ASSESSMENT OF DROUGHT INDICES AND WATER AVAILABILITY USING STATISTICAL Z-SCORE AND MOCK MODEL

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ABSTRACT

The phenomenon of drought and water scarcity due to climate change is a major problem in many countries. Assessing drought conditions and water availability in a watershed helps the government and communities implement sustainable watershed management. The study was conducted in Krueng Jreue Sub Watershed, Krueng Aceh Watershed, Aceh Province, Indonesia. The meteorological and hydrological indices in the watershed were analyzed using statistical Z-Score for Precipitation (ZSP) and Discharges (ZSD). Discharges originated from Mock model was used to examine the water availability in a watershed. The results showed the ZSP and ZSD indices from 2008 to 2017 were almost categorized as normal. In certain months, drought indices with the criteria of extreme wet (EW), very wet (VW), and severe drought (SD) also occurred. In general, the ZSP and ZSD indices were consistent, but for certain months (April 2008, November 2010, and March 2017) inconsistencies were found due to differences in signs and index classes. The Mock model parameters for the proportion of surface soil uncovered by vegetation (m), infiltration factor (IF), initial soil moisture (ISM), and flow reduction coefficient (Rc) were 20 %, 0.4, 200 mm month^{-1}, and 0.6, respectively. The average monthly discharge during the period of 2008-2017 ranged from 3.16-31.18 m^{3}s^{-1}. The total water needs of 5.041 m^{3} s^{-1} per month. The water availability per month was surplus in the rainy season (October-April), but deficit in the dry season (May-September). This research not only contributes to enriching references for similar research in Krueng Aceh Watershed, Indonesia but can also be applied to other watersheds according to the current conditions of watershed characteristics.

Key words: watershed management; water management; surplus and deficit of water

تقييم مؤشرات الجفاف وتوافر المياه باستخدام نموذج إحصائي Z-SCOR و MOCK

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المستخلص

أجريت الدراسة في Krueng Jreue Sub Watershed، Krueng Aceh Watershed ، مقاطعة آتشيه ، إندونيسيا. تم تحليل مؤشرات الأرصاد الجوية والهيدرولوجية في مستجمعات المياه باستخدام درجة Z الإحصائية للهطول (ZSP) والتصريف (ZSD). تم استخدام التصريفات الناتجة عن نموذج Mock لفحص توافر المياه في مستجمعات المياه. أظهرت النتائج أن مؤشرات ZSP و ZSD من 2008 إلى 2017 تم تصنيفها تقريبًا على أنها طبيعية. في أشهر معينة ، حدثت أيضًا مؤشرات الجفاف مع معايير الرطب الشديد (EW) ، والرطوبة الشديدة (VW) ، والجفاف الشديد (SD). بشكل عام ، كانت مؤشرات ZSP و ZSD متسقة ، ولكن لبعض الأشهر (أبريل 2008 ، نوفمبر 2010 ، مارس 2017) تم العثور على تناقضات بسبب الاختلافات في العلامات وفئات الفهرس. كانت معلمات النموذج الوهمي لنسبة التربة السطحية المكشوفة بواسطة الغطاء النباتي (م) ، وعامل التسلل (IF) ، ورطوبة التربة الأولية (ISM) ، ومعامل تقليل التدفق (Rc) (20 ٪ ، 0.4، 200 ملم شهر −1 ، و 0.6 على التوالي.

الكلمات المفتاحية: إدارة مستجمعات المياه ؛ ادارة المياه؛ فائض وعجز المياه

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INTRODUCTION

Climate change causes not only drought and flooding in various countries but also water scarcity. Every country needs to anticipate this problem early so that it does not affect the water adequacy for the community, agriculture, tourism and industry. One of the important activities that must be carried out is to evaluate meteorological and hydrological drought as well as water availability based on the current biophysical conditions of a watershed (28, 33, 34). A hydrological disaster cannot be avoided, but with the science and technology development supported by accurate data (52), it can be anticipated to minimize environmental damage losses. Both are caused by the main and additional components of the hydrological disaster vulnerability parameters (27). This fact implies the importance of understanding the area description, the land biophysical characteristics and its response to changes in the hydrological cycle due to global climate change and extreme weather (56), including the Krueng Aceh Watershed. The Krueng Jreue Sub Watershed is a part of Krueng Aceh Watershed located at the upper stream of Krueng Aceh, which plays an important role as the water source for Aceh Besar District and Banda Aceh City, Indonesia. The increased intensity of land conversion negatively impacts the hydrological conditions of the Krueng Aceh watershed, such as the increase in peak discharge, discharge fluctuations between the dry and rainy seasons, runoff coefficients, as well as the increase in erosion, sedimentation, flooding and drought (36). The Krueng Aceh watershed is one of the priorities and critical watersheds out of the 108 priority handling watersheds in Indonesia (5). The land area of the rather critical category in the Krueng Aceh watershed, particularly in the Krueng Jreue Sub-watershed, increased from 2,320.88 ha (10.00%) in 2013 to 10,969.85 ha (47.25%) in 2018. The decreasing forest cover can reduce the water discharge in a watershed, marked by insufficient water in the dry season. Therefore, the watershed sustainability can be achieved by identifying the links between land, hydrology, and the upstream-downstream areas that are interconnected and affect the watershed and sub-watershed ecosystem units (51). The water availability in the Krueng Jreue sub-watershed range from 0.24 to 3.22 m^3s^{-1}. The total water demand for household and irrigation is 0.18 - 6.44 m^3s^{-1} (21). However, this study did not specifically analyze drought indices but instead studied the economic value of water in the Sub-watershed of Krueng Jreue. Furthermore, climate change and land use change are predicted to affect the drought indices and water availability in this region. Drought indices in the watershed can be analyzed using the Standard Precipitation Index (SPI) (30) and Standard Discharge Index (SDI) (12). Discharges are originated using the rainfall-runoff model, called Mock model, introduced by Mock, to predict the potential water availability (20, 32). The water surplus or deficit can evaluate based on the potential water availability, which is useful to anticipate the occurrence of hydrological drought and utilize the water as well as possible (9). Researchers define the term Standard Precipitation Index (SPI) differently. The SPI was firstly introduced using the Gamma distribution (30) and used by other researchers in many countries (10, 17, 18, 26 ,35, 38, 48). World meteorological organization released a Standard Precipitation Index Guide and the latest SPI program (SPI_SL_6.exe) is downloadable for free (59). Some researchers also use the term SPI in the form of Z-score statistics to examine the abnormal occurrence of rainfall or discharges (4, 14, 16, 22, 25, 37, 50, 60, 54). SPI analysis using the Gamma distribution seems more complicated than using the Z-Score statistic. Models with many input parameters do not always perform better than those with several input parameters (3). The simpler the formula for evaluating hydrological drought, the more applicable it is in the field, and vice versa. Therefore, this research not only contributes to enriching references for similar research in Krueng Aceh Watershed, Indonesia but can also be applied to other watersheds according to the current conditions of watershed characteristics. Further research by comparing the use of the Mock model with other rainfall-runoff models is very interesting to do to enrich the reference for watershed management.

MATERIALS AND METHODS

Times and Site: The research was carried out in the Krueng Jreue Sub Watershed of 23,218.06 ha located at 5°12 '- 5°28' N and 95°20 '- 95°32' E, which is part of the Krueng Aceh Watershed, Aceh Province, Sumatera, Indonesia (Figure 1). It was conducted in period from January to December, 2019.

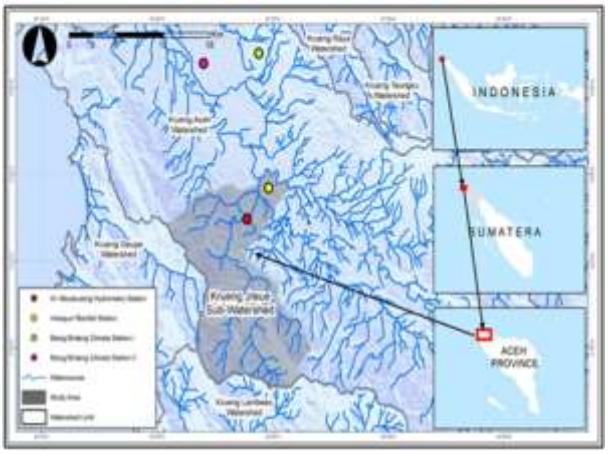

Figure 1. Location of study area

Data Collection

Materials needed included some maps (administrative, topography, soil type, and land use), monthly rainfall, evapotranspiration, irrigation area, and population for 2008-2017. Land use map was obtained from Krueng Aceh Watershed Management Board. Climatology data were from Blang Bintang Meteorological, Climatological, and Geophysical Agency, and monthly river discharge data was derived from the Center of River Basin Sumatera-I. There are three climatological stations in Krueng Aceh Watershed, but only one is located in Sub Krueng Jreue Watershed. In this study, rainfall data from Indrapuri rainfall station was used, as shown in Figure 1. Furthermore, the discharges data was collected from Kr. Meulesong hydrometry station.

Drought Indices

The Z-score statistics for precipitation (ZSP) is used in this study to evaluate the meteorological drought using the following equation:

$$ZSP = \frac{P_i - P_{avg}}{S} \quad .... (1)$$

Where, P_i = precipitation (mm); P_{avg} = average of precipitation; S = standard deviation of precipitation

Using the same concept, the statistical of Z-score for discharges (ZSD) is calculated for evaluating hydrological drought using the following equation:

$$ZSD = \frac{D_i - D_{avg}}{Sd} \quad ...... (2)$$

Where, D_i = discharge (m^3s^{-1}); D_{avg} = average of discharge; S_d = standard deviation of discharge. Drought criteria to justify the drought class (10), both for ZSP and ZSD, is shown in Table 1.

Table 1. Drought class for ZSP and ZSD

No	Drought criteria	Values of ZSP and ZSD
1	**Extreme wet (EW)**	**≥ 2.00**
2	**Very wet (VW)**	**1.50 to 1.99**
3	**Moderate wet (MW)**	**1.00 to 1.49**
4	**Normal (N)**	**-0.99 to 0.99**
5	**Moderate drought (MD)**	**-1.00 to -1.49**
6	**Severe drought (SD)**	**-1.50 to -1.99**
7	**Extreme drought (ED)**	**≤ -2.00**

Mock Model

The basic approach of the Mock model is to consider factors of rainfall, evapotranspiration, water balance at the soil surface, and groundwater content. The main input of the Mock method is rainfall data. To analyze the water availability in the river, monthly rainfall data is strongly needed. The longer the recording period, the better the results will be. Many researchers (11, 13, 24, 29, 43, 46, 47) used the Mock model to assess water discharges or water availability of watersheds. Generally, the researchers reported that the Mock model is reasonable to evaluate the water balance in certain watersheds. The equations used to calculate water balance parameters by the Mock model (20, 32) are as follows.

Evapotranspiration:

$E = ET_0 - \Delta E$ ……(3)

$\Delta E = ET_0\ (m1/20)\ (18 - n_1)$ …(4)

Where, ΔE= the difference between potential and actual evapotranspiration (mm $month^{-1}$); ET_0= potential evapotranspiration (mm $month^{-1}$); m_1 = the proportion of soil surface that is not covered by vegetation (set as 20%); n_1= total of rainy days; E = actual evapotranspiration (mm $month^{-1}$).

Discharges of a river:

$Q_{river} = (Q_{total} \times A)/t$ ……(5)

$Q_{total} = Q_{base} + Q_{direct} + Q_{storm}$ …(6)=

Where, Q_{river} = discharges of a river (m^3s^{-1}), Q_{total} = total runoff (mm $month^{-1}$), A =

watershed area (Ha), t = time (second) Q_{base} = baseflow (mm month^{-1}), Q_{direct} = direct runoff (mm month^{-1}), and Q_{storm} = storm runoff (mm month^{-1}).

Baseflow:

$Q_{base} = inf - G.\ STOR_t + G.\ STOR_{(t-1)}$ …(7)

$inf = WS \times IF$ …………………(8)

$WS = ISM + R_e - E - SMS$ ……(9)

$SMS = ISM + R_e - E$ …………….(10)

$G.STOR_t = G.\ STOR_{(t-1)} \times Rc + 0.5(1 + Rc) \times inf$ ……………………….....(11)

Where, inf = infiltration (mm month^{-1}); $G.\ STOR_t$ = ground water storage at the beginning of the month (mm month^{-1}); $G.\ STOR_{(t-1)}$ = ground water storage at the end of the month (mm month^{-1}); IF = infiltration factor (set as 0.4); WS = water surplus (mm month^{-1}); ISM = initial soil moisture (set as 200 mm month^{-1}); R_e = monthly rainfall (mm month^{-1}); SMS = soil moisture storage (mm month^{-1}); Rc = flow reduction coefficient (set as 0.6).

Direct runoff:

$Q_{direct} = Ws \times (1 - IF)$.….(12)

Where, Ws = water surplus (mm)

Storm runoff:

$Q_{storm} = Re \times PF$..... (13)

Where, PF = precipitation factor (%).

Water Demand

Two kinds of water needs were considered for calculating the water demand. First, water demand for irrigation in the Krueng Jreue Sub-watershed for the period of 2008-2017, it was projected based on the area of irrigated land according to irrigation water needs calculated as follows.

$$DR = \frac{NFR}{e \times 8.64} \text{ ……(14)}$$

Where, DR = diversion requirement (l s^{-1}ha^{-1}); NFR = net water requirement in paddy field (l s^{-1}ha^{-1}); e = irrigation efficiency; 1/8.64 = conversion value from (mm day^{-1}) to (l s^{-1} ha^{-1}).

Second, the water demand for households in the Krueng Jreue Sub-watershed for the period of 2008-2017, it was calculated using the assumption of population growth (1.4% year^{-1}) and the standard water demand per capita (0.06 m^{3}day^{-1}).

RESULTS AND DISCUSSION

Discharges Originated Using Mock Model: Monthly discharges are fluctuating, depending on the amount of rainfall (Figure 2) as the main input of the Mock model. Table 2 shows the discharges of the Krueng Jreue Sub-watershed originated from Mock Model. The higher the rainfall, the higher the water discharge generated by the Mock model. The average monthly discharge of the Krueng Jreue Sub-watershed during the period of 2008-2017 ranged from 3.16-31.18 m^{3}s^{-1}. The highest monthly average discharges in the rainy season (October-March), occurred in November (31.18 m^{3}s^{-1}), and December (28.02 m^{3}s^{-1}), while the lowest monthly discharge in the dry season (April-September), occurred in July (3.16 m^{3}s^{-1}), and June (3.36 m^{3}s^{-1}). Further analysis provides information that for the entire observation year, February, which is included in the rainy season, has a very low monthly discharge value (1.78 - 3.76 m^{3}s^{-1}), below the average monthly discharge, except for 2012 and 2013.

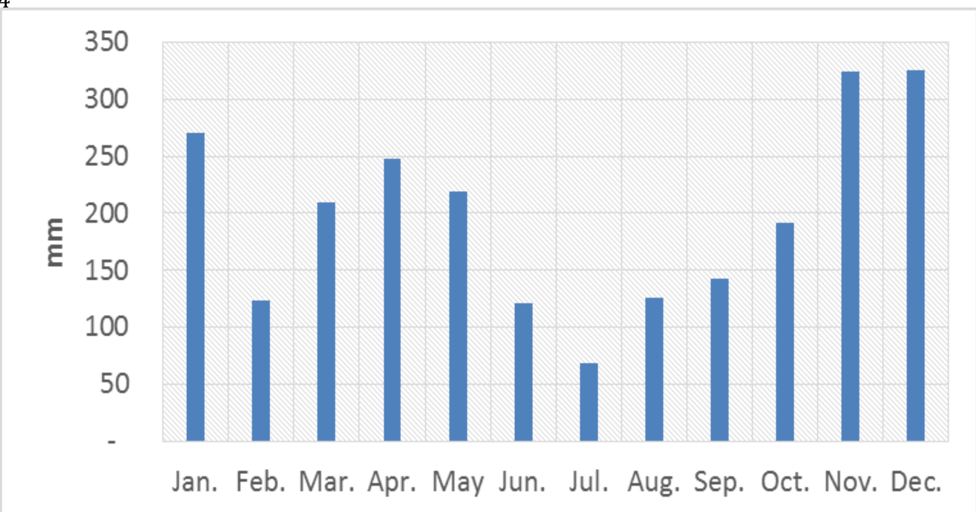

Figure 2. Average of Monthly Rainfall in Sub Krueng Jreue Watershed (2008-2017)

Table 2. Discharges of the Krueng Jreue Sub-watershed

Month	Discharges ($m^3 s^{-1}$)											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	Avarage
Jan.	4.39	16.99	3	29.9	17.44	40.59	13.58	24.23	40.18	45.75	236.05	23.61
Feb.	2.75	2.17	2.31	3.06	26.55	19.81	1.78	2.18	3.76	3.31	67.68	6.77
Mar.	15.8	5.14	4.29	15.99	7.97	3.44	2.1	2.35	2.26	6.16	65.5	6.55
Apr.	41.79	14.46	4.97	22.71	32.09	28.46	4.01	27.14	2.41	6.6	184.64	18.46
May	2.69	13.13	15.81	2.76	5.02	28.77	5.82	6.71	2.67	14.84	98.22	9.82
Jun.	6.86	2.42	8.82	2.17	1.73	2.9	2.05	1.92	2.51	2.2	33.58	3.36
Jul.	3.5	2.19	9.17	2.4	2.82	2.18	1.64	2.56	2.89	2.24	31.59	3.16
Aug.	5.65	2.96	8.44	3.81	2.97	2.23	3.43	6	3.11	3.25	41.85	4.19
Sep.	14.47	2.97	43.03	6.65	2.52	2.64	3.79	4.93	2.55	15.9	99.45	9.95
Oct.	5.01	4.25	6.3	16.93	7.41	2.75	19.21	23.3	2.99	3.81	91.96	9.2
Nov.	37.45	38.85	44.32	11.74	30.3	5.84	46.68	39.95	25.19	31.51	311.83	31.18
Dec.	11.31	21.25	44.96	23.34	38.6	45.33	41.9	13.72	10.73	29.04	280.18	28.02
Total	151.67	126.78	195.42	141.47	175.42	184.94	145.99	154.99	101.25	164.61	1,542.54	154.25
Average	12.64	10.57	16.29	11.79	14.62	15.41	12.17	12.92	8.44	13.72	128.55	12.85

Furthermore, in several years (2013, 2014, 2015, and 2016), March has the discharges (2.1-3.44 m^3s^{-1}) below the average monthly discharge. Conversely, in the dry season, for August 2008 and 2009, the monthly discharge was 6.86 m^3s^{-1} and 8.82 m^3s^{-1}, respectively, above the average monthly discharge. This shows that the discharge for certain months does not follow the dry season and rainy season patterns. There are two important questions whether this is due to the phenomenon of climate change or the Mock model being used needs further investigation. Many previous researchers use rainfall-runoff modelling, such as Tank model (49, 2), NRECA model (19, 23), IHACRES (15), Sacramento model, Stanford model, Monash model (57), ARNO model (53), Artificial Neural Network Model (45). The rainfall-runoff model, known as the Mock model, was introduced by Mock (32) based on a long-term study of rivers on the island of Java-Indonesia. Many Indonesian researchers used the Mock model for islands outside Java to analyze water availability in a watershed. However, this model sets certain values for parameters that are specifically related to factors m (proportion of surface soil that is not covered by vegetation), *ISM* (initial soil moisture), *PF* (precipitation factor), *Rc* (flow reduction coefficient) and *IF* (infiltration factor). The parameters values vary between watersheds due to differences in climate, land use and soil types. In this study, the values of m, *IF*, *ISM*, *Rc* are 20%, 0.4, 200 mm month^{-1}, and 0.6, respectively. Maulana et al (29) reported the values of m =30 %, *IF* =0.75, *ISM*= 250 mm month^{-1}, *Rc* = 0.85. Indonesia irrigation planning standard recommended values are m = 30 %, ISM 50-200 mm month^{-1}, and *IF*= 0-1(20).

Values of ZSP and ZSD

The values of ZSP and ZSD from 2008 to 2017 are shown in Table 3. Positive ZSP or ZSD values indicate greater than median precipitation or discharges, vice versa for negative values (54). Generally, drought indices are normal. The ZSP indices categorized as severe drought are found in June 2011 and August 2013. The ZSD indices categorized as extreme wet are found in April 2008 and November 2014. The ZSP and ZSD indices in the dry season (April–September) tend to be negative, indicating that rainfall or discharge is under the average indices, vice versa for the rainy season (October – March). Generally, the ZSP and ZSD values are consistent from 2008 to 2017. It is also proved by the coefficient determination or R^2 (0.77), as shown in Figure 3. It indicates that the rainfall as the main input to the Mock model resulted in a reasonable discharge. However, some cases, for example, in April 2008 and September 2010, were inconsistent due to the opposite index values and the difference in drought classes between ZSP and ZSD (Table 3). This study indicates that the ZSP and ZSD methods can be used to determine the reliability of a rainfall-runoff model, such as the Mock model. Logically, it can be said that the rainfall input determines the number of discharges generated by the model used. In this study, some rainfall events and discharges are rather illogical so it requires further investigation, for example for April 2008, the ZSP = -0.44 (Normal) and ZSD = 2.5 (Extreme Wet), likewise November 2010, the ZSP = 0.92 (Normal) and ZSD = 2.33 (Extreme wet), May 2016, the ZSP = 2.26 (Extreme Wet) and ZSD = -0.75 (Normal), and March 2017, the ZSP = 4.34 (Extreme wet) and ZSD = -0.50 (Normal). Several researchers explained that it is related to inconsistencies such as in Rajasthan Province in India. The negative SPI anomaly does not always match the drought in the province. Conversely, drought can occur in a hydrological environment even though SPI is positive (4). SPI correlates well with fluctuations in shallow groundwater levels in irrigated areas in Australia (22). A comparison of drought severity indices in Turkey, the Z-Score is an index that is easy to compute and the response is similar to the complex SPI, but slightly less consistent (14). Simple methods such as SPI with the help of geoinformatics can be used as the basis for a drought monitoring system over an area of the Island of Crete (54). This is a challenge for other researchers to explain whether this is affected by watershed conditions, in particular land cover, or the model used needs to be further evaluated. Changes in land use in the upper watershed of Komering Indonesia to plantations to reduce infiltration during the rainy season. The reduced infiltration decreases soil water storage and vice versa for surface flow (13). Regarding the rainfall-runoff model, some efforts can increase the model reasonability, especially the tank model, by considering soil types, land use types, rainfall, and actual discharges (2).

Table 3. Values of ZSP and ZSD

Year	2008				2009				2010				2011				2012			
Month	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria
Jan.	-0.33	N	-0.63	N	0.24	N	0.31	N	-0.44	N	-0.73	N	0.32	N	1.26	VW	0.49	N	0.34	N
Feb.	-0.91	N	-0.75	N	-0.20	N	-0.79	N	-1.10	MD	-0.78	N	-0.71	N	-0.73	N	-0.73	N	1.02	MW
Mar.	0.16	N	0.22	N	-0.49	N	-0.57	N	-0.49	N	-0.63	N	0.27	N	0.23	N	-0.34	N	-0.36	N
Apr.	-0.44	N	2.15	EW	-0.70	N	0.12	N	0.18	N	-0.58	N	0.07	N	0.73	N	-0.30	N	1.43	MW
May.	-0.89	N	-0.75	N	-0.77	N	0.02	N	0.03	N	0.22	N	-0.85	N	-0.75	N	-0.37	N	-0.58	N
Jun.	-0.78	N	-0.44	N	-1.21	MD	-0.77	N	-0.40	N	-0.30	N	-1.28	MD	-0.79	N	-1.26	MD	-0.82	N
Jul.	-1.15	MD	-0.69	N	-1.36	MD	-0.79	N	-0.64	N	-0.27	N	-0.84	N	-0.77	N	-0.98	N	-0.74	N
Aug.	-0.99	N	-0.53	N	-0.37	N	-0.73	N	-0.82	N	-0.33	N	-0.83	N	-0.67	N	-1.04	MD	-0.73	N
Sep.	-0.70	N	0.12	N	-0.80	N	-0.73	N	-0.68	N	2.24	EW	-0.51	N	-0.46	N	-0.79	N	-0.77	N
Oct.	-0.58	N	-0.58	N	-0.80	N	-0.64	N	-0.50	N	-0.49	N	-0.56	N	0.30	N	-0.37	N	-0.40	N
Nov.	0.46	N	1.82	VW	-0.07	N	1.93	VW	0.92	N	2.33	EW	-0.02	N	-0.08	N	1.30	MW	1.29	MW
Dec.	0.29	N	-0.11	N	0.92	N	0.62	N	0.43	N	2.38	EW	0.11	N	0.78	N	0.01	N	1.91	MW
Year	2013				2014				2015				2016				2017			
Month	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria	ZSP	Citeria	ZSD	Criteria
Jan.	1.15	MW	2.06	EW	-0.85	N	0.05	N	0.62	N	0.84	N	1.91	VW	2.03	EW	2.02	EW	2.44	EW
Feb.	-0.17	N	0.52	N	-0.90	N	-0.82	N	-0.93	N	-0.79	N	-0.39	N	-0.67	N	0.78	N	-0.71	N
Mar.	-0.07	N	-0.70	N	-0.94	N	-0.80	N	-0.58	N	-0.78	N	-0.98	N	-0.79	N	4.34	EW	-0.50	N
Apr.	-0.20	N	1.16	MW	-0.20	N	-0.66	N	1.18	MW	1.06	MW	1.46	MW	-0.77	N	2.47	EW	-0.46	N
May.	0.44	N	1.18	MW	-0.21	N	-0.52	N	0.68	N	-0.46	N	2.26	EW	-0.75	N	1.24	MW	0.15	N
Jun.	-0.39	N	-0.74	N	-0.83	N	-0.80	N	0.09	N	-0.81	N	1.24	MW	-0.77	N	-0.56	N	-0.79	N
Jul.	-0.94	N	-0.79	N	-1.19	SD	-0.83	N	-0.44	N	-0.76	N	-0.22	N	-0.74	N	-1.36	MD	-0.79	N
Aug.	-1.13	MD	-0.79	N	-0.97	N	-0.70	N	-0.26	N	-0.51	N	0.77	N	-0.72	N	0.53	N	-0.71	N
Sep.	-0.07	N	-0.76	N	-0.25	N	-0.67	N	-0.54	N	-0.59	N	-0.34	N	-0.76	N	0.83	N	0.23	N
Oct.	-0.82	N	-0.75	N	0.70	N	0.47	N	1.43	MW	0.77	N	0.15	N	-0.73	N	0.92	N	-0.67	N
Nov.	-0.05	N	-0.52	N	1.50	VW	2.51	EW	2.13	EW	2.01	EW	1.24	MW	0.91	N	1.59	VW	1.38	MW
Dec.	0.71	N	2.41	EW	1.86	VW	2.15	EW	1.41	VW	0.06	N	2.21	EW	-0.16	N	1.15	MW	1.20	MW

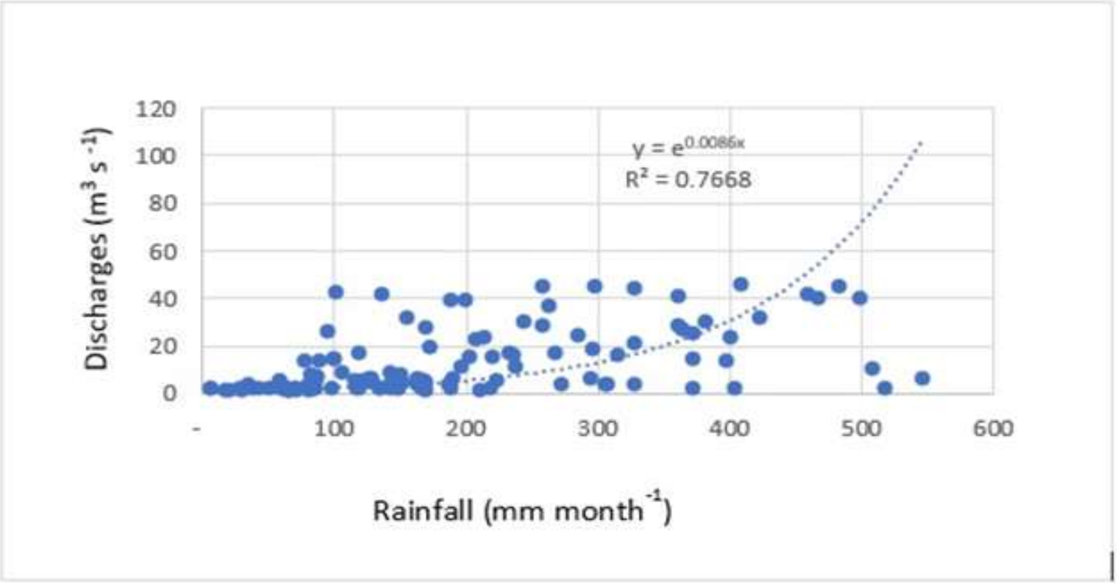

Figure 3. Relationship between rainfall and discharges for the period of 2008-2017

Water Availability

Surplus and water deficits in the Krueng Jreue Sub-watershed were calculated by the difference between water availability (discharges) and water demand (water irrigation + water for households). A positive difference indicates a surplus, and vice versa (Figure 4). Generally, it is shown in the rainy season (October – March), the water availability is surplus, and vice versa for the dry season (April – September). However, water deficit also occurs in both the rainy and dry season. Conversely, water surplus is found in the rainy and dry seasons. This finding shows uncertainty in the rainy and dry season. This is likely related to climate change that occurred around the world, including in this area. The water surplus and deficit in the Krueng Jreue Sub-watershed are also related to the farming system. The Krueng Jreue Sub-watershed has two rice growing seasons: the *rendeng* planting season (October-February) in the rainy season and the *gadu* planting season (May-September) in the drought season. There is a two-month *bera* period (March-April) when farmers rest and provide opportunities for the land to recover. Usually, for the *rendeng* planting season, the water availability can meet the irrigation and household needs, vice versa for the *gadu* planting season. However, in the last ten years, the water availability could not meet the irrigation and household needs for certain months. The monthly average of water needs for irrigation and household are 5 m^3 s^{-1} and 0.041 m^3 s^{-1}, respectively (6,7). With total water needs of 5.041 m^3 s^{-1} per month, the average of water availability (Table 2 and Figure 4) in June (3.36 m^3 s^{-1}), July (3.16 m^3 s^{-1}) and August (4.19 m^3 s^{-1}) were unable to meet the water needs. A more detailed evaluation related to water availability for each year was conducted. In 2009, there are five consecutive months (June, July, August, and September) with water availability smaller than 3 m^3 s^{-1}. Hydrological drought causing inadequate water for irrigation and households can occur every year, especially in the dry season. Various technical and non-technical hydrological drought mitigation efforts, as part of a sustainable watershed management system can be implemented to mitigate hydrological drought (1). The technical method, including maintaining the function of the irrigation network (58), building water trap, terraces, and water retention pond (42), maintaining conservation areas, especially the upstream as a natural reservoir to increase infiltration into the soil (31), and reforestation in the upper catchment area by planting trees to increase spring water discharge and the water availability (8), can be conducted in the Krueng Jreue Sub-watershed. The non-technical method can be done by enforcing some available regulations to prevent the forest to non-forest land conversion (44), conducting soil and water conservation (55), river development and river water damage (40), as well as monitoring and evaluating watershed management (39, 41).

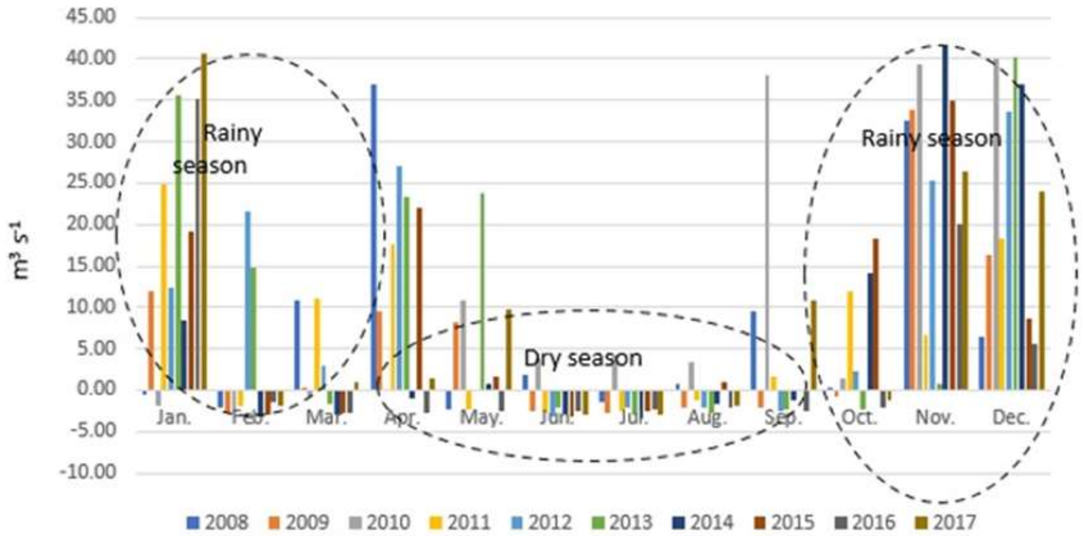

Figure 4. Surplus (+sign) and deficit (-sign) of water in Krueng Jrueu Sub Watershed

CONCLUSIONS

The results showed the ZSP and ZSD indices from 2008 to 2017 were almost categorized as normal. The coefficient determination (R^2) between rainfall and discharges was 0.77. In general, the ZSP and ZSD indices are consistent, but for certain months (April 2008, November 2010, and March 2017) inconsistencies were found due to differences in signs and index classes. The Mock model parameters for the proportion of land surface soil uncovered by vegetation (m), infiltration factor (IF), initial soil moisture (ISM), and flow reduction coefficient (Rc) were 20 %, 0.4, 200 mm month^{-1}, and 0.6, respectively. The average monthly discharge during the period of 2008-2017 ranged from 3.16-31.18 m^3s^{-1}. The total water needs of 5.041 m^3 s^{-1} per month. The water availability per month was surplus in the rainy season (October-April), but deficit in the dry season (May-September). The average water availability for certain months, such as June (3.36 m^3 s^{-1}), July (3.16 m^3 s^{-1}), and August (4.19 m^3 s^{-1}) were unable to meet the needs. Especially in 2009, the water availability in four consecutive months (June, July, August, September) was less than 3 m^3 s^{-1}. The finding suggests that the ZSP and ZSD can be used to analyze the drought indices in a watershed. Some Mock model parameters have to be adjusted when implemented in another watershed.

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REFFERENCES

1. Asdak, C., S. Supian and Subiyanto. 2018. Watershed management strategies for flood mitigation: A case study of Jakarta’s flooding, Weather and Climate Extremes 21:117-122

2. Basri, H. 2013. Development of rainfall-runoff modelling using a tank model: problems and challenges in province of Aceh, Indonesia. Aceh International Journal of Science and Technology, 2(1), pp.26-37

3. Bilewu, S.O., B. Sule and A. Ayanshola. 2015. Optimum parameter selection for the morphometric description of watersheds: a case study of Central Nigeria. Journal of Ecological Engineering, 16(4).

4. Bhuiyan, C., R.P. Singh and F.N Kogan. 2006. Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. International Journal of Applied Earth Observation and Geoinformation, 8(4), pp.289-302

5. BPDASHL Krueng Aceh. 2019. Tabel Luasan Lahan Kritis Periode 2015- 2018, Kementerian Lingkungan Hidup dan Kehutanan, Banda Aceh, pp 2. (in Indonesian)

6. BPS. 2018. Kecamatan Indrapuri Dalam Angka. Badan Pusat Statitistik Kabupaten Aceh Besar. pp 124. (in Indonesian)

7. BWSS-I. 2015. Pola Pengelolaan Sumber Daya Air Water District Aceh-Meureudu,

Balai Wilayah Sungai Sumatera-I Provinsi Aceh, Dirjen Sumber Daya Air, Kementerian Pekerjaan Umum & Perumahan Rakyat, Banda Aceh. pp. 145-160. (in Indonesian)
8. Cao, S., T.Tian, L.Chen, X. Dong, X.Yu and G.Wang. 2010. Damage caused to the environment by reforestation policies in arid and semi-arid areas of China, Ambio 39(4): 279-283
9. Caraka, R.E., M.Tahmid, R.M Putra, A.Iskandar, M.A. Mauludin, N.E Hermansah, H.Rohayani and B. Pardamean. 2018. Analysis of plant pattern using water balance and cimogram based on oldeman climate type. In IOP Conf. Ser. Earth Environ. Sci, 195 (012001): 1-11
10. Ceglar, A., C. Zalika and K.B Lucka. 2008. Analysis of meteorological drought in Slovenia with two drought indices. Proceedings of the BALWOIS 2008: 27-31
11. Chandrasasi, D., L.M. Limantara, and R.W. Juni. 2020. Analysis using the FJ Mock method for calculation of water balance in the upper Konto sub-watershed. In IOP Conference Series: Earth and Environmental Science, 437 (1):012019. IOP Publishing
12. David, V. and T. Davidová. 2016. Assessment of summer drought in 2015 using different indices in the catchment of Blanice River. Procedia engineering, 162: 45-55
13. Dinar, D.A.P., L.Y. Agus and S. Sarino. 2020. Effect of land use changes of upstream Komering sub watershed on declining water availability. Journal of Ecological Engineering (JEE), 21(2): 126-130
14. Dogan, S., A. Berktay and V.P. Singh. 2012. Comparison of multi-monthly rainfall-based drought severity indices, with application to semi-arid Konya closed basin, Turkey. Journal of Hydrology, 470: 255-268
15. Dye, P.J. and B.F. Croke. 2003. Evaluation of streamflow predictions by the IHACRES rainfall-runoff model in two South African catchments. Environmental Modelling & Software, 18(8-9): 705-712
16. Jain, V.K., R.P. Pandey, M.K. Jain and H.R. Byun. 2015. Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. Weather and Climate Extremes, 8, pp.1-11
17. Jang, D., 2018. Assessment of meteorological drought indices in Korea using RCP 8.5 scenario. Water, 10(3):283
18. Jiménez-Donaire, M.D.P., A.Tarquis and J.V. Giráldez,. 2020. Evaluation of a combined drought indicator and its potential for agricultural drought prediction in southern Spain. Natural Hazards and Earth System Sciences, 20(1).
19. Hatmoko, W. and B. Diaz. 2020. Comparison of rainfall-runoff models for climate change projection–case study of Citarum River Basin, Indonesia. In IOP Conference Series: Earth and Environmental Science, 423 (1): 012045. IOP Publishing
20. Irigasi, S.P. 2013. Perencanaan Jaringan Irigasi KP-01. Kementerian Pekerjaan Umum, Direktorat Jenderal Dumberdaya Air Direktorat Irigasi dan Rawa, Jakarta. (in Indonesian)
21. Isnin, M., H. Basri and R. Romano. 2012. Nilai ekonomi ketersediaan hasil air dari daerah aliran sungai (DAS) krueng Jreu kabupaten Aceh Besar. Jurnal Manajemen Sumberdaya Lahan, 1(2): 184-193. (in Indonesian)
22. Khan, S., H.F. Gabriel and T.Rana. 2008. Standard precipitation index to track drought and assess impact of rainfall on water tables in irrigation areas. Irrigation and Drainage Systems, 22(2): 159-177
23. Komariah, I. and T. Matsumoto. 2019. Application of hydrological method for sustainable water management in the upper-middle Ciliwung (UMC) river basin, Indonesia. Journal of Water and Environment Technology, 17(4): 203-217
24. Krisnayanti, D.S., W. Bunganaen, E.E. Hangge, F. Munaisyah, N.A. Nursyam and D.N. Khaerudin. 2019. Analysis of runoff coefficient value on retention ponds in Flores Island. Civil and Environmental Science Journal, 2(1):15-23
25. Li, F., H. Li, W. Lu, G. Zhang and J.C Kim. 2019. Meteorological drought monitoring in northeastern China using multiple indices. Water, 11(1):72
26. Liu, D.H., J.F. You, Q.J. Xie, Y.Y Huang and H.J.Tong. 2018. Spatial and temporal characteristics of drought and flood in Quanzhou based on standardized precipitation

index (SPI) in recent 55 years. Journal of Geo science and Environment Protection, 6: 25-37.
27. Lohani, A.K., G. Krishan and S.K Chandniha. 2017. Hydrological disasters management and risk assessment. Current World Environment, 12(3): 520-529.
28. Mahmood, Y. A. 2020. Drought effects on leaf canopy temperature and leaf senescence in barley. Iraqi Journal of Agricultural Science, 51(6):1684-1693.
https://doi.org/10.36103/ijas.v51i6.1197
29. Maulana, H., E. Suhartanto, and D. Harisuseno. 2019. Analysis of Water Availability Based on Satellite Rainfall in the Upper Brantas River Basin
30. McKee, T.B., N.J. Doesken, and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, 17 (22): 179-183
31. Meitasari, I., A. Aspan and R. Irsan. 2014. Pengaruh perkebunan kelapa sawit terhadap kuantitas air dengan pendekatan neraca air tanaman (Studi Kasus di PT. Rezeki Kencana), Jurnal Mahasiswa Teknik Lingkungan Universitas Tanjung Pura 1(1): 1-10. (in Indonesian)
32. Mock, F.J. 1973. Land capability appraisal Indonesia water availability appraisal, Food and Agriculture Organization of The United Nation, Bogor.
33. Mohammed, A. K., and F. A. Kadhem 2017. Screening drought tolerance in bread wheat genotypes (*Triticum aestivum*L.) using drought indices and multivariate analysis Iraqi Journal of Agricultural Science, 48(special issue):41-51.
https://doi.org/10.36103/ijas.v48iSpecial.244
34. Nada, K. P, M.S.Salman, A.F. Harpy, A R .Ajeena, A .H. Falih. 2022. Stable isotopes and hydrochemical parameter as indicators of al-razzaza lake water interaction with groundwater surrounding karbala governorate-iraq.. Iraqi Journal of Agricultural Science, 53(2):341-352.
https://doi.org/10.36103/ijas.v53i2.1541
35. Naresh M. Kumar., C.S. Murthy, M.V.R. Sesha Sai and P.S Roy. 2009. On the use of standardized precipitation index (SPI) for drought intensity assessment. Meteorological applications: A journal of forecasting, practical applications, training techniques and modelling, 16(3): 381-389
36. Nasrullah, N. and B. Kartiwa. 2010. Analisis alih fungsi lahan dan keterkaitannya dengan karakteristik hidrologi DAS Krueng Aceh. J. Tanah dan Iklim, 31(7): 81-98. (in Indonesian)
37. Omonijo, T.O. and E.C. Okogbue, 2014. Trend analysis of drought in the Guinea and Sudano-Sahelian climatic zones of northern Nigeria (1907-2006). Atmospheric and Climate Sciences, 4(04):483
38. Pathak, A.A. and B.M. Dodamani, 2016. Comparison of two hydrological drought indices. Perspectives in Science, 8: 626-628
39. PP. 2012. Peraturan Pemerintah Republik Indonesia Nomor 37 Tahun 2012, Tentang Pengelolaan Daerah Aliran Sungai, Tanggal 1 Maret 2012, pp 44, Jakarta. (in Indonesian)
40. Permenhut. 2011. Peraturan Menteri Kehutanan Republik Indonesia Nomor 38 Tahun 2011, Tentang Sungai, Tanggal 27 Juli 2011, Jakarta. pp 32. (in Indonesian)
41. Permenhut. 2014. Peraturan Menteri Kehutanan Republik Indonesia Nomor P.61/Menhut/II/2014, Tentang Monitoring dan Evaluasi Pengelolaan Daerah Aliran Sungai, Tanggal 8 September 2014, pp 33, Jakarta. (in Indonesian)
42. Pramono, I. B. and E. Savitri. 2017. Evaluasi tata air DAS Palung, Pulau Lombok, Nusa Tenggara Barat, Prosiding Seminar Nasional Geografi UMS 2017, Pengelolaan Sumberdaya Wilayah Berkelanjutan: 508-521. (in Indonesian)
43. Putro, S.S. 2016. The study of water quantity and quality (Case study: Gajahwong watershed). In Journal of the Civil Engineering Forum, 2(3): 147-156
44. Qanun Aceh. 2013. Qanun Provinsi Aceh Nomor 19 Tahun 2013, Tentang Rencana Tata Ruang Wilayah Aceh 2013-2033, Tanggal 31 Desember 2013, Banda Aceh. pp 72. (in Indonesian)
45. Riad, S., J. Mania, L. Bouchaou and Y. Najjar.2004. Rainfall-runoff model using an artificial neural network approach. Mathematical and Computer Modelling, 40(7-8): 839-846
46. Sari Damayanthi Sebayang, I. and C. Trianing. 2018. Comparison rainfall-runoff

model for Ciujung-Sabagi river. MS&E, 453(1): 012025
47. Setyawan, C., C.Y. Lee and M. Prawitasari. 2016. Hydrologic modeling for tropical watershed monitoring and evaluation. American Journal of Engineering Research (AJER), 5(11): 36-42
48. Shah, R., N. Bharadiya, and V. Manekar. 2015. Drought index computation using standardized precipitation index (SPI) method for Surat District, Gujarat. Aquatic Procedia, 4: 1243-1249
49. Sugawara, M., I. Watanabe, E. Ozaki, and Y. Katsugama. 1984. Tank model with snow component. Research Notes of the National Research Center for Disaster Prevention No. 65. Science and Technology, Ibaraki-Ken, Japan
50. Suribabu, C.R. and E.R. Sujatha. 2019. Evaluation of moisture level using precipitation indices as a landslide triggering factor—A Study of Coonoor Hill Station. Climate, 7(9), p 111
51. Susetyaningsih, A. 2012. Pengaturan penggunaan lahan di Daerah Hulu DAS Cimanuk sebagai upaya optimalisasi pemanfaatan sumberdaya air, Jurnal Konstruksi 10(1):1-8. (in Indonesian)
52. Tallaksen, L.M., H. Hisdal and H.A. Van Lanen. 2009. Space–time modelling of catchment scale drought characteristics. Journal of Hydrology, 375(3-4): 363-372
53. Todini, E., 1996. The ARNO rainfall—runoff model. Journal of hydrology, 175(1-4): 339-382
54. Tsakiris, G. and H. Vangelis. 2004. Towards a drought watch system based on spatial SPI. Water resources management, 18(1): 1-12
55. Undang-Undang. 2014. Undang-undang Republik Indonesia Nomor 37 Tahun 2014, Tentang Konservasi Tanah dan Air, Tanggal 17 Oktober 2014, Jakarta. pp 33 (in Indonesian)
56. Van Huijgevoort, M.H.J., H.A.J. Van Lanen, A.J. Teuling, and R. Uijlenhoet 2014. Identification of changes in hydrological drought characteristics from a multi-GCM driven ensemble constrained by observed discharge. Journal of Hydrology, 512: 421-434
57. Weeks, W.D. and R.H.B. Hebbert. 1980. A comparison of rainfall-runoff models. Hydrology Research, 11 (1): 7–24.
58. Wibowo, R. S., W. Wardoyo and Edijatno. 2018. Strategi pemeliharaan jaringan irigasi daerah irigasi Blimbing', Jurnal Aplikasi Teknik Sipil 16(1): 23-29. (In Indonesia)
59. World Meteorological Organization. 2012. Standardized precipitation index user guide. World Meteorological Organization, (1090).
60. Wu, H., M.J. Hayes, A. Weiss and Q. Hu. 2001. An evaluation of the standardized precipitation index, the China-Z index and the statistical Z-score. International Journal of Climatology: A Journal of the Royal Meteorological Society, 21(6):745-758.