Drought and water availability analysis for irrigation and household water needs in Krueng Jrue Sub-Watershed (#76813)

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Drought and water availability analysis for irrigation and household water needs in Krueng Jrue Sub-Watershed

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Background. Due to climate change and biophysical conditions, drought and water availability are critical issues faced by many countries globally, including Indonesia. This study aimed to analyze drought conditions and evaluate irrigation water availability and household water needs in Krueng Jrue Sub-Watershed, Aceh Province, Indonesia. **Methods.** The Z-score statistics method was developed to analyze the drought and FJ Mock introduced a rainfall-runoff model known as the Mock model to generate discharges to examine the water availability in the watershed. The Mock model parameters for the proportion of surface soil uncovered by vegetation, infiltration factor, initial soil moisture, and flow reduction coefficient (Rc) were 20%, 0.4, 200 mm month^{-1}, and 0.6, respectively. **Results.** The results showed the Z-Score for Precipitation (ZSP), namely normal (N) with 90 events (75%), moderate wet (MW) with 6 events (5%), very wet (VW) with 7 events (5.8%), extreme wet (EW) with 6 events (5%), moderate drought (MD) with 11 events (9.2%), and 0 events (0%) for severe drought (SD) and extreme drought (ED). Furthermore, this region had drought indices for the Z-Score for Discharge (ZSD), namely, normal (N) with 89 events (74.2%), moderate wet (MW) with 11 events (9.2%), very wet (VW) with 4 events (3.3%), extreme wet (EW) with 6 events (5 %), moderate drought (MD) with 9 events (7.5%), and severe drought (SD) with 1 event (0.8 %). The consistency between the ZSP and ZSD indices, which reached 85.8%, indicates that the meteorological droughts were analyzed based on rainfall (ZSP) and hydrological droughts analyzed based on water discharge (ZSD) were in line. The ZSP and ZSD indices in the dry season (April–September) tend to be negative, thereby indicating that rainfall or discharge was under the average index and vice versa for the rainy season (October–March). The highest monthly average discharges in the rainy season (October–March) occurred in November (31.18 m^3s^{-1}) and December (28.02 m^3s^{-1}), while the lowest monthly discharge in the dry

season (April–September) occurred in July (3.16 m^3s^{-1}), and June (3.36 m^3s^{-1}). The water availability for irrigation and household water needs is surplus in the rainy season and vice versa for the dry season. However, water deficit also occurred in certain months during *rendeng* planting season in the rainy season, for example, in October of 2013, 2016, and 2017. Conversely, water surplus occurred during *gadu* planting season in the dry season, for example, in February from 2008 to 2011 and from 2014 to 2017. It probably happened depending on the worldwide climate change, including in this area. This study offers necessary information for farmers, the community, and the government to anticipate the drought phenomenon and can also be applied to evaluate water availability in other watersheds for future work.

Drought and Water Availability Analysis for Irrigation and Household Water Needs in Krueng Jrue Sub-Watershed

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Abstract

Background. Due to climate change and biophysical conditions, drought and water availability are critical issues faced by many countries globally, including Indonesia. This study aimed to analyze drought conditions and evaluate irrigation water availability and household water needs in Krueng Jrue Sub-Watershed, Aceh Province, Indonesia.

Methods. The Z-score statistics method was developed to analyze the drought and FJ Mock introduced a rainfall-runoff model known as the Mock model to generate discharges to examine the water availability in the watershed. The Mock model parameters for the proportion of surface soil uncovered by vegetation, infiltration factor, initial soil moisture, and flow reduction coefficient (Rc) were 20%, 0.4, 200 mm month^{-1}, and 0.6, respectively.

Results. The results showed the Z-Score for Precipitation (ZSP), namely normal (N) with 90 events (75%), moderate wet (MW) with 6 events (5%), very wet (VW) with 7 events (5.8%), extreme wet (EW) with 6 events (5%), moderate drought (MD) with 11 events (9.2%), and 0 events (0%) for severe drought (SD) and extreme drought (ED). Furthermore, this region had drought indices for the Z-Score for Discharge (ZSD), namely, normal (N) with 89 events (74.2%), moderate wet (MW) with 11 events (9.2%), very wet (VW) with 4 events (3.3%), extreme wet (EW) with 6 events (5 %), moderate drought (MD) with 9 events (7.5%), and severe drought (SD) with 1 event (0.8 %). The consistency between the ZSP and ZSD indices, which reached 85.8%, indicates that the meteorological droughts were analyzed based on rainfall (ZSP) and hydrological droughts analyzed based on water discharge (ZSD) were in line. The ZSP and ZSD indices in the dry season (April–September) tend to be negative, thereby indicating that rainfall or discharge was under the average index and vice versa for the rainy season (October–

March). The highest monthly average discharges in the rainy season (October–March) occurred in November (31.18 m^3s^{-1}) and December (28.02 m^3s^{-1}), while the lowest monthly discharge in the dry season (April–September) occurred in July (3.16 m^3s^{-1}), and June (3.36 m^3s^{-1}). The water availability for irrigation and household water needs is surplus in the rainy season and vice versa for the dry season. However, water deficit also occurred in certain months during *rendeng* planting season in the rainy season, for example, in October of 2013, 2016, and 2017. Conversely, water surplus occurred during *gadu* planting season in the dry season, for example, in February from 2008 to 2011 and from 2014 to 2017. It probably happened depending on the worldwide climate change, including in this area. This study offers necessary information for farmers, the community, and the government to anticipate the drought phenomenon and can also be applied to evaluate water availability in other watersheds for future work.

Introduction

Climate change causes drought, flooding, and water scarcity in various countries. 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 essential activities that must be conducted is the evaluation of meteorological and hydrological drought and water availability based on the current biophysical conditions of a watershed.

A hydrological disaster cannot be avoided. However, with scientific and technological development supported by accurate data (Tallaksen, Hisdal & Van Lanen, 2009), it can be anticipated to minimize losses of environmental damage. Both are caused by the primary and additional components of the hydrological disaster vulnerability parameters (Lohani, Krishan & Chandniha, 2017). This fact implies the importance of understanding a combination of the area description, the land's biophysical characteristics, and its response to changes in the hydrological cycle due to global climate change and extreme weather (Van Huijgevoort et al., 2014), including the Krueng Aceh watershed.

The Krueng Jrue Sub-Watershed is a part of the Krueng Aceh watershed located at the upper stream of Krueng Aceh, which plays a vital 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 (Nasrullah & Kartiwa, 2010).

The Krueng Aceh watershed is one of the priorities and critical watersheds out of Indonesia's 108 priority handling watersheds. The area of land with the crucial category to be handled in the Krueng Aceh watershed, especially in the Krueng Jrue sub-watershed, increased from 2,320.88 ha (10.00%) in 2013 to 10,969.85 ha (47.25%) in 2018. A decrease in the biophysical quality of a watershed can be caused by a reduced land cover that can increase surface runoff or otherwise reduce soil infiltration capacity (Basri et al., 2022). The decreasing forest cover can reduce the water discharge in a watershed, marked by insufficient water in the dry season. Therefore, watershed sustainability can be achieved by identifying the links between land, hydrology, and the related upstream and downstream areas that affect the watershed and sub-watershed ecosystem units (Susetyaningsih, 2012). The water availability in the Krueng Jreu-watershed ranges from 0.24 to 3.22 m^3s^{-1}. The total water demand for households and irrigation is 0.18–6.44 m^3s^{-1} (Ishin et al., 2012). However, although climate change and land use change are predicted to affect this region's drought indices and water availability, this study did not specifically analyze drought indices since it only studied the economic value of water in the Sub-Watershed of Krueng Jrue.

Drought indices in the watershed can be analyzed using the Standard Precipitation Index (SPI) (McKee, Doesken & Kleist, 1993) and Standard Discharge Index (SDI) (David & Davidová, 2016). Discharges originated using the rainfall-runoff model, called the Mock model, introduced by FJ Mock to predict the potential water availability (Mock, 1973). Useful in aiding the anticipation of the occurrence of hydrological drought and utilizing the water as well as possible (Caraka et al., 2018), the water surplus or deficit can be evaluated based on the potential water availability.

The SPI was firstly introduced using the Gamma distribution (McKee, Doesken & Kleist, 1993) and used by other researchers in many countries (Ceglar et al., 2008; Shah et al., 2015; Pathak & Dodamani, 2016; Jang, 2018; Liu et al., 2018; Naresh Kumar et al., 2009; Jiménez-Donaire et al., 2020). World meteorological organizations released a Standard Precipitation Index Guide, and the latest SPI program (SPI_SL_6.exe) is downloadable for free (Svoboda et al., 2012).

Some researchers also use the term SPI in the form of Z-score statistics to examine the abnormal occurrence of rainfall or discharges (Wu et al., 2001; Bhuiyan et al., 2006; Tsakiris & Vangelis, 2004; Khan et al., 2008; Omonijo & Okogbue, 2014; Dogan et al., 2012; Jain et al., 2015; Suribabu & Sujatha, 2019; Li et al., 2019). The Z-score statistic method was developed to analyze the drought due to the simplicity of this method. Furthermore, the Mock model was used to obtain the discharge data based on the water balance analysis. Related research on drought analysis using the Z-score statistical method and the use of Mock models to evaluate water availability in the Krueng Jrue Sub-Watershed has never been done. Thus, this study aims to: 1) analyze the drought; and 2) evaluate the availability of water for irrigation needs and household water needs in Krueng Jrue of Sub-Watershed, Aceh Province, Indonesia.

Materials & Methods

Times and Site

The research was conducted in the Krueng Jrue 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, Sumatra, Indonesia (Fig. 1). It was conducted from January to December 2019.

Data Collection

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

Drought Indices

The Z-score for precipitation (ZSP) are used in this study to evaluate the meteorological drought, as shown in equation (1).

$$ZSP = \frac{P_i - P_{avg}}{S}, \ldots\ldots (1)$$

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

Using the same concept, the Z-score for discharges (ZSD) is calculated for evaluating hydrological drought using the formula shown in equation (2).

$$ZSD = \frac{D_i - D_{avg}}{Sd}, \ldots\ldots (2)$$

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 for ZSP and ZSD are shown in Table 1.

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. With monthly rainfall, data being strongly needed to analyze the river's water availability, the primary input of the Mock method is rainfall data. The longer the recording period, the better the results will be. Many researchers (Setyawan et al., 2016; Putro, 2016; Sebayang & Trianing, 2018; Chandrasasi et al., 2020; Maulana et al., 2019; Krisnayanti et al., 2019; Dinar, Agus & Sarino, 2020) used the Mock model to assess water discharges or water availability of watersheds. Generally, the researchers reported that the Mock model is reasonable for evaluating the water balance in specific watersheds. The equations used to calculate water balance parameters by the Mock model (Mock, 1973; Umum, 1986) are as follows.

Evapotranspiration:

$$E = ET_0 - \Delta E \ldots\ldots (3)$$

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

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:

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

$$Q_{total} = Q_{base} + Q_{direct} + Q_{storm}, \ldots (6)$$

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)

$inf = WS \ x \ IF$ …………………(8)

$WS = ISM + R_e – E – SMS$ ……(9)

$SMS = ISM + R_e – E$ …………….(10)

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

where, *inf* = infiltration (mm month^{-1}); $G.\ STOR_t$ = groundwater storage at the beginning of the month (mm month^{-1}); $G.\ STOR_{(t-1)}$ = groundwater 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:

$Q_{direct} = Ws \ x \ (1–IF)$, …(12)

where *Ws* = water surplus (mm)

Storm runoff:

$Q_{storm} = Re \ x \ PF$,... (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 Jrue Sub-Watershed for 2008–2017 was projected based on the area of irrigated land according to irrigation water needs calculated as follows.

$DR = \frac{NFR}{e \times 8.64}$, ……(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 Jrue Sub-Watershed for the period of 2008–2017 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

Discharges Originated Using Mock Model

The average monthly rainfall in the Krueng Jrue Sub-Watershed (2008–2017) is shown in Fig. 2. Indonesia has two seasons, namely the rainy season (October–March) and the dry season (April–September). The highest monthly average rainfall occurred in December, November, and January at 325.7, 324.4, and 269.9 mm, respectively. The lowest monthly average rainfall occurred in February (98.3 mm) and July (68.7 mm). February is included in the month of the rainy season, but the rainfall observed in February (98.3 mm) is less than the average rainfall observed for all months (190.3 mm). On the contrary, April and May are included in the month of the dry season, which has an average rainfall of 247.4 and 219.6, respectively, above the average rainfall for all months. This indicates a shift in seasons that may be influenced by global climate change.

Table 2 shows the discharges of the Krueng Jrue Sub-Watershed originated from the Mock model. The higher the rainfall, the higher the water discharge generated by the Mock model. The average monthly discharges of the Krueng Jrue Sub-Watershed from 2008–2017 ranged from 3.16–31.18 m^3s^1. The highest monthly average discharges in the rainy season (October–March) occurred in November (31.18 m^3s^{-1}) and December (28.02 m^3s^{-1}), while the lowest monthly discharge in the dry season (April–September) occurred in July (3.16 m^3s^{-1}), and June (3.36 m^3s^{-1}). Further analysis provides information for the entire observation year. February, which is included in the rainy season, has a meager monthly discharge value (1.78–3.76 m^3s^{-1}), below the average monthly discharge, except for 2012 and 2013.

Table 2 shows that the average monthly discharge is 12.85 m^3 s^{-1}. Average monthly debits for 2010, 2012, 2013, 2015, and 2017 were above the average monthly debits for the whole year and vice versa for the average debits for 2008, 2019, 2011, and 2016. Based on the average debits for each month, 8 months had an average discharge below the average monthly discharge throughout the year. In the rainy season (October–March), the average monthly discharge should be above the average monthly discharge for the whole year, but the average discharge for October, February, and March was below the average monthly discharge for the whole year. Conversely, for the dry season (April–September), the average discharge should be below the monthly average discharge for the entire year, but the results of the average discharge for April were above the monthly average discharge for the entire year.

Values of Z-Score for Precipitation and Z-Score for Discharge

The values of Z-score for precipitation (ZSP) and Z-score for discharge ZSD from 2008 to 2017 are shown in Tables 3 and 4. Positive ZSP or ZSD values indicate greater than median precipitation or discharges, and vice versa for negative values (Tsakiris & Vangelis, 2004). This region had drought indices for ZSP, namely normal (N) with 90 events (75%), moderate wet (MW) with 6 events (5%), very wet (VW) with 7 events (5.8%), extreme wet (EW) with 6 events (5 %), and moderate drought (MD) with 11 events (9.2%). Drought indices for ZSP with severe drought and extreme drought were not found in this region. Furthermore, this region had drought indices for ZSD namely normal (N) with 89 events (74.2%), moderate wet (MW) with 11 events (9.2%), very wet (VW) with 4 events (3.3%), extreme wet (EW) with 6 events (5 %), moderate drought (MD) with 9 events (7.5%), and severe drought (SD) with 1 event (0.8 %). Drought indices for ZSD with extreme drought were not found in this region. The ZSP and ZSD indices in the dry season (April–September) tend to be negative, indicating that rainfall or discharge was under the average index and vice versa for the rainy season (October–March).

The agreement between ZSP and ZSD indices reached 85.8%, with hydrological drought analyzed based on water discharge (ZSD), and meteorological drought analyzed based on rainfall (ZSP). Both indices tend to be negative during the dry season (April–September) indicating that rainfall or discharge was below the average index and vice versa during the rainy season (October–March) (Table 5).

Water Availability and Water Demand

Surplus and water deficits in the Krueng Jrue Sub-Watershed were calculated by the difference between water availability (discharges) and water demand (water irrigation + water for households). A positive difference between water availability and water demand indicates a surplus and vice versa (Table 6 and Fig. 3). Generally, the water availability is surplus in the rainy season (October–March) and vice versa for the dry season (April–September). The monthly average water needs for irrigation and household are 5 $m^3 s^{-1}$ and 0.041 $m^3 s^{-1}$, respectively. With a total water need of 5.041 $m^3 s^{-1}$ per month, the average water availability (Table 2) from 2008 to 2017 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 (Table 6 and Fig. 3). In 2009, there were five consecutive months in the *gadu* planting season (June, July, August, and September) with water availability smaller than 3 $m^3 s^{-1}$ as well as from 2011 to 2012 (May to August) and from 2013 to 2017 (June to September). On the other side, in the *rendeng* planting season (rainy season) such as in October 2009, 2013, 2016, and 2017, the water availability was not enough for the irrigation and household needs as well as in February (2008–2011 and 2014–2017). The water deficit also occurs in the rainy and dry seasons. Conversely, water surplus was found in the rainy and dry seasons. With it likely being related to worldwide climate change, including in this area, this finding shows uncertainty during the rainy and dry seasons.

Discussion

Monthly discharges fluctuate depending on the amount of rainfall as the primary input of the Mock model. The rainfall-runoff model, known as the Mock model, was introduced by (Mock, 1973) 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. 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), *IF* (infiltration factor), and flow reduction coefficient). In this study, the m, ISM, IF, and Rc values are 20%, 200 mm $month^{-1}$, 0.4, and 0.6, respectively. The study of water availability based on satellite rainfall in the upstream Brantas watershed, Indonesia uses the Mock model parameters, namely m = 30%, *ISM* = 250 mm month−1, *IF* = 0.75, and *Rc* = 0.85 (Maulana et al., 2019). The research on hydrologic modeling for tropical watershed monitoring and evaluation uses the values of m=30%, ISM = 100, IF = 0.5, and Rc = 0.85 (Setyawan et al., 2016). This shows that, due to differences in climate, land use, and soil types, the parameter values of the Mock model vary between watersheds.

The discharges generated from the Mock model are influenced by rainfall, evapotranspiration, land cover, and soil types, where usually, the higher the rainfall, the higher the discharge produced. Taking this into account, a high evapotranspiration value will cause a decrease in discharge, although it is not very significant. The reduced land cover causes the process of surface runoff to be higher, otherwise, the infiltration process will be hampered (Basri &

Chandra, 2021). Land use and soil types in a watershed influence the availability of water in a watershed (Basri et al., 2022; Alayani et al., 2021; Ihsan et al., 2021), where soil types with high clay content have a higher water holding capacity than sandy soils.

Rainfall has a strong influence on discharges in a watershed. Thus, the meteorological drought represented by the ZSP value can be analyzed with the hydrological drought represented by the ZSD value. In this study, the consistency between the ZSP and ZSD indices, which reached 85.8%, indicates that the meteorological droughts were analyzed based on rainfall (ZSP) and hydrological droughts analyzed based on water discharge (ZSD) are in line. However, there are 14.2% in the inconsistent category that may be influenced by climate change or watershed biophysical conditions that affect water balance components such as evapotranspiration, land cover, infiltration, surface runoff, and subsurface flow.

Several researchers explained that it is related to inconsistencies, such as in the Rajasthan Province in India. With the drought occurring, with infiltration decreasing soil water storage, and vice versa for surface flow, this is to reduce infiltration during the rainy season. 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 (Basri, 2013).

Analysis between water availability and water demand for irrigation and household needs is very important to anticipate water shortages. The need for irrigation water in Indonesia is influenced by the growing season. The Krueng Jrue 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 (rainy season), the water availability can meet the irrigation and household needs, and vice versa for the *gadu* planting season (dry season). However, in the last 10 years, the water availability could not meet the irrigation and household needs for specific months, such as in June, July, and August. In 2009, there were five consecutive months in the *gadu* planting season (June, July, August, and September) with water availability smaller than 3 m^3 s^{-1} as well as from 2011 to 2012 (May to August) and from 2013 to 2017 (June to September). On the other side, in the *rendeng* planting season (rainy season) for example in October 2009, 2013, 2016, and 2017, the water availability was not enough for the irrigation and household needs as well as in February (2008–2011 and 2014–2017). Although water surplus is found in the rainy and dry seasons, the water deficit also occurs in both the rainy and dry seasons. This finding shows uncertainty during the rainy and dry seasons. This is likely related to worldwide climate change, including in this area.

Hydrological drought causing inadequate water for irrigation and households, especially in the dry season can occur yearly. Various technical and nontechnical hydrological drought mitigation efforts, as part of a sustainable watershed management system, can be implemented to mitigate hydrological drought (Asdak & Supian, 2018). The technical method that can be implemented in the Krueng Jrue Sub-Watershed includes maintaining the function of the irrigation network (Wibowo, Wardoyo & Edijatno, 2018), building water traps, terraces, and water retention ponds

(Pramono & Savitri, 2017), and maintaining conservation areas, especially the upstream as a natural reservoir. It will increase infiltration into the soil and reforestation in the upper catchment area by planting trees to increase the spring water discharge and water availability (Cao et al., 2010). The nontechnical method can be done by enforcing some available regulations to prevent forest to nonforest land conversion, conducting soil and water conservation, river development, and river water damage, as well as monitoring and evaluating watershed management.

Conclusions

Water insufficiency in the Krueng Jrue Sub-Watershed for irrigation and households, especially during the dry season, is caused due to the meteorological and hydrological drought trend in recent years. Analysis of drought conditions and water availability is crucial to anticipate water scarcity for irrigation and household needs in the Krueng Jrue Sub-Watershed. The findings indicate that ZSP and ZSD can be used to analyze the drought index in a watershed. This research recommends the Mock model parameters for the proportion of soil surface that is not covered by vegetation (m), infiltration factor (IF), initial soil moisture (ISM), and flow reduction coefficient (Rc) of 20%, 0.4, 200 mm month^{-1}, and 0.6, respectively. The consistency between the two indices, which reached 85.8%, was shown by the congruence between the analysis of meteorological drought results based on rainfall (ZSP) and drought hydrology based on water discharge (ZSD). The negative results in the dry season (April–September) indicate that rainfall or discharge was below the average index and vice versa in the rainy season (October–March). The water availability for irrigation and household water needs is surplus in the rainy season and vice versa for the dry season. However, water deficit also occurred in certain months during *rendeng* planting season in the rainy season, for example, in October of 2013, 2016, and 2017. Conversely, water surplus occurred during *gadu* planting season in the dry season, for example, in February from 2008 to 2011 and from 2014 to 2017. It is likely related to worldwide climate change, including in this area. This research not only contributes to enriching references for similar research in the Krueng Aceh watershed, Indonesia but also can be applied to other watersheds, according to each watershed condition, overcoming the problem of water shortages in this area can be done through technical and nontechnical means.

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Figure 1

Location of Study Area ini Krueng Jrue Sub-Watershed

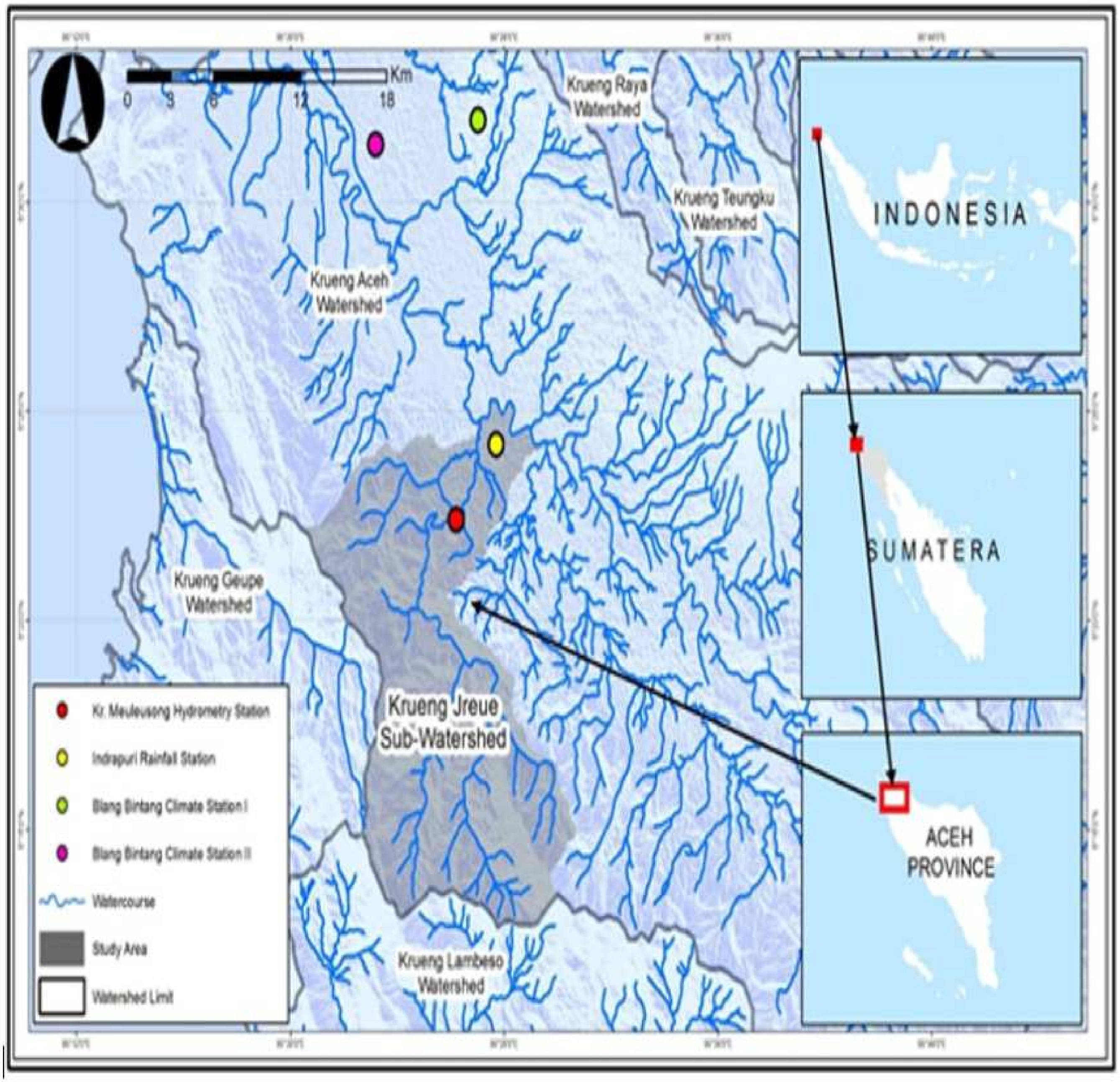

Figure 1. Location of study area in Krueng Jrue Sub-Watershed

Figure 2

Average of Monthly Rainfall in the Krueng Jrue Sub-Watershed

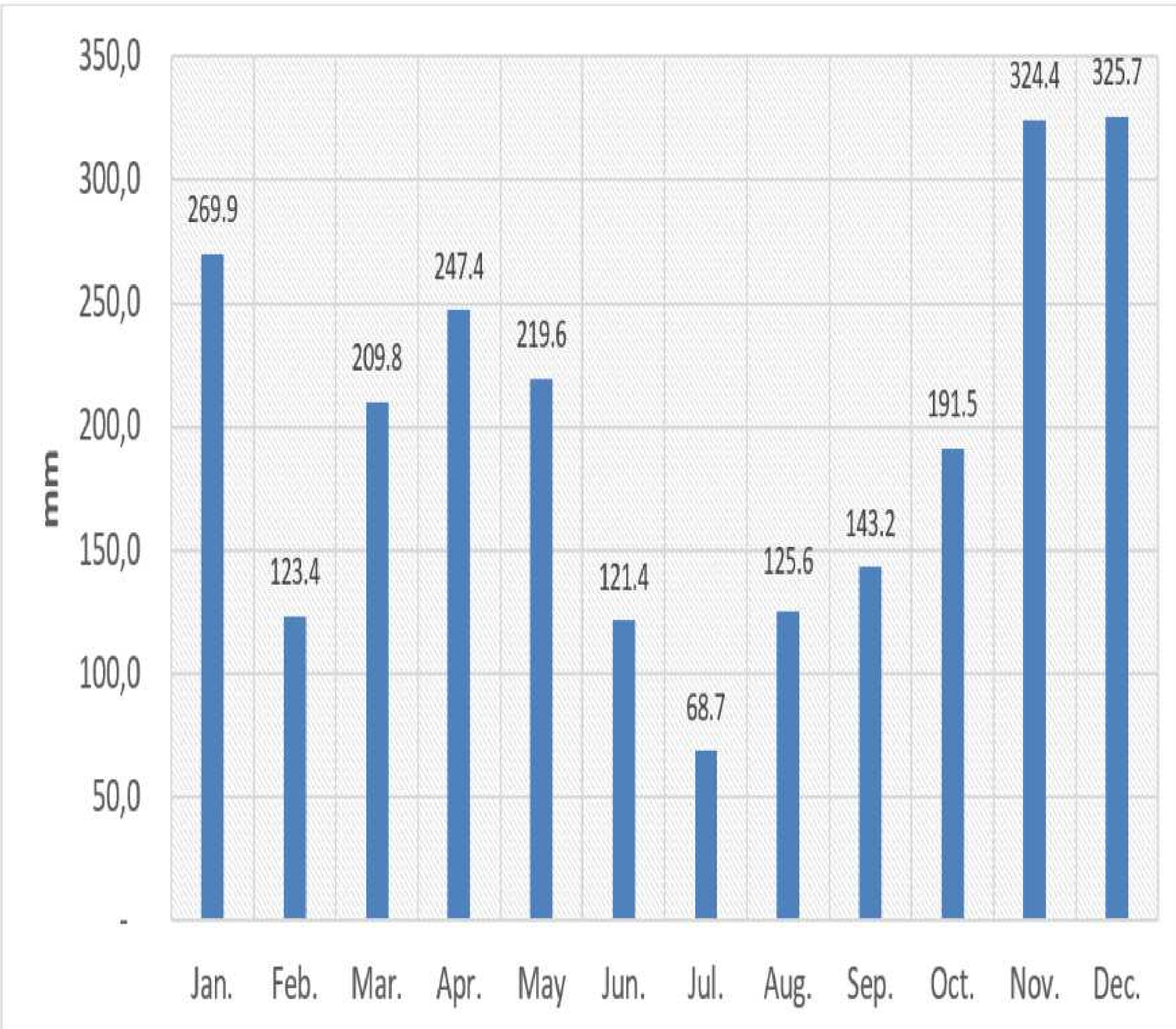

Figure 2. Average of Monthly Rainfall in the Krueng Jrue Sub-Watershed (2008-2017)

Figure 3

Surplus (+ sign) and deficit (- sign) of water in Krueng Jrue Sub-Watershed

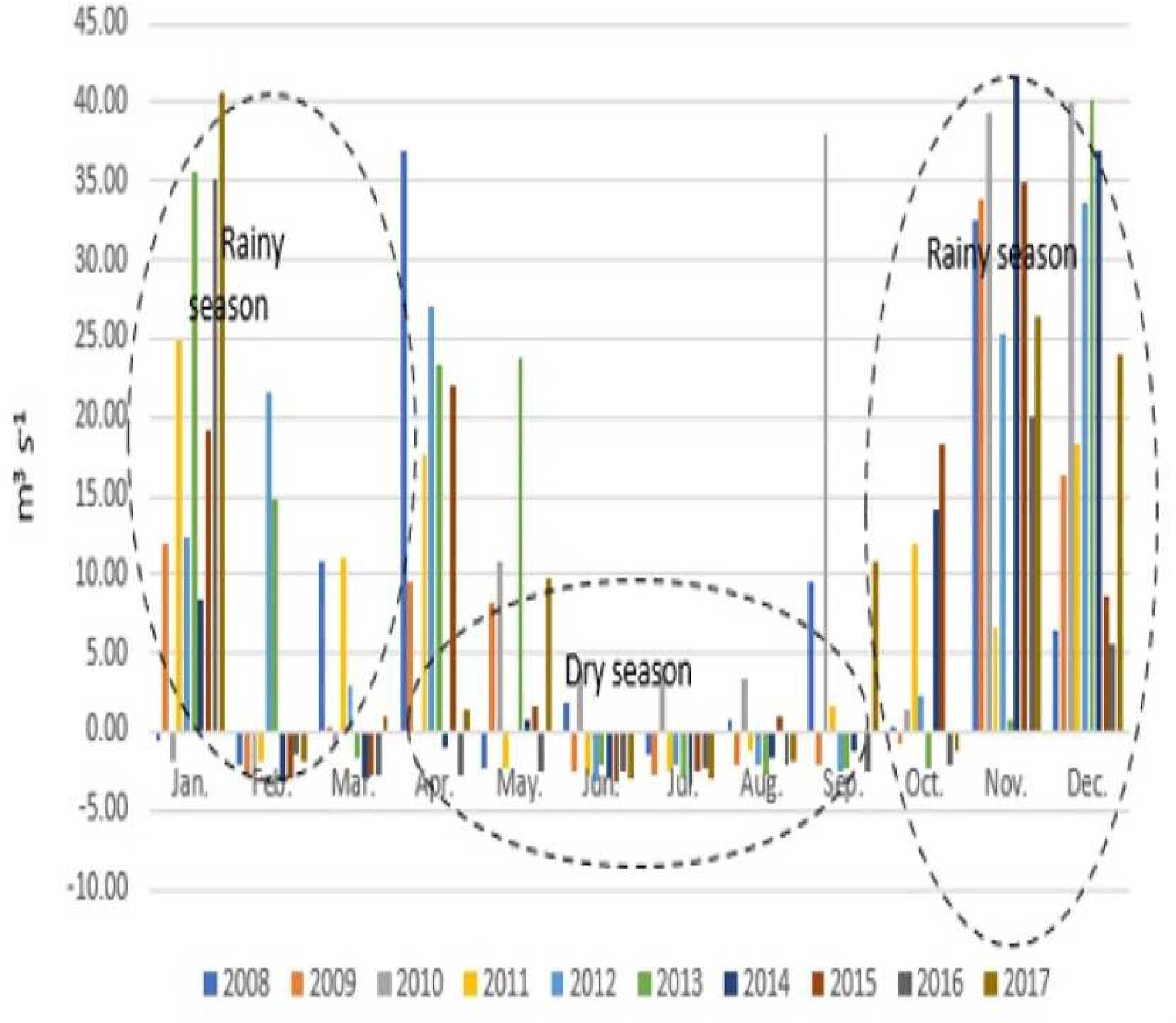

Figure 3. Surplus (+ sign) and deficit (- sign) of water in Krueng Jrueu Sub Watershed

Table 1(on next page)

Drought class for ZSP and ZSD

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

Source: Ceglar et al.,2008

Table 2(on next page)

Discharges of the Krueng Jrue Sub-Watershed

Table 2. Discharges of the Krueng Jrue Sub-Watershed

Month	Discharges ($m^3 s^{-1}$)											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	Avarage
1	4.39	16.99	3	29.9	17.44	40.59	13.58	24.23	40.18	45.75	236.05	23.61
2	2.75	2.17	2.31	3.06	26.55	19.81	1.78	2.18	3.76	3.31	67.68	6.77
3	15.8	5.14	4.29	15.99	7.97	3.44	2.1	2.35	2.26	6.16	65.5	6.55
4	41.79	14.46	4.97	22.71	32.09	28.46	4.01	27.14	2.41	6.6	184.64	18.46
5	2.69	13.13	15.81	2.76	5.02	28.77	5.82	6.71	2.67	14.84	98.22	9.82
6	6.86	2.42	8.82	2.17	1.73	2.9	2.05	1.92	2.51	2.2	33.58	3.36
7	3.5	2.19	9.17	2.4	2.82	2.18	1.64	2.56	2.89	2.24	31.59	3.16
8	5.65	2.96	8.44	3.81	2.97	2.23	3.43	6	3.11	3.25	41.85	4.19
9	14.47	2.97	43.03	6.65	2.52	2.64	3.79	4.93	2.55	15.9	99.45	9.95
10	5.01	4.25	6.3	16.93	7.41	2.75	19.21	23.3	2.99	3.81	91.96	9.2
11	37.45	38.85	44.32	11.74	30.3	5.84	46.68	39.95	25.19	31.51	311.83	31.18
12	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
Avarage	12.64	10.57	16.29	11.79	14.62	15.41	12.17	12.92	8.44	13.72	128.55	12.85

Table 3(on next page)

Values of Z-Score for Precipitation (ZSP)

Table 3. Values of Z-Score for Precipitation (ZSP)

Month	ZSP		ZSP		ZSP		ZSP		ZSP		ZSP		ZSP		ZSP		ZSP		ZSP	
	2008	Criteria	2009	Criteria	2010	Criteria	2011	Criteria	2012	Criteria	2013	Criteria	2014	Criteria	2015	Criteria	2016	Criteria	2017	Criteria
Jan.	-0.88	N	-0.28	N	-1.00	MD	-0.20	N	-0.02	N	0.67	N	-1.43	MD	0.12	N	1.46	MW	1.57	VW
Feb.	-0.37	N	0.91	N	-0.72	N	-0.004	N	-0.04	N	0.95	N	-0.35	N	-0.40	N	0.56	N	2.65	EW
Mar.	0.33	N	-0.09	N	-0.09	N	0.40	N	0.01	N	0.18	N	-0.38	N	-0.15	N	-0.41	N	3.02	EW
Apr.	-0.78	N	-1.04	MD	-0.17	N	-0.28	N	-0.65	N	-0.54	N	-0.54	N	0.82	N	1.09	MW	2.09	EW
May	-1.03	MD	-0.91	N	-0.12	N	-0.98	N	-0.52	N	0.27	N	-0.36	N	0.52	N	2.07	EW	1.06	MW
Jun.	-0.32	N	-0.88	N	0.18	N	-0.97	N	-0.94	N	0.19	N	-0.38	N	0.82	N	2.33	EW	-0.03	N
Jul.	-0.63	N	-1.16	MD	0.71	N	0.19	N	-0.18	N	-0.07	N	-0.74	N	1.23	MW	1.81	VW	-1.16	MD
Aug.	-0.71	N	0.21	N	-0.46	N	-0.48	N	-0.78	N	-0.92	N	-0.69	N	0.38	N	1.89	VW	1.54	VW
Sep.	-0.64	N	-0.84	N	-0.60	N	-0.26	N	-0.83	N	0.65	N	0.27	N	-0.31	N	0.08	N	2.48	EW
Oct.	-0.68	N	-0.95	N	-0.57	N	-0.65	N	-0.40	N	-0.97	N	0.93	N	1.85	VW	0.24	N	1.20	MW
Nov.	-0.57	N	-1.24	MD	0.02	N	-1.17	MD	0.51	N	-1.22	MD	0.77	N	1.57	VW	0.43	N	0.89	N
Dec.	-0.83	N	0.01	N	-0.64	N	-1.07	MD	-1.20	MD	-0.27	N	1.28	MW	0.67	N	1.74	VW	0.33	N

Note : N = Normal, MW = Moderate wet, VW = Very wet, EW = Extreme wet, MD = Moderate drought, SD = Severe drought, and ED = Extreme drought

Table 4 (on next page)

Values of Z-Score for Discharges (ZSD)

Table 4. Values of Z-Score for Discharges (ZSD)

Month	ZSD		ZSD		ZSD		ZSD		ZSD		ZSD		ZSD		ZSD		ZSD		ZSD	
	2008	Criteria	2009	Criteria	2010	Criteria	2011	Criteria	2012	Criteria	2013	Criteria	2014	Criteria	2015	Criteria	2016	Criteria	2017	Criteria
Jan.	-1.27	MD	-0.44	N	-1.36	MD	0.41	N	-0.41	N	1.12	MW	-0.66	N	0.04	N	1.09	MW	1.46	MW
Feb.	-0.46	N	-0.52	N	-0.51	N	-0.42	N	2.24	EW	1.48	MW	-0.57	N	-0.52	N	-0.34	N	-0.39	N
Mar.	1.76	VW	-0.27	N	-0.43	N	1.79	VW	0.27	N	-0.59	N	-0.85	N	-0.80	N	-0.81	N	-0.07	N
Apr.	1.68	VW	-0.29	N	-0.97	N	0.31	N	0.98	N	0.72	N	-1.04	MD	0.63	N	-1.16	MD	-0.86	N
May	-0.85	N	0.40	N	0.72	N	-0.84	N	-0.57	N	2.26	EW	-0.48	N	-0.37	N	-0.85	N	0.60	N
Jun.	1.44	MW	-0.39	N	2.25	EW	-0.49	N	-0.67	N	-0.19	N	-0.54	N	-0.59	N	-0.35	N	-0.48	N
Jul.	0.16	N	-0.45	N	2.77	EW	-0.35	N	-0.16	N	-0.45	N	-0.70	N	-0.28	N	-0.12	N	-0.42	N
Aug.	0.76	N	-0.64	N	2.22	EW	-0.20	N	-0.64	N	-1.02	MD	-0.40	N	0.94	N	-0.56	N	-0.49	N
Sep.	0.36	N	-0.55	N	2.62	EW	-0.26	N	-0.59	N	-0.58	N	-0.49	N	-0.40	N	-0.59	N	0.47	N
Oct.	-0.55	N	-0.65	N	-0.38	N	1.02	MW	-0.24	N	-0.85	N	1.31	MW	1.85	VW	-0.82	N	-0.71	N
Nov.	0.46	N	0.57	N	0.97	N	-1.44	MD	-0.07	N	-1.87	SD	1.15	MW	0.65	N	-0.44	N	0.02	N
Dec.	-1.20	MD	-0.49	N	1.22	MW	-0.34	N	0.76	N	1.24	MW	1.00	MW	-1.03	MD	-1.24	MD	0.07	N

Note : N = Normal, MW = Moderate wet, VW = Very wet, EW = Extreme wet, MD = Moderate drought, SD = Severe drought, and ED = Extreme drought

Table 5(on next page)

Consistency between ZSP and ZSD

Table 5. Consistency between ZSP and ZSD

Month/Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**%**
January	C	C	C	C	C	C	C	C	C	C	100
February	C	C	C	C	IC	C	C	C	C	IC	80
March	IC	C	C	IC	C	C	C	C	C	IC	70
April	IC	C	C	C	C	C	C	C	C	IC	80
May	C	C	C	C	C	IC	C	C	C	C	90
June	C	C	IC	C	C	C	C	C	IC	C	80
July	C	C	IC	C	C	C	C	C	C	C	90
August	C	C	IC	C	C	C	C	C	C	IC	80
September	C	C	IC	C	C	C	C	C	C	IC	80
October	C	C	C	C	C	C	C	C	C	C	100
November	C	C	C	C	C	C	C	IC	C	C	90
December	C	C	C	C	C	C	C	C	IC	C	90
										Average	85.8

Note:

1. C = Consistent (If the difference in drought class between ZSP and ZSD ≤ one class), for example: ZSP = Normal (N) and ZSD = Normal (N)/Medium Drought (MD)/Medium Wet (MW).
2. IC = Inconsistent (If the difference in drought class between ZSP and ZSD > one class), for example: ZSP = Normal (N) and ZSD = Very Wet (VW)/Very Drought (VD)/Extreme Wet (EW)/Extreme Drought (ED).

Table 6(on next page)

Deviation of Water Availability and Water Demand in Krueng Jrue Sub-Watershed

Table 6. Deviation of Water Availability and Water Demand in Krueng Jrue Sub-Watershed

Month/Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jan.	−0.56	12.02	−1.99	24.89	12.41	35.54	8.51	19.14	35.07	40.62
Feb.	−2.20	−2.80	−2.68	−1.95	21.52	14.76	−3.29	−2.91	−1.35	−1.82
Mar.	10.85	0.17	−0.70	10.98	2.94	−1.61	−2.97	−2.74	−2.85	1.03
Apr.	36.84	9.49	−0.02	17.70	27.06	23.41	−1.06	22.05	−2.70	1.47
May.	−2.26	8.16	10.82	−2.25	−0.01	23.72	0.75	1.62	−2.44	9.71
Jun.	1.91	−2.55	3.83	−2.84	−3.30	−2.15	−3.02	−3.17	−2.60	−2.93
Jul.	−1.45	−2.78	4.18	−2.61	−2.21	−2.87	−3.43	−2.53	−2.22	−2.89
Aug.	0.70	−2.01	3.45	−1.20	−2.06	−2.82	−1.64	0.91	−2.00	−1.88
Sep.	9.52	−2.00	38.04	1.64	−2.51	−2.41	−1.28	−0.16	−2.56	10.77
Oct.	0.06	−0.72	1.31	11.92	2.38	−2.30	14.14	18.21	−2.12	−1.32
Nov.	32.50	33.88	39.33	6.73	25.27	0.79	41.61	34.86	20.08	26.38
Dec.	6.36	16.28	39.97	18.33	33.57	40.28	36.83	8.63	5.62	23.91

Note: Surplus (+sign) and deficit (-sign)