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Water Availability Analysis in Krueng Aceh Watershed

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Abstract

The main purpose of this present study is to investigate and analyze water availability in Krueng Aceh watershed area. Data were collected from three rainfall observation stations in Aceh province, covered whole Krueng Aceh watershed area. Rainfall data were analyzed using Thiessen polygon method while water availability were estimated using Mock method. As comparison, prediction results were validated and compared with actual measurement using AWLR method. Obtained results showed that rainfall occurred in Krueng Aceh watershed is 1714.57 mm/year with an area of 174 785.79 ha. Moreover, potential evapotranspiration occurring within the Krueng Aceh watershed is 103.7-128.8 mm/month or 3.46-4.48 mm / day with the highest month evapotranspiration is in November at 84.87%. The monthly discharge obtained in the Krueng Aceh watershed using the Mock method in November represent a maximum discharge of 43.35 m^3/s and minimum discharge occurred in July, is 3.56 m^3/s. The water availability in January was 55 458 043.58 m^3, the month of February decreased 43.12% ie 31 547 140.38 m^3 until July at 9 533 945.38 m^3, in August the water flow increased by 11 991 471.76 m3 until the month of November was 120 151 120.44 m^3 . December there was a 16.76% discharge rate of 100 004 811.55 m^3.

Keywords: watershed; Krueng Aceh; water resources; availability.

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1. Introduction

Water, natural source derived from rain, must be protected and well managed, so that this water can always be utilized by human or other living creatures of this earth as well as needed. As water resources availability per capita increases, humans and the ecosystem find it easier to sustain life both in the present and in the future [1, 2]. Water availability has become one of the main factors affecting field crops yield and variability [3, 4]. Water availability is also one of the fundamental points in hydrology [5, 6].

Indonesia as a tropical area with an average rainfall of 2 620 mm / year and land area about 1 918 410 km^2. After loss and evaporation, the available effective abundance is 1 450 mm or 55% [7]. Falling rain will be infiltrated into the ground and caused evapotranspiration infiltrated water in the soil will fill the stash until it reaches saturation resulting in interflow, and water will move into the soil (percolation) until finally into a base flow. The total run off of the water flows accumulated from this process is known as the river flow [8]. The readily available water can be extracted from the soil fast enough for the evapotranspiration rate to equal what is called the reference evapotranspiration crop rate [9, 10].

Continuous decreased of water resources availability, quality and quantity are the most prominent problems in Indonesia's water resources especially in the destruction of water sources. This is caused by the large pressure of the population in the use of water to meet their daily water needs so that it exceeds the carrying capacity of the environment [11].

The Krueng Aceh watershed in Aceh Besar and Banda Aceh flows through the tributaries to the main river of Krueng Aceh in the district of Aceh Besar and downstream in Banda Aceh City. The need of water for the people of Banda Aceh, central city of Aceh Province, is highly dependent on the availability of water in the Krueng Aceh watershed. Water availability in the Krueng Aceh watershed is very close to the geographic and climatic factors of the region.

The availability of water in the Krueng Aceh watershed can be determined by the flow duration curve constructed from the climatic and geographical data can be analyzed in the form of water discharge. The decrease of debit data based on rainfall data of Krueng Aceh watershed area by Thiessen polygon using Mock method [12]. Available water discharges can be utilized for various purposes. It is necessary to obtain reliable water supply (probable discharge) probability that is fulfilled 80% or 90% [13]. Based on the description above, it is necessary to perform a study in determining and analyzing the state of water availability in the area of Krueng Aceh watershed.

2. Materials and Method

This research was conducted from January to December 2016 in Krueng Aceh watershed area, Aceh Province. Geographically, research site is located between 5˚03 '41 "- 5˚38' 10" North Latitude and 95˚11 '41 "- 95˚49'46" East Longitude with total area of 174 785.79 ha. The location of this study is presented in Figure 1.

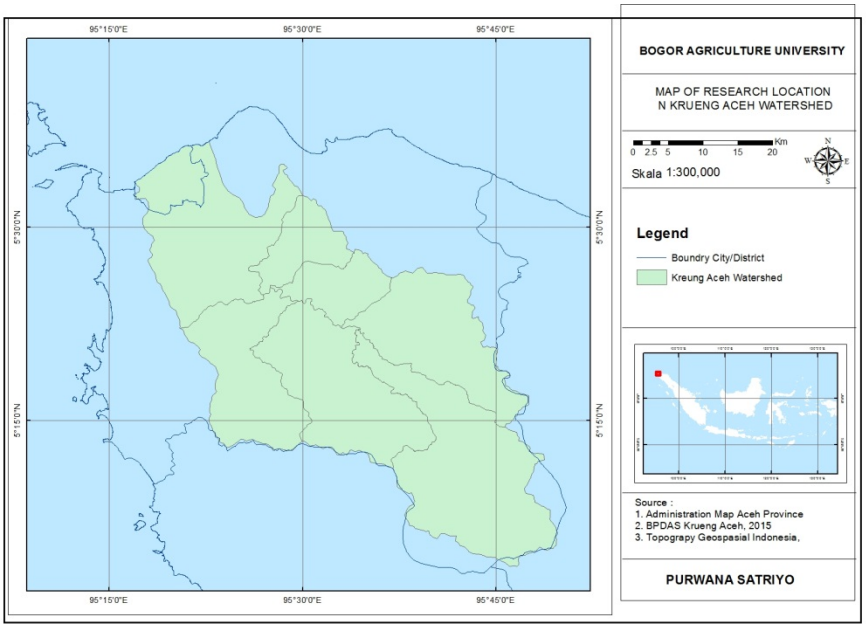

Figure 1: Krueng Aceh Watershed area as a research site location.

Materials also used in this study: Administrative map of Aceh Province with 1: 100.000 scale, Krueng Aceh Watershed Map scale 1: 250,000, population census data and population growth rate of Banda Aceh City and Aceh Besar District, and rainfall data from 1995-2015 [14]. Moreover supported with a set of personal computer, ArcGis 10.1 software digital camera stationery and Microsoft Office 2010 software packages.

2.1. Regional rainfall analysis

Analysis of regional rainfall is aimed to obtain the results of water availability in the river or land. Water availability analysis is performed to meet the consumption of goods and services for the community in water management in the Krueng Aceh watershed. It is the result of water balance analysis and taking into account the inputs and debits needed in the Krueng Aceh watershed area at a given time/year (year) mainstay.

This analysis covers upstream to downstream watersheds using 21 years (1995-2015) rainfall data from 3 (three) rain gauge stations, namely BMKG Sultan Iskandar Muda Airport, BMKG Indrapuri, and BMKG Jantho rain stations. The water availability analysis is based on analysis of the average rainfall value of an area using the Thiessen polygon method. This method takes into account the weight of each station that represents the surrounding area [13]. Study of [15] states that the amount of rainfall recorded in each rain station can only represent the amount of rainfall for the area including half the distance of the line between the surrounding stations. Thus, each weighting station is appropriate within the area it represents and can provide accurate rainfall data in each catchment area representing each raindrop proportionally with the following equation:

$$P=(R\_1a1/A)+(R\_2a2/A)+\cdots\ldots\ldots\ldots+(R\_nan/A) \qquad (1)$$

Where P = average rainfall in area (mm), R1, R2, Rn=Rainfall for each rain gauge (mm), a1, a2, an =Total area for each polygon area (ha), A= Watershed area (ha).

2.2. Water availability analysis

In the hydrologic cycle, the explanation of the relationship between inward flow and outflow in an area for a given period is called water balance [16]. Water availability analysis in Krueng Aceh watershed area based on the concept of water balance to estimate the extent of water in the watershed. It is produce the amount of discharge using Mock method based on hydrological cycle [12]. This method assumes that falling water (precipitation) will lose as evapotranspiration, some runs off, some goes into the soil (infiltration) and flows down due to gravity (percolation) to the ground water, so it will come out into the river as the base stream (Base flow). The Mock method is a method used to calculate the average monthly flow of a river, based on a water balance analysis that describes the runoff relationship with monthly rainfall, evapotranspiration, soil moisture and storage in the soil [12]. The water balance equation is described as follows:

$$P = E + \Delta S + TRO \qquad (2)$$

Where :P = precipitation (mm), E = evapotranspiration (mm), ΔGS= groundwater storage (mm),

TRO= total runoff (mm).

2.3. Evapotranspiration

Evapotranspiration (ETo) was obtained by modified Penmann method (FAO) in certain land areas. It requires input of climate data in the form of temperature, air velocity, humidity and solar irradiance [17]. The equations used for ETo calculations by Penmann method are as follows:

$$Eto=c[W.Rn+(1-W).f(u).(ea-ed)] \qquad (3)$$

where: Eto=evapotranspiration (mm/day), c=weather condition adjustment factor due to day and night, W= weighting factors that affect from temperature and altitude, Rn=solar irradiation (mm/day), (1-W) =weighting factors influenced by wind and humidity ,f(u)=weight factor influenced by wind and humidity, ea=saturated vapor pressure depending on temperature (mbar), ed=actual vapor pressure, (ea- ed) =the difference between saturated and actual vapor pressure at the average air temperature.

2.4. Mock Model

It is a method for calculating the average monthly flow of rivers or river flow simulations from monthly rainfall data, evapotranspiration, soil moisture and storage in the soil. This mock model is a hydrological model to analyze the availability of water that describes the true state of nature through the process. The Mock method equation [12] is described as follows:

$$QS = Qtotal \times A \qquad (4)$$

where: (Qs)= Debit, A = Watershed area (km^2)

2.5. Reliable discharge analysis

It defines as the amount of discharge available to meet water demand with the risk of failure being calculated [18]. The amount of available discharge will determine the water availability of a watershed. In determining the magnitude of the reliable discharge or rainfall mainstay with an opportunity of 80% of the rainfall value of the area has a probability exceeded by 80% used probability Weibull method based on the monthly average that has been sorted from the largest to the smallest, the value of river reliable discharge generated from the analysis with Mock method. The equation is as follows:

$$P = m/(n+1)x100\% \qquad (5)$$

where: P = The probability of a set of expected values during observed periods or precipitation with a probability of 80 percent, m= Serial number of data (rank) sorted from largest to smallest, n= number of total data

The value of the reliable discharge generated by water availability. Thereby, the value of discharge which is close to or equal to the probability value 80% is the 80% probable discharge that is likely to be met.

3. Result and Discussion

3.1. Rainfall

Krueng Aceh watershed has an area of 174 785.79 ha with its main river Krueng Aceh having a long river of 141 km at the top of Mount Seulawah in Aceh Besar District and flowing downstream of Banda Aceh City. Monthly average rainfall data in the Krueng Aceh watershed is represented form three rainfall observation stations for 21 years, from 1995 to 2015. Average rainfall from these three observation points within a watershed area may represent rainfall whole Krueng Aceh watershed area. Rainfall data in watershed area were generated using Thiessen polygon method. Thiessen polygon area represents every point of the observer's rain station is; The polygon point of Sultan Iskandar Muda rainfall station is 31 162.32 ha (17.83%), while the polygon point of Indrapuri rainfall station is 62 492.21 ha (35.75%) and the Jantho station is 81 131.26 ha (46.42%).

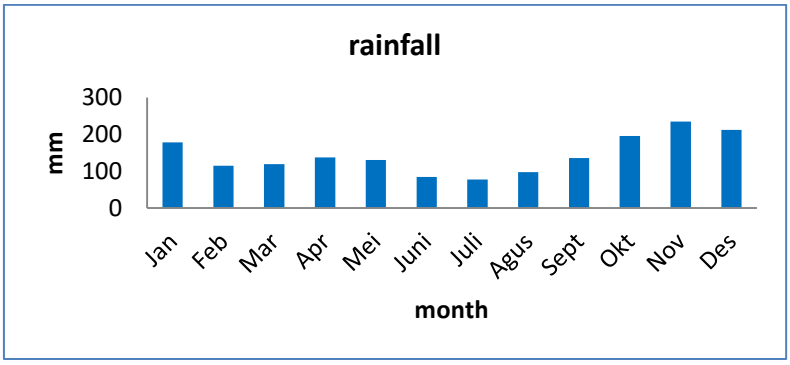

Figure 2: Average monthly rainfall of Krueng Aceh watershed (1995-2015)

Average annual rainfall in the Krueng Aceh watershed for 21 years (1995-2015) is 1 714.57 mm/year, from which the highest monthly average rainfall was in November with 234.24 mm/month. On the other hand, the lowest average rainfall was happened in July with 77.20 mm/month as shown in Figure 2. Thus, we can inferred that in November, potential water availability was the biggest in the Krueng Aceh watershed.

3.2. Evapotranspiration

Potential evapotranspiration (ETo) is an evapotranspiration that occurs in the smallest to largest extent in a grass-cultivated unit as high as 8-15 cm in conditions of water adequacy and optimal growth [17]. Potential evapotranspiration in Krueng Aceh watershed was analyszed using a modified Penman method supported by Climate of Sultan Iskandar Muda rain survey system for 10 years (2006-2015).

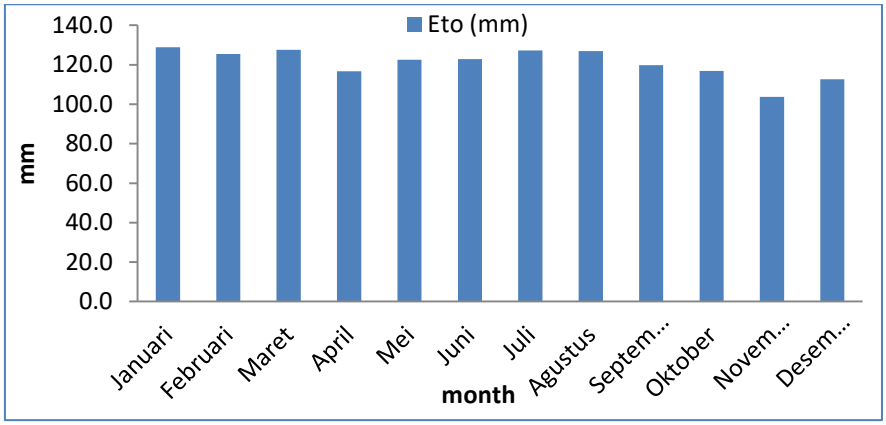

Figure 3: Monthly average evapotranspiration (ETo) in Krueng Aceh watershed.

Figure 3 shows the average potential evapotranspiration in the Krueng Aceh watershed ranging from 103.7-128.8 mm / month or 3.46-4.48 mm / day. The highest evapotranspiration value was occurred in January with 128.8 mm / month and the lowest was happened in November with 103.7 mm/month. The highest monthly rainfall area was 234.24 mm, the highest relatife humidity was 84.97% in November. However, 65% relative humidity is considered to have the highest sensitivity [19].

3.3. Water availability

The Krueng Aceh watershed is one of the water providers for the downstream area of the provincial capital of Aceh, namely the city of Banda Aceh through the main river Krueng Aceh. The availability of water in the Krueng Aceh watershed area is a top priority for the survival of living things to meet the basic needs of the community. The availability of water in the Krueng Aceh watershed resulted from the Mock method with the parameters suggested by Mock namely: the proportion of land surface not covered by vegetation (0-50%), soil moisture capacity 200 mm, infiltration factor 0.4 and runoff recession 0.6. Basically, rain-flow simulation according to the Mock model is a calculation of water balance in three zones: surface, sub surface and aquifer [20]. Rainfall that reaches the soil surface (ΔS) in the Krueng Aceh watershed area is 130.39 mm in November and the minimum in July is -50.11 mm. This calculation results from evapotranspiration in Krueng Aceh

watershed with rainfall data of Krueng Aceh watershed area is shown in Figure 4.

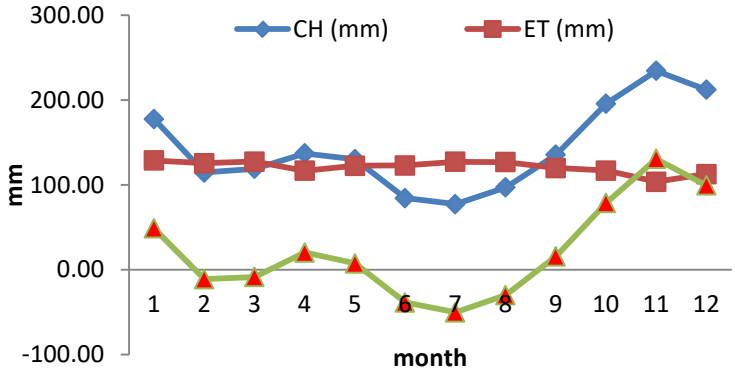

Figure 4: Average rainfall reaching ground level (ΔS) in Krueng Aceh watershed.

The moisture content of groundwater depends on the rainfall reaching the ground [21]. The value of rainfall that reaches the soil surface ΔS> 0; thus, the moisture content of ground water is 0 (zero) and vice versa if ΔS <0, the value of moisture content of ground water is the value of rainwater reaching the ground surface itself. When the value of rainfall that reaches the ground surface is negative then the soil moisture will decrease. Rainfall that reaches negative soil surface in February, March, June, July and August deficit part of the ground water will come out and positive value of ΔS in September-January and April-May water will enter into soil if capacity Soil moisture has not been met as shown in Figure 5.

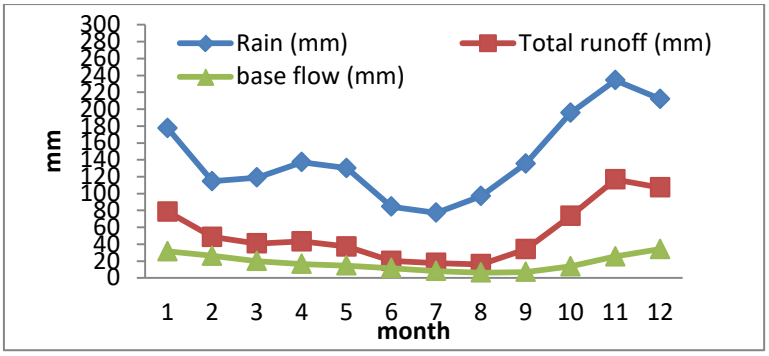

Figure 5: Rainfall, base flow and total runoff relationship in Krueng Aceh watershed.

Figure 5 shows that rainfall, base flow and total runoff occurred in Krueng Aceh watershed generated water availability using the Mock formula. Total run-off and base flow occurring in the Krueng Aceh watershed for monthly average (1995-2015 period) was decreased in April - July, this was due to the reduced rainfall. The deficit of rain then the supply of water in the soil will also decrease [22]. The water availability calculation using the Mock method, estimates the average monthly discharge in the Krueng Aceh watershed based on the concept of water balance in the results of the maximum reliable discharge occurred in November of 43.35 m^3/s and the minimum discharge occurred in July at 3.56 m^3/s. Analysis results of the average debit recapitulation by Mock method. Meanwhile, to ensure the prediction using Mock method, the river flow were also measured by Automatic Water Lavel Recorder (AWLR) in Senyui village, Indrapuri sub-district, Aceh Besar district, and the

result is presented in Figure 6. From comparison result, it shows that Mock estimation was nearly same with actual measurement on river flow in Krueng Aceh.

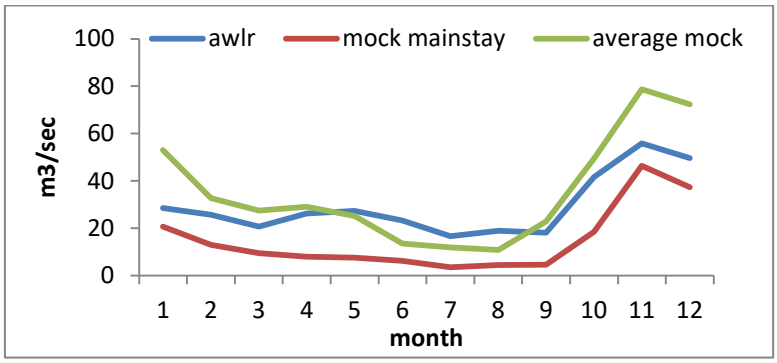

Figure 6: Comparison results between Mock estimation and actual surface discharge measurement using AWLR in Krueng Aceh.

Reliable discharge analysis in Krueng Aceh watershed is likely to be fulfilled by 80% which is arranged with the order of the discharge data from biggest to the smallest with 21 years data of 473 417 048.89 m^3/year. Monthly water supply flow curve of Krueng Aceh river based on watershed characteristics for 21 years rainfall data is presented in Figure 7. The water availability in January was 55 458 043.58 m^3, the month of February decreased 43.12% ie 31 547 140.38 m^3 until July at 9533 945.38 m^3, in August the water flow increased by 11 991 471.76 m^3 until the month of November was 120 151 120.44 m^3. In December there was a 16.76% discharge rate of 100 004 811.55 m^3. The availability of water from one watershed greatly affects the daily life of the community in sustaining its life. Reduced discharge that will directly affect the availability of water, especially for Irrigation Areas Krueng Aceh and the use of domestic water through company Regional drinking water.

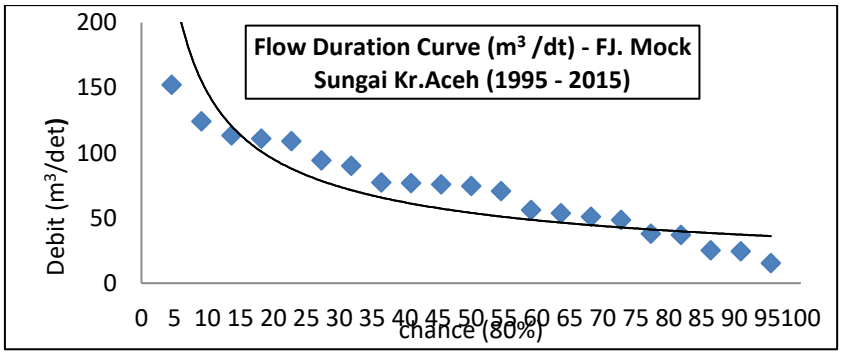

Figure 7: Monthly discharge curve in Krueng Aceh river using Mock method.

4. Conclusionsigures

Rainfall analysis of Krueng Aceh watershed using Thiessen polygon method from three rainfall observation stations for 21 years, from 1995 to 2015 is 1 714.57 mm/year with an area of 174 785.79 ha. Moreover, Potential evapotranspiration occurring within the Krueng Aceh watershed is 103.7-128.8 mm / month or 3.46-

4.48 mm/day with the highest month evapotranspiration is in November at 84.87%. On the other hand, monthly discharge obtained in the Krueng Aceh watershed using the Mock method in November represent a maximum discharge of 43.35 m^3 / s and minimum discharge occurred in July was 3.56 m^3/s.

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