

## Analysis of Drought Severity Level as a Hydrological Disaster Mitigation Effort in Sub-Watershed of Krueng Jreue, Aceh Besar Regency-Indonesia

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### ABSTRACT


Drought affects the availability of water reserves in the soil in *Krueng Jreue* Sub-Watershed, for the benefit of agriculture as well as for human needs. There were three stages of analysis for the research of the severity of the *Krueng Jreue* drought, namely: (1) identify the rainfall station for the area of study. Monthly rainfall data used is the result of observation data for 10 years (2005-2014) from two stations of rainfalls; *Indrapuri* and *Jantho*, according to isohyets method analysis; (2) analysis of precipitation to obtain meteorological drought index of each station with the method of precipitation Standardized Precipitation Index (SPI); and (3) analysis of interpolation method of Inverse Distance Weighted (IDW) drought index values of each rainfall stations to get the spread of drought. The results of the analysis using the method of SPI scale 3 monthly (SPI-3), indicating that the historical rainfall in 2005-2014 not experiencing dry conditions, because during the 12 months from January-December for 10 years, only in June-July-August (JJA) are experiencing conditions slightly dry with average drought index between (-1,23) - (-0,39). The rest of September-October-November (SON), December-January-February (DJF) and March-April-Mai (MAM) experienced a medium (normal) condition, the value of SPI in range (0,99) - (-0,99). Hydrological disaster mitigation efforts in the zone of the severity of the drought with the criteria slightly dry can be done by means of structural and non-structural. Structurally it is done through optimizing the development of dams and building *Krueng Jreue*, rehabilitation and maintenance of the irrigation network. The storage of excess water in the rainy season is for use in the dry season. Non-structural way is by making predictions of drought, drought index map, agroforestry, planting water-efficient plants, the use of mulch and organic materials.

### KEYWORDS

Standardized Precipitation Index, The severity of the drought, The spread of drought, Hydrological disaster mitigation, Sub-Watershed of *Krueng Jreue*.

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## Introduction

Pressure on the Sub-Watershed *Krueng Jreue*, Watershed of *Krueng Aceh*, is caused by human activity. The high rate of population growth increases the level of activity and land use causes changes in land use on the Sub-Watershed *Krueng Jreue*. According to the decision of the Minister of forestry No. 328/2009, Watershed Krueng Aceh is critical and is set as a priority.

The results of the analysis of the land cover at Citra Spot during the period 2009 – 2013 reveals land use changes in the Sub-Watershed *Krueng Jreue*. These changes led to a reduction in primary forest from 1584.81 ha to 1576.51 ha, a reduction of 8.30 ha (Regional Development Planning Agency Aceh, 2013). The decline in forest lands impacted the water debit and resulting in the dwindling of the watershed's water supply. The availability of water in the Sub-Watershed *Krueng Jreue* ranged from 0.24 to 3.22 m sec<sup>-1</sup>. However, the total water needs for agriculture and household registration is anywhere between 0.18 and 6.44 m sec<sup>-1</sup> (Isnin et al., 2012).

The relationships between water and land resources are crucial to the hydrological cycle. Climate change has an impact on changes in hydrological cycle (Tallaksen et al., 2009) via hydrological disasters such as floods and droughts. Besides flooding, the impact of other changes in hydrological cycle due to climate change as well as inquiries watershed is dryness. Drought is a natural disaster with potential impacts on various sectors and scales (Swetalina & Thomas, 2016), including agriculture, forestry, plantations and water resources. Drought is a threat that often disrupts the system and agricultural production of food crops (Van Vliet & Zwolsman, 2008). While droughts are a relatively routine matter in many territories, if prevention is lacking and countermeasures are slow, the problems it causes can become prolonged if left unresolved.

Hydrological disasters are often inevitable, but with the development of science and technology supported by accurate data, they can be anticipated to minimize losses and all sorts of environmental damage. Early warning is a non-structural measure applied in developing countries (Jayawardena, 2015) as a major effort in the risk reduction of a drought disaster (Wilhite et al., 2014). By anticipating the occurrence of a hydrological disaster, steps can be taken to minimize and prepare for losses for stakeholders (Bokal et al., 2014).

The facts indicate the importance of understanding the characteristics of a region and its response to changes in the hydrological cycles resulting from climate change (Van Huijgevoort et al., 2014). It is essential to include the research on the Sub-Watershed *Krueng Jreue* in planning, management of the territory and the early anticipation of risks of damage from a hydrological disaster, both in the short and long term.

In order to achieve the above goals, it is necessary to do research that analyzes the parameters that may cause hydrological disasters to occur in the sub-watershed based on biophysical and climatological aspects. This research aims to analyze the severity of drought based on Standardized Precipitation Index (SPI) (Shah et al., 2015), and how the changes in land characteristics have affected the classification of the severity of the drought in the Sub-Watershed *Krueng Jreue*. The research will propose disaster mitigation efforts in the Sub-Watershed of

*Krueng Jreue*, so that the negative impact and the risk of damage from drought can be minimized.

### Materials and methods

The research was carried out at the Watershed of *Krueng Aceh*, Sub-Watershed of *Krueng Jreue*. The research area is part of the *Aceh Besar* Regency, with coordinates of 5°28' N and 95°20'– 95°32' E and an area of 23,218.06 ha. The research was carried out from October to December of 2015. The materials used include an administrative map, map of rainfall stations and rainfall maps, each at a scale of 1:50,000 and the rainfall data from 2005-2014. The tools used were GPS, altimeter, and a digital camera.

Analysis of rainfall in the Sub-Watershed *Krueng Jreue* was done using the isohyets method. The method involves distinguishing lines by connecting regions that experience equal amounts of rainfall. These lines are then multiplied by each width (Verrina et al., 2013). The results are summed and divided by the total area of the region so that it can describe the rainfall or precipitation of the area. Rainfall between two lines of the isohyets is considered equal to the average value of both of the isohyet lines. The isohyets were derived from data at the *Indrapuri* and *Jantho* stations. Rainfall is calculated according to the following equation (Triatmodjo, 2009):

$$\bar{R} = \frac{A_1 R_1 + A_2 R_2 + \dots + A_n R_n}{A_1 + A_2 + \dots + A_n}$$

where:  $\bar{R}$  = Average rainfall in 10<sup>th</sup> annual

$A_1, A_2$  = Wide section between two isohyets lines

$R_1, R_2, R_n$  = Average annual rainfall in 10 years in part  $A_1, A_2, \dots,$

$A_n$

Drought index values were calculated from monthly rain data from January to December 2005 – 2014 using the Standardized Precipitation Index (SPI) method (Guttman, 1999):

$$Z_{ij} = \frac{X_{ij} - \bar{X}_j}{\sigma}$$

where:  $Z_{ij}$  = Variables  $Z$ , year as  $-i$  and month as  $-j$

$X_{ij}$  = Monthly rainfall, year as  $-i$  and month as  $-j$

$\bar{X}_j$  = Average rainfall month to  $-j$

$\sigma$  = Raw byway month to  $-j$

Analysis of SPI uses the time scale SPI-3 (3 months). To determine the distribution of drought, the SPI-generated value is interpolated using the Inverse Distance Weighted (IDW) method (Shepard, 1968), a simple



determination method that considers nearby points (Hartkamp et al. 1999). The assumption of this method is that the interpolated value will be more similar to the data samples that are closer than those that are farther. Weight will change linearly in accordance with the distance and sample data. This weight will not be influenced by the location of the sample data. The IDW method equation is as follows (Azpurua & Ramos, 2010):

$$Z^* = \sum_{i=1}^N w_i Z_i$$

where:  $Z_i$  = Value that will be interpolated number of  $N$  points

$w_i$  = Weight

The severity of the drought based on the SPI value consists of five classes: (1) dry; (2) slightly dry; (3) medium (normal); (4) slightly wet; and (5) wet, indicated in Table 1.

**Table 1** The severity of the drought according to SPI value

| No. | SPI Value       | The severity of the drought |
|-----|-----------------|-----------------------------|
| 1   | $\leq -1.50$    | Dry                         |
| 2   | $-1.00 - -1.49$ | Slightly Dry                |
| 3   | $0.99 - -0.99$  | Medium (Normal)             |
| 4   | $1.49 - 1.00$   | Slightly Wet                |
| 5   | $\geq 1.50$     | Wet                         |

Source: Modification of Ceglar (2009)

## Results and discussion

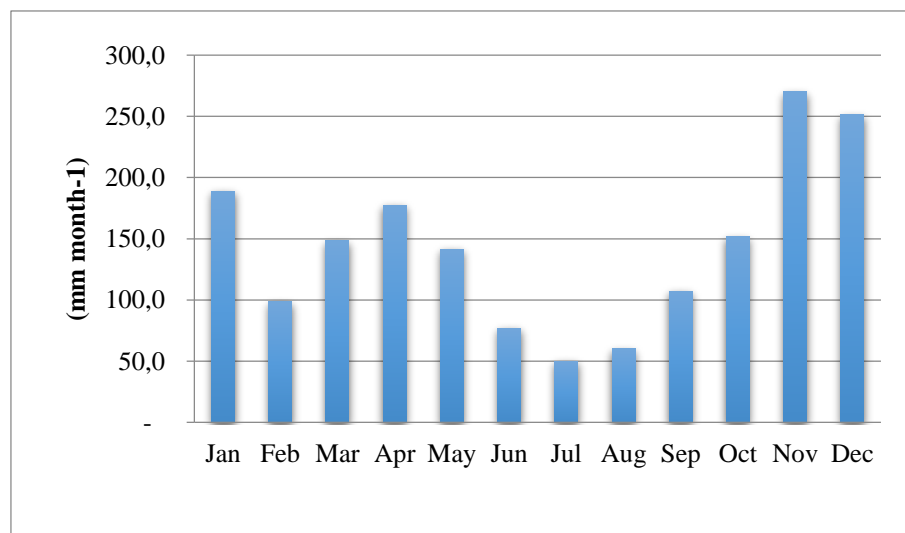
### Profile of precipitation

The data used was monthly rainfall from 2005 to 2014, calculated by the Isohyet method. The Isohyets method is the most accurate method and suitable to determine the average rain because most of the Sub-Watershed *Krueng Jreue* has slopes that ramps (8-15%) and rather steep (15-25%). Isohyets method is suitable for a hilly and irregular area (Syofyan & Kisman, 2013). Total and average rainfall for 10 years at *Indrapuri* station and *Jantho* station is 17.225 mm and 19.392 mm respectively, quite low. From the comparison of dry months and wet months, each value of  $Q = 27.39\%$  and  $Q = 17.64\%$  with climate type B (wet).

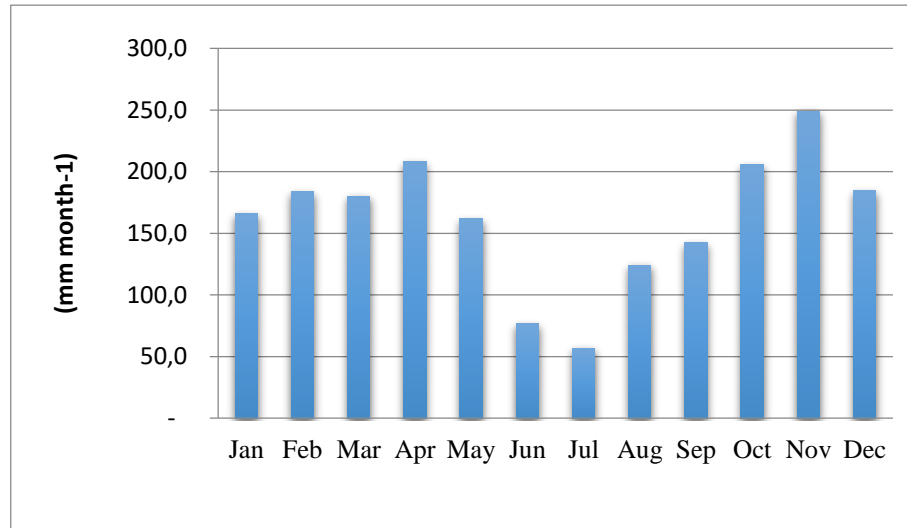
Average monthly rainfall for the *Indrapuri* and *Jantho* stations, presented in Figure 1 and 2, shows the same rainfall patterns: the monsoonal rain pattern with peak rainfall in November (average of 270.5 mm month<sup>-1</sup>) and 249.2 mm month<sup>-1</sup>, minimum rainfall in July (average of 49.9 mm month<sup>-1</sup>) in *Indrapuri*

station and 57.0 mm month<sup>-1</sup> in the *Jantho* station. Analyzing on a scale of three months, the maximum rainfall period occurs in September-October-November (SON), while the minimum rainfall is during June-July-August (JJA). the maximum ranges from 358-867 mm month<sup>-1</sup> and the minimum ranges from 130-330 mm month<sup>-1</sup> in the northern sub-watershed. In the southern sub-watershed, the maximum and minimum range from 416-800 mm month<sup>-1</sup> and 193-415 mm month<sup>-1</sup> respectively.

According to the criteria of monthly rainfall of <100 mm month<sup>-1</sup>, climatologically, dry months in the north sub-watershed occur in June-August, while in the southern sub-watershed, dry months occur between June and July. Based on the criteria of genesis dry month for three consecutive months or more with rainfall between <100 mm month<sup>-1</sup> and <200 mm month<sup>-1</sup> (Borger, 2001), the meteorological drought in the north sub-watershed occurs from the period between May and September, while the southern sub-watershed drought occurs in the period between May and August.



**Figure 1** The monthly rainfall profile of *Indrapuri*

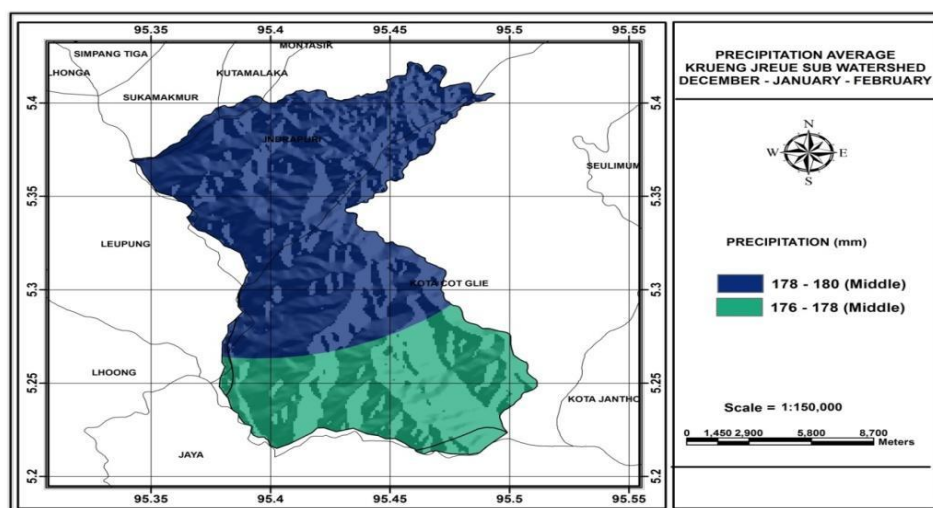


**Figure 2** The monthly rainfall profile of *Jantho*

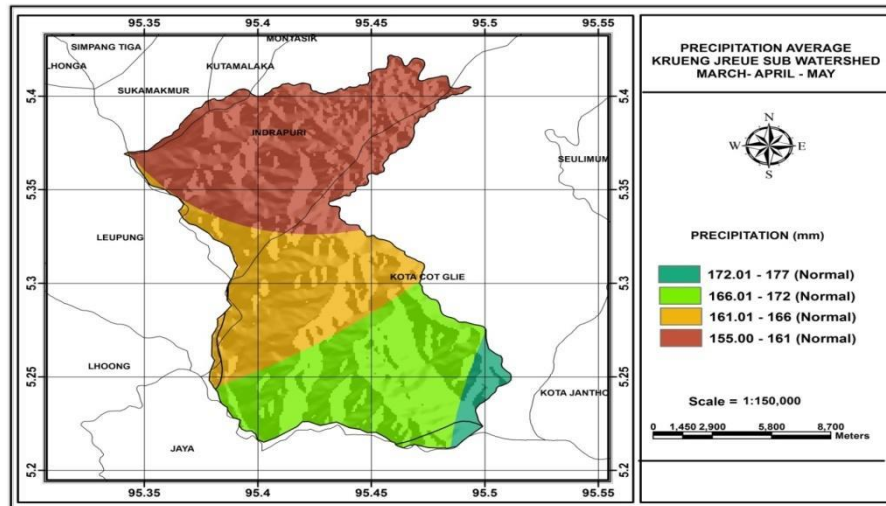
Figure 1 and 2 show the difference in the period of meteorological drought between the north and the south of the sub-watershed. The dry period in the north sub-watershed is longer than that of the southern sub-watershed. According to the BKNPB (2007), meteorological drought is a drought that relates to the level of rainfall under normal conditions in one season as a result of moisture in the ground and when the amount of water that is stored is lower than the normal condition. Meteorological drought is based on the comparison between the number of normal or average and the dry period. The measurement of meteorological drought is a former indication of the drought (Triatmoko et al., 2012).

### **Analysis of spatial seasonal rainfall**

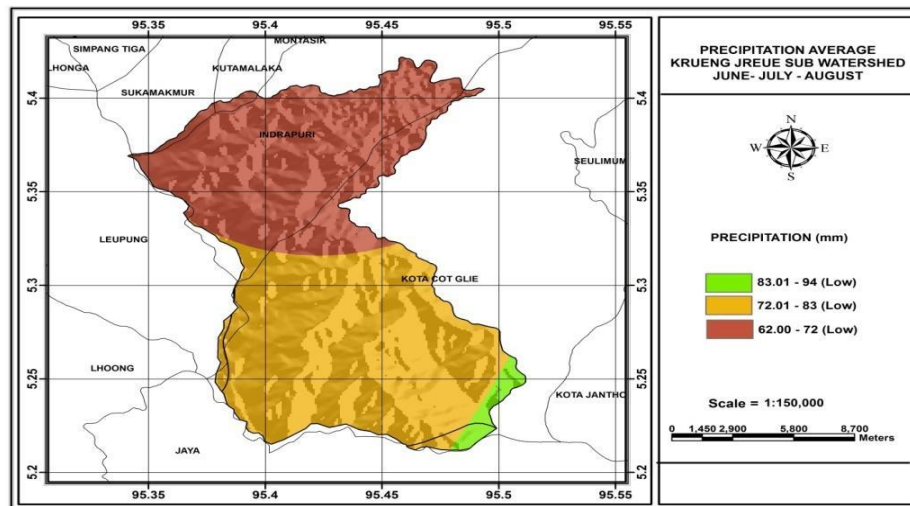
The spatial analysis of rainfall was conducted to see which region has the most drought potential based the intensity of rainfall and to compare the intensity of rainfall in each rainfall station. The result of the Spatial seasonal analysis in the region of Sub-Watershed of *Krueng Ireue* is taken from January to December from 2004 – 2014 and can be seen on the map of Isohyets in figures 3, 4, 5 and 6.



**Figure 3** Isohyets maps of December, January and February (DJP) periods

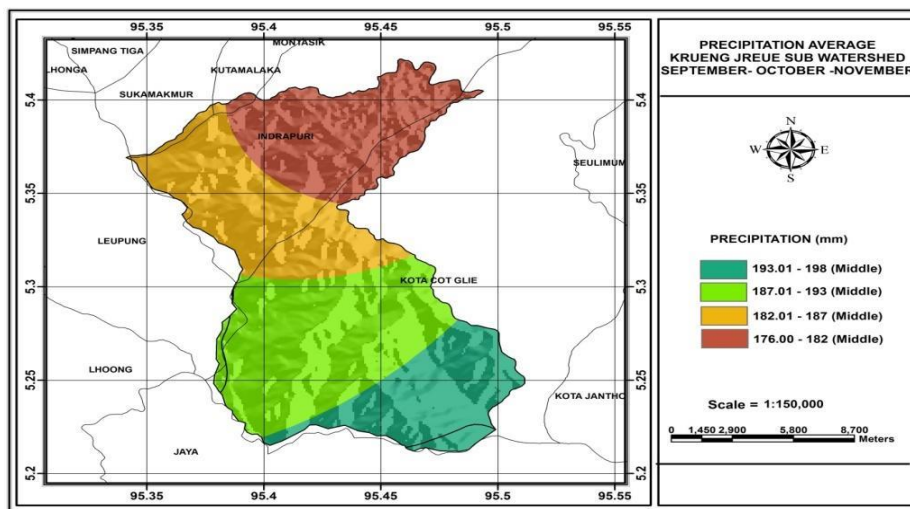


**Figure 4** Isohyets map from March, April and May (MAM) periods



**Figure 5.** Isohyets map from June, July and August (JJA) periods





**Figure 6** Isohyets map from September, October, and November (JJA) periods

Figures 3, 4, 5, and 6 show the rainfall in the southern part of the sub-watershed is higher than in the north. The region with the most rainfall is located in the southern part of the sub-watershed, with peak rainfall occurring in the period of September-October-November (SON), followed the period of March-April-May (MAM), with average  $199.10 \text{ mm month}^{-1}$  and  $183,4 \text{ mm month}^{-1}$ . Areas that have the least rainfall are located in the northern part of the sub-watershed, with minimum rainfall in that region occurring during the period of June-July-August (JJA) followed by the period May-March-April (MAM), with an average of  $62.4 \text{ mm month}^{-1}$  and  $155,7 \text{ mm month}^{-1}$  respectively. Overall, the Sub-Watershed *Krueng Jreue* has maximum rainfall in November and minimum rainfall in July.

In the southern part of the sub-watershed, land use is dominated primarily by forest, secondary forest and grassland that experience high levels of rainfall, while the northern part is dominated by lowland scrub, settlements and rice fields that experience low levels of rainfall. In addition to lower rainfall conditions, the northern part has experienced a reduction of vegetation density as water storage and the rise in surface temperature can increase evaporation. Based on physiographic conditions in the northern part of the sub-watershed, this area has a great possibility to experience an imbalance in the input and output of water. Therefore, this area has high drought potential. The decline in vegetation cover from deforestation generally increases the average volume of run off and total water yield (Suryatmojo, 2015).

The Sub-Watershed of *Krueng Jreue* has varied topography, with elevations between 32-322 meters above sea level (m asl), this causes the variety of intensity and amount of rainfall. Therefore, local topographical factors are very influential in the region of Sub-Watershed *Krueng Jreue*. In some areas, topography affects the intensity of rainfall (Loo et al., 2015). Spatial and temporal patterns of rainfall in some areas vary and heighten rainfall intensity and its variability due to the season variations (Bhatt & Mall, 2015). The *Indrapuri* rainfall station that is located in the northern part of the Sub-Watershed in *Krueng Jreue* is a lowland



area far from mountains, characteristics that result in low rainfall levels. This is in accordance with the assertions of Van Loon & Laaha (2015), that the intensity of rainfall is influenced more by local factors, including altitude. The combination of climatic factors and watershed control affects the duration of drought and water deficit, and changes the number of droughts per year in a region (Hisdal et al., 2001).

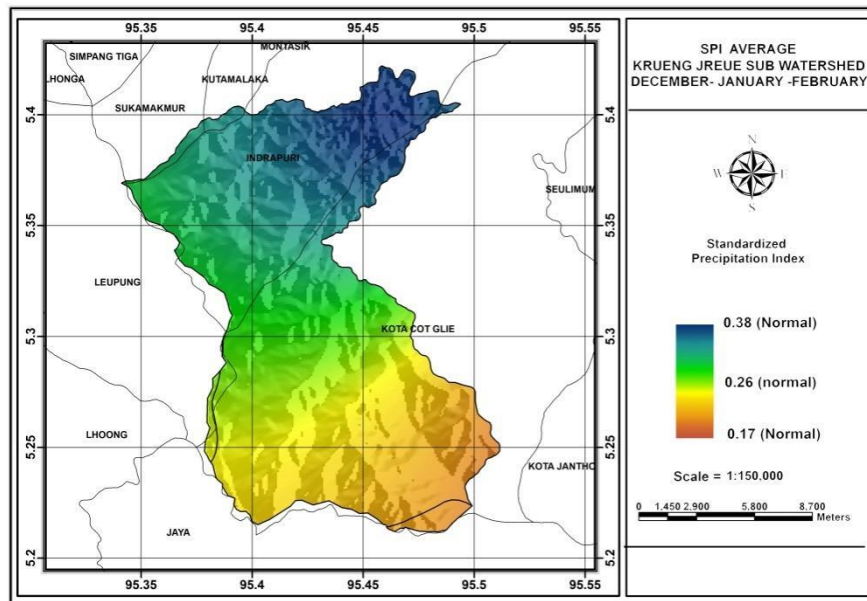
### Index and severity of drought

The meteorological drought index value is calculated using the SPI method (Hayes et al., 1999) and only depends on rainfall. A positive SPI value indicates normal conditions to wet conditions, while a negative SPI value indicates normal conditions to dry conditions (Shah et al., 2015). In 2005-2014, SPI in the Sub-Watershed *Krueng Jreue* experienced slightly dry conditions that occurred in July in the north sub-watershed with an SPI value of -1.16 and rainfall of 49.9 mm month<sup>-1</sup>. In the southern part of sub-watershed, the condition is slightly dry from June to July; SPI values are -1.23 and -1.08 and rainfall are 76.7 mm month<sup>-1</sup> and 57.0 mm month<sup>-1</sup>. In the northern sub-watershed, the severity of drought for wet and slightly wet categories occurs in November and December, with SPI values of 2.15 and 1.13, while the other months have normal conditions. In the southern sub-watershed, the severity of the drought for the wet category only happens in November with an SPI value of 1.74, while the other months are in normal conditions.

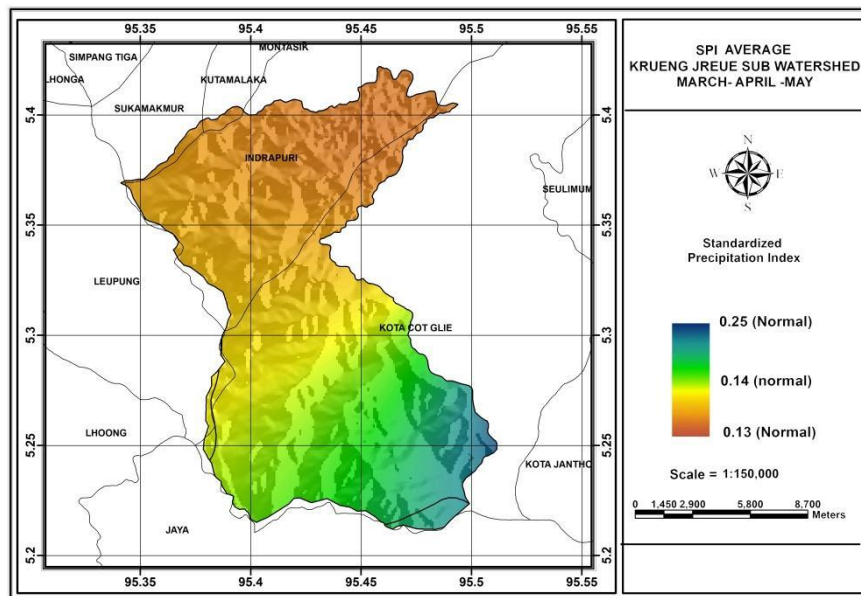
From 2005 to 2014, there were no extreme dry conditions except or the June-July-August (JJA) period of each year. The rest of the months experienced slightly wet, wet and normal conditions. The worst drought recorded was in July that reached a SPI value of -1.23, a value categorized as slightly dry severe according to the SPI index (-1.49 to -1.00). The results of previous research indicate the duration and the severity of a drought have different spatial patterns in every watershed (Agwata, 2014), and there is no drought index that applies universally (Niemeyer, 2008). The severity of the drought is recognized as a phenomenon associated with water shortages due to a decrease in the amount of rainfall over a certain period, usually in a season, that lasts a year or longer.

### The spread of drought

To determine the distribution of drought, the SPI value scaled three-monthly (SPI-3) that resulted from *Indrapuri* and *Jantho* stations in December-January-February (DJF), March-April-May (MAM); June-July-August (JJA) and September-October-November (SON) is interpolated with the Inverse Distance Weighted (IDW) method. IDW interpolation method already describes the rill condition in the field of study. The use of the IDW interpolation methods gives results that are similar to the conditions of the topography area of research (Pasaribu & Haryani, 2012). The map of drought spread or drought index SP-3 in each period in the Sub-Watershed of *Krueng Jreue* is indicated in Figures 7, 8, 9 and 10.



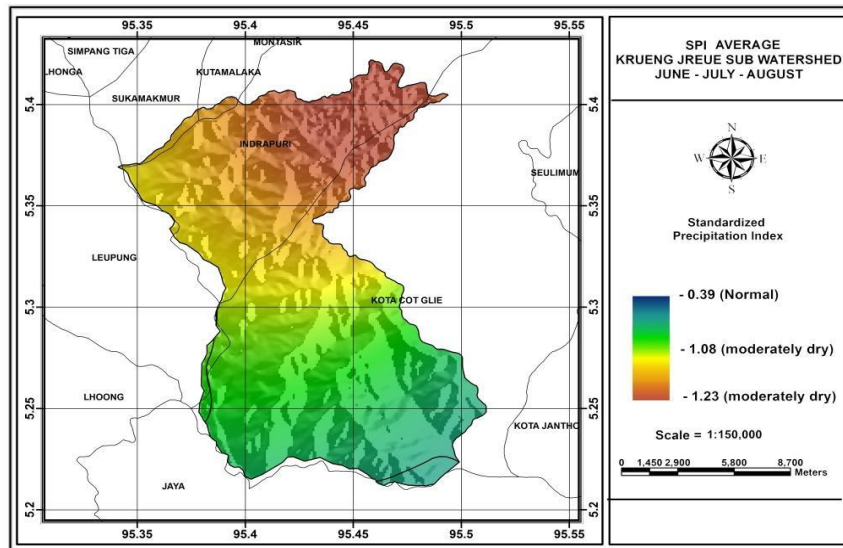
**Figure 7** Map of drought index in December-January-February (DJF) periods



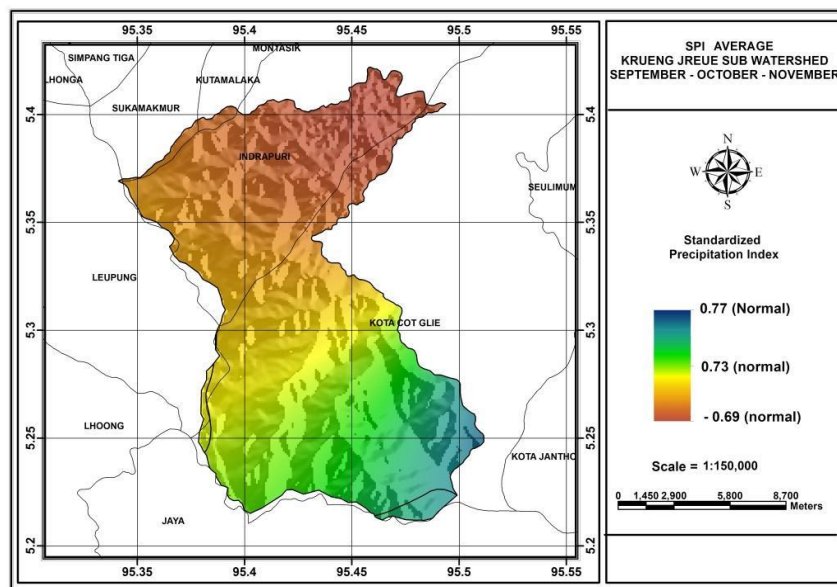
**Figure 8** Map of drought index in March-April-May (MAM) periods

The average of drought distribution during the period December-January-February (DJF) is illustrated in Figure 7. The drought index of SP-3 was about (0.38)-(0.17). The drought spreads to the northern side while the middle and the northern sides of the sub-watershed was in not too dry condition. The level of drought during the DJF period is in medium level, where the severity level of the drought was still in normal condition (0.99)-(-0.99). The average of drought distribution during the March-April-May (MAM) period is displayed in Figure 8.

The SP-3's drought index value was between (0.25)-(0.13). The drought spread over to the middle and the northern part of the sub-watershed while the southern side tends not too dry. The drought level during this period is in the medium category, where the severity level is still in normal condition (0.99)-(0.99), but it slightly improves compared with the period of DJF.



**Figure 9** Map of Drought Index in June-July-August (JJA) periods



**Figure 10** Map of Drought Index in September-October-November (SON) periods



The average spread of the drought in the June-July-August (JJA) period is shown in Figure 9. The value of the index drought SP-3 ranged from (-1.39) - (-1.23). Average drought spread more evenly distributed toward the north and central area with nearly half of the sub-watershed wide, while the southern Sub-Watershed *Krueng Jreue* tended to be normal. The severity of the drought for the period of JJA was higher than that of the MAM period. The severity of drought categories in the northern sub-watershed was slightly dry, with a drought index value of -1.23. On the other hand, the severity of drought categories in the southern sub-watershed was normal, with a dryness index value of -0.39. The spread of drought in the September-October-November (SON) period tended to be evenly distributed, almost the same as in the JJA period (Figure 10). However, the SON period experienced the displacement on the north area of the sub-watershed with a lower drought index value between (0,77) and (-0,69). However, the severity of the drought in normal categories ranged between (0.99) and (-0.99), where a decrease in the level of drought occurred in comparison with the JJA period.

The spread of drought in the area of study exhibited alternating patterns; this is due to the limitations of the narrow scope of the area. According to the results of the research and statement of Nurrahman & Pamungkas (2013) in *Lamongan*, East Java, the change of drought pattern would be clearly visible when the observed area is wider, where a watershed can include more than one sub-watershed. The pattern of the spread of drought that always changes is also related to the hydrological cycle and the meteorological conditions that are affected by the climate of a sub-watershed region (Van Loon & Laaha, 2015).

According to the value of drought index of SPI-3, the severity of drought in the Sub-Watershed *Krueng Jreue* from the category of slightly dry to slightly wet are JJA, MAM, DJF and SON. The impact of El Nino Southern Oscillation (ENSO) and the Dipole Mode Index (DMI) phenomena positively result in a decrease in the number of annual and seasonal rainfall events, especially in JJA periods, whereas negatively, these phenomena can cause an increase in precipitation, mainly in SON periods. According to Kumar et al. (2013), variability and intensity of drought will increase if it is affected by ENSO. The ENSO causes changes in temperature and precipitation that produce extreme events such as droughts and forest fires (Brolley et al., 2007). The DMI phenomenon is closely connected with the temperature of the sea surface in the tropics region (Saji & Yamagata, 2003). The DMI is a phenomenon that greatly influences the weather and climate in Aceh Province. The positive index of DMI value indicates that there is only a small chance for the movement of moist air from the Indian Ocean of the western region of Indonesia, especially Aceh Province, so the formation of rain clouds will likely still be low (BMKG, 2016).

### **Components and Hydrological disaster mitigation measures**

Under normal average rainfall conditions and temperature rise, soil porosity and certain land uses in relation to dry climate potential, there is a danger of drought. The risk of damage caused by drought disaster is obtained from the separation of drought disaster threat in the form of total run-off of below average normal rainfall <996 mm year<sup>-1</sup> (ICCSR, 2010), still below the average rainfall in *Krueng Jreue* Sub-Watershed 1830.9 mm year<sup>-1</sup>. A further risk of

drought is a decrease in water availability, both in intensity and extent. Water management and water resource are a challenge under climate change, as it is particularly vulnerable to changing climate patterns, so policy mitigation and effective strategies are needed to minimize the impact of climate change on water resources and irrigation. In agricultural areas, among others, must be wary of cultivation and harvest failure due to drought. To minimize the negative impact and risk of drought damage in *Krueng Jreue* Sub-Watershed, the drought-severity zone with slightly dry criteria (SPI value = -1.00- -1.49), hydrological disaster mitigation measures in a structural and non-structural way.

### Structural

Optimizing the development of the *Krueng Jreue* dam, rehabilitation and maintenance of irrigation networks to meet the needs of crop water under limited water availability conditions and increasing the use of water. Rain harvesting technology, is one of the alternative water management with the principle of collecting excess water in the rainy season and use it during the dry season to irrigate the crop, in the form of reservoir. In the dry season farmers rely on irrigation sources from reservoirs. By the end of the water drain, the reservoirs can be used by farmers to grow crops by utilizing the remaining puddles and moisture of the soil. The groundless application can reduce the risk of failure due to drought compared to conventional soil. Making the terrace, intended to hold water so as to reduce the speed and number of run-offs, and increase the chance of water absorption by the soil. On the farmland is applied bench terrace type and ridge terrace on the topography is rather steep (15-25%) and steep (25- <40%).

### Non-structural

Utilizing dry land in the form of shrubs and moor with drought tolerant species, namely: corn, sugar cane, *gude* bean, soybean and green beans. Apply a simple and complex agroforestry system. In a simple agroforestry system, trees are grown intercropping with one or more seasonal crops. In a simple agroforestry system, a tree is planted as a fence around a plot of land, in a plot of land or a pattern lined up in a run, thus forming an aisle or fence. Various crops, economic value (rambutan, areca nut, coconut, oil palm, cocoa, pecan, mango, orange, jackfruit and *langsai*) or low economic value (rambutan, *dadap*, *lamtoro*). Types of seasonal plants as food crops (upland rice, corn, soybeans, peanuts, cassava), vegetables and grasses. In complex agroforestry, trees are planted either intentionally or grow naturally on a plot of land and managed by farmers following cropping patterns and ecosystems that resemble forests. Decrease in evaporation by using mulch and organic matter. Monitor and process meteorological data, make drought predictions using telemetry systems (remote and timely observation), and drought disaster threat coverage. The socialization of climate change and global warming to the community in *Krueng Jreue* Sub-Watershed area.

### Conclusion

According to the isohyets method, the total rainfall from 2005 to 2014 in the southern part of the sub-watershed is higher than that in the northern parts, namely 19.392 mm and 17.225 mm, values in the quite low category. Maximum rainfall occurs in November, while minimum rainfall is in July.



In the period between 2005 and 2014, there were no dry conditions during January-December, only the June-July-August (JJA) period experienced some dryness while the rest of the month DJF, while MAM and SON experienced normal conditions. The worst dryness reached SPI values of -1.23 and -1.08 in July and June on the southern sub-watershed, and -1.16 in July in the northern part of the sub-watershed.

The severity of drought according to the Standardized Precipitation Index method with the scale of three monthly (SPI-3) was interpolated using the Inverse Distance Weighted method, consisting of normal and slightly dry categories. The value of the drought index ranged from (0.38) to (0.17) in the December-January-February (DJF) periods; (0.25)-(0.13) in the March-April-May (MAM) periods; (0.77)-(-0.69) in the September-November (SON) periods; and (-1.39)-(-1.23) in the June-July-August (JJA) periods.

Hydrological disaster mitigation efforts in the zone of the severity of the drought with the criteria slightly dry can be done by means of structural and non-structural. Structurally it is done through optimizing the development of dams and building *Krueng Jreue*, rehabilitation and maintenance of the irrigation network. Non-structural way is by making predictions of drought, drought index map, agroforestry, planting water-efficient plants, the use of mulch and organic materials.

### Disclosure statement

No potential conflict of interest was reported by the authors.

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