrated parameters are include: for loss is Constant Loss Rate and Initial Loss, for Clark UH is R and T_c, for Baseflow is Initial Flow and Constant Recession, and for routing is K and X.

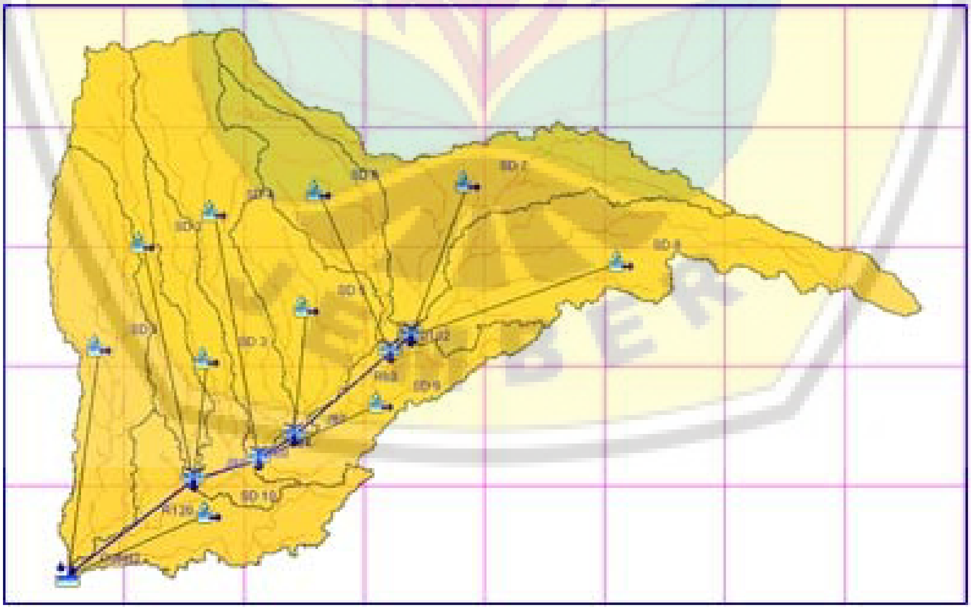


Fig. 1. Sub-watershed with Parameters

2.4. Potential river discharge

Potential river discharge can be determined based on the result of the generation of synthetic daily discharge from modeling rainfall into streams at a location that does not have the tools to measure the discharge. Considering the hydropower plan using river runoff, it should be known that there is a dependable discharge in the river. Dependable discharge can be calculated by using method of flow duration curve assisted with hydro-office program.

2.5. Potential hydropower

Based on the equation (1), the potential energy generated by hydropower is influenced by two important factors that is the effective height difference and dependable discharge. Effective height difference can be determined with the GIS approach that is from generation riverbed topographycal profile. While the dependable discharge is the result of the FDC calculation.

3. Result and discussion

This research was performed in the Rowotamtu watershed. Based on the results of sub-watershed delineation are found the number of tributaries for order 3 is 10 tributaries that can be seen in Figure 1. The tributary have a variety of shapes, the slope of the riverbed and spacious. The total area of watershed is 667.82 km^2. The slope in this watershed can be classified into three parts, that is high (1157-3325), low (124-148 m), and medium (148-1157). Length, area, and the slope of the river bed are shown in Table 1, the longest tributary is Suger tributary and the next is Pakem tributary. Tributaries with a largest river slope is the Jompo tributary and that has the largest watershed area is Sumber Pakem tributary.

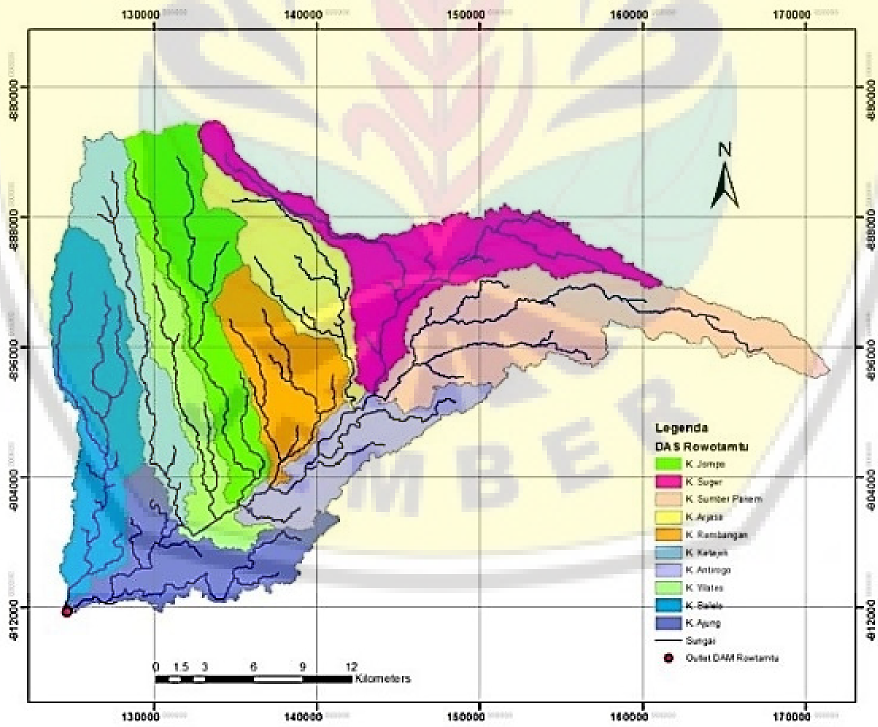


Fig. 2. Location of study

Table 1. Physical Condition of Rowotamtu Tributaries.

Sub-Watershed	Length (km)	Slope (%)	Area (km^2)
Balelo	80.542	26.269	85.140
Ketajek	83.670	31.277	51.297
Kaliwates	77.536	19.814	40.601
Jompo	85.081	42.273	82.326
Rembangan	53.183	22.070	53.481
Arjasa	61.833	34.635	50.300
Suger	120.476	17.507	91.380
Sumber Pakem	109.925	15.117	111.205
Antirogo	71.586	10.429	46.205
Ajung	82.198	9.120	55.887

The majority land use of Rowotamtu Watershed is the forest. Forest land use will have a positive impact on the existence of hydropower, because the forest will provide baseflow in rivers which makes continuous availability of water in the dry season [17].

Based on the results of hydrological modeling with outlets in Rowotamtu that have been optimized indicate that this modeling can respond baseflow well with EFF value of 0.99. Recession sensitive parameter is constant and constant loss rate. Generally the model has some similarities pattern that shows in figure 3, but has not been able to show a good response for extreme rainfall conditions. As a basis for planning Hydroelectric the main requirement is low flow, so that the model parameters can be used to predict the flow of water at a location that does not have the tools to measure the discharge.

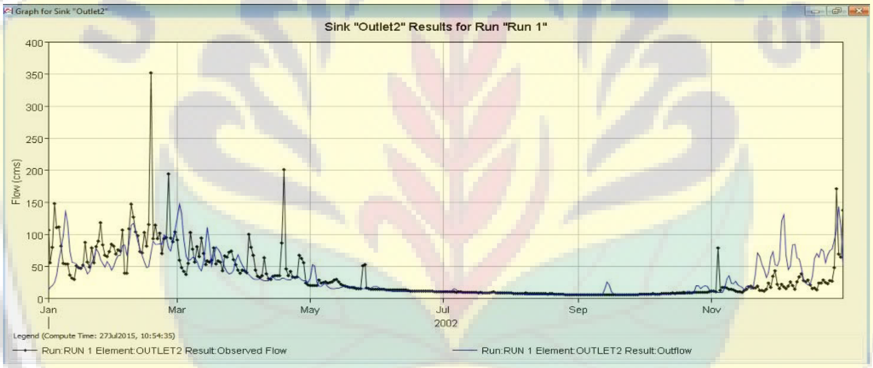
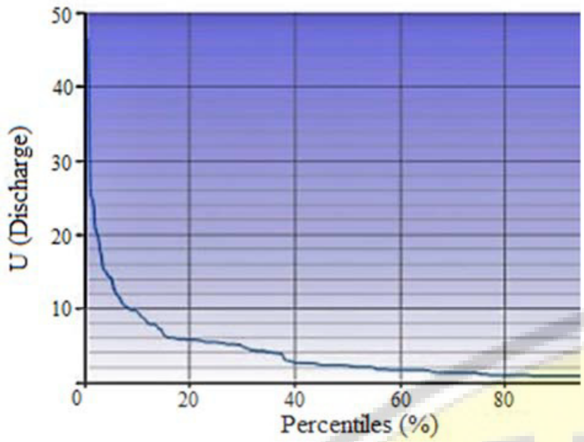
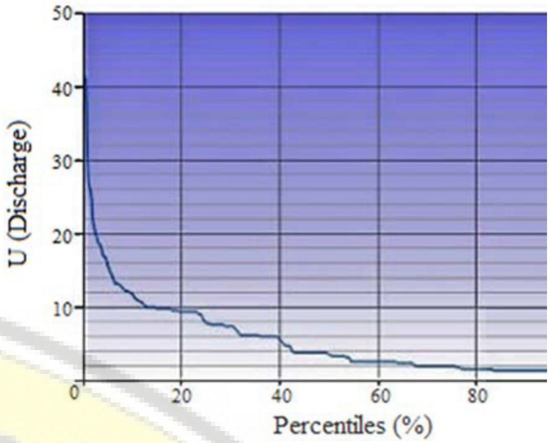


Fig.3. The result of model calibration.

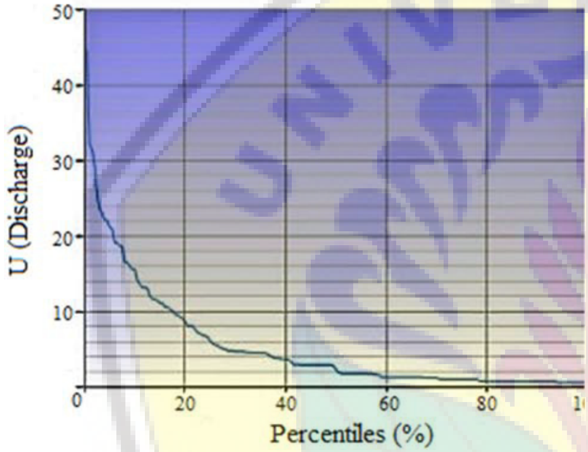
Based on the results of generation discharge in nine locations in seven tributaries obtained FDC values for the reliability of 90% with a range of values between 0.3 m^3/s up to 1 m^3/s (Figure 4 and Table 2). The largest water source is from Sumber Pakem tributary, and the smallest is from Kaliwates tributary. Based on the results of running model showed that the value of dependable discharge and minimum discharge have a significant linear correlation value of respectively 0.9611 and 0.9272 with sub-watershed area (figure 5), while the maximum discharge had a fairly good correlation value of 0.6777 with river length and 0.6695 with percentage of slope. Therefore, this rain-flow modelling is more suitable for low-flow stream.



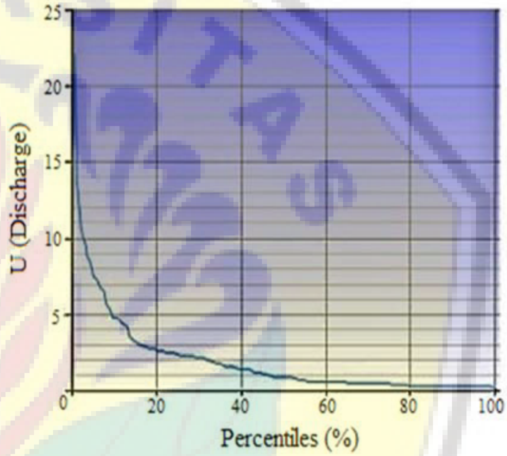
Arjasa tributary



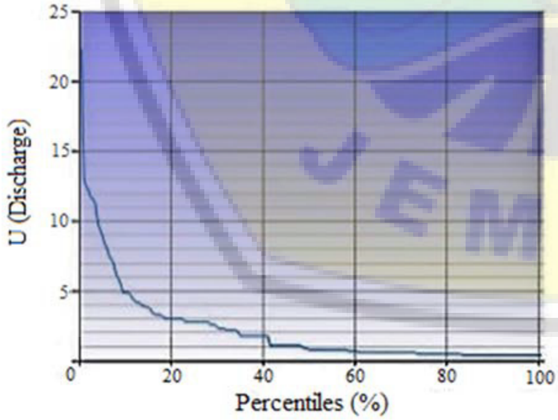
Balelo tributary



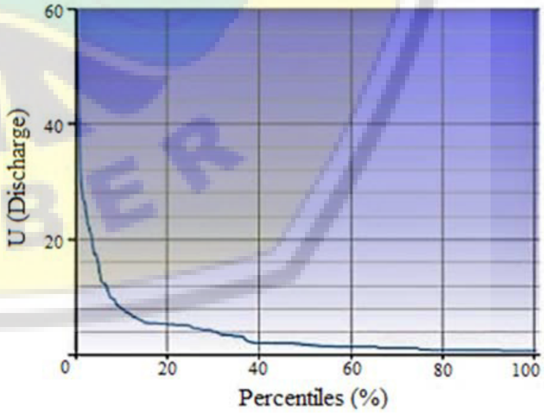
Jompo tribute



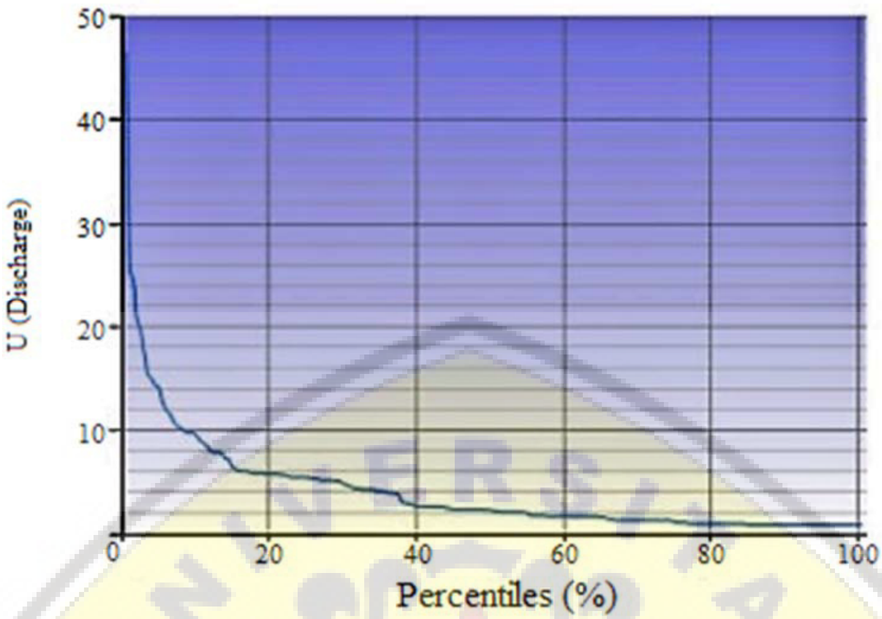
Kaliwates tributary



Ketajek tributary



Suger tributary



Sumber Pakem tribute

Fig. 4. FDC of Rowotamtu Tributaries

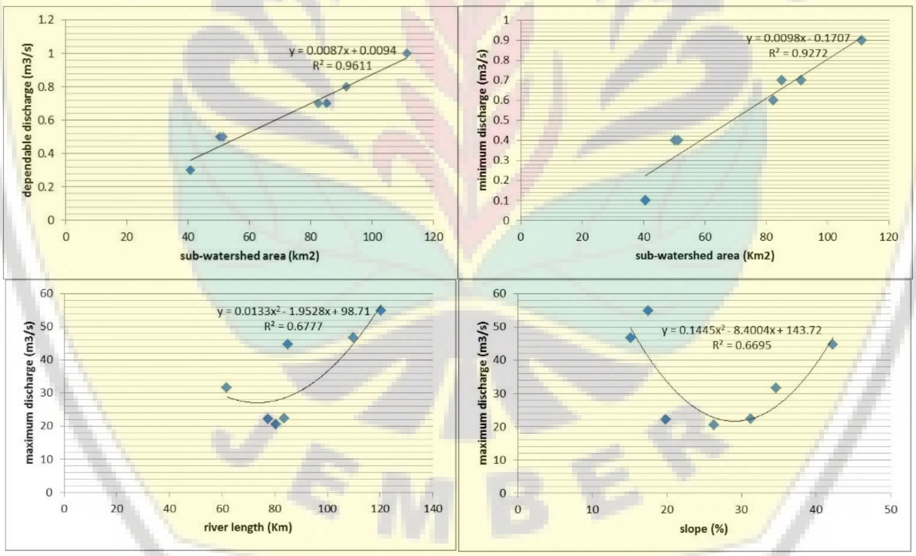


Fig. 5. Correlations between discharge, sub-watershed area, river length, and slope

The potential value of the generated electric power ranging from 24 kW up to 157 kW. The location of potential hydro power as shown in Figure 6. According to [18] , the capacity of hydropower can be classified into four classes, that is high (> 10,000 kW), medium / small-hydro (up to 1.000-9.999 kW), low / micro -hydro (100-999 kW), and small / mini-hydro (<99 kW). Therefore, the potential of hydropower in the Rowotamtu watershed classified as mini-hydro in Balelo and Ketajek tributaries and the remaining category is micro-hydro. Balelo and Ketajek tributaries and has a great potential for power generation because of their effective height difference is quite high.

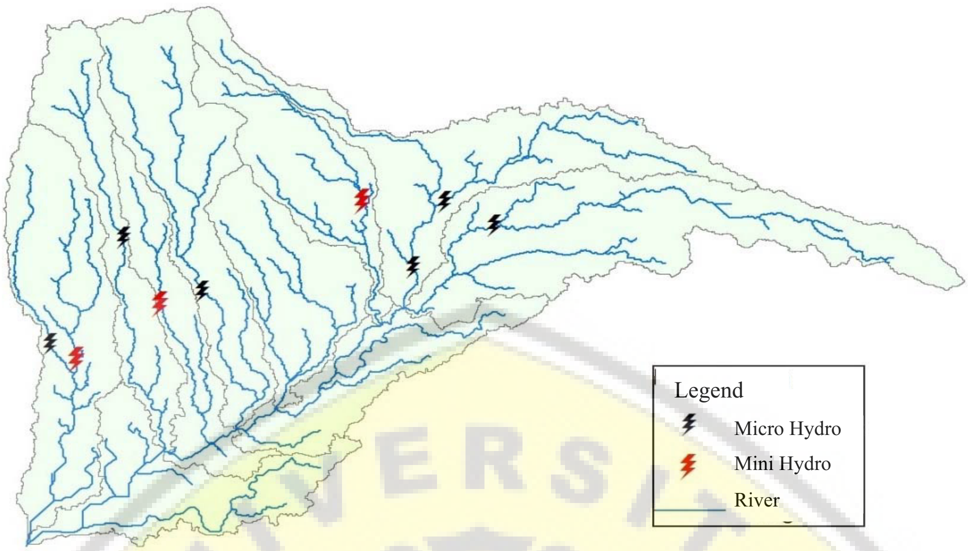


Fig. 6. Potential Hydropower Location

Table 2. Resulting Analysis of Potential Hydropower

Tributary	Q (90%)	H (m)	P (kW)	Information
Balelo	0.7	10	55	Micro-Hydro
Balelo	0.7	20	110	Mini-Hydro
Ketajek	0.5	40	157	Mini-Hydro
Kaliwates	0.3	10	24	Micro-Hydro
Jompo	0.7	15	82	Micro-Hydro
Arjasa	0.5	18	71	Micro-Hydro
Suger	0.8	10	63	Micro-Hydro
Suger	0.8	7	44	Micro-Hydro
Sumber Pakem	1.0	6	47	Micro-Hydro

4. Conclusion and recommendation

This analysis able to provide an initial estimate from the feasibility of developing hydropower plant project in a specific location. Rowotamtu watershed has the potential head and good enough water discharge to use as Hydropower. Hydropower potential in the Rowotamtu watershed found in nine locations with power ranging from 24 kW- 157 kW. There are two locations that are categorized as mini-hydro and 7 locations were classified as micro-hydro. Further research should be conducted ground checking for flow and slope data so it is expected to provide more accurate planning results.

Acknowledgements

Further thanks to Department of Water Resource Jember Regency who have provided the hydrometeorological data and Irdian Dwi Yuliar and Imam Saputro Yuliar that helps the completion of data processing.

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