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Research Paper

Drought Assessment in Aceh and North Sumatra Using Effective Drought Index

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Abstract

Indonesia has two seasons and witnesses three rainfall patterns throughout the year. Although Aceh and North Sumatra experience low rainfall, the underlying causes of this condition are unknown. Unfortunately, studies on drought in these regions are very limited. This study uses the Effective Drought Index (EDI) to assess drought in these regions using daily rainfall data from 1985–2019 (35 years) from the meteorology, climatology, and geophysics agency stations. These stations are Sultan Iskandar Muda, Malikussaleh, Deli Serdang, and FL Tobing. In this study, the Ocean Niño Index (ONI) and the Dipole Mode Index (DMI) were used to identify El Niño years and positive and negative phases of the Indian Ocean Dipole (IOD). These indices were used to analyze drought-related climatic phenomena. The results obtained indicated that some drought events were not associated with a positive Indian Ocean Dipole or El Niño, as is typically the case. These include the extreme drought in 1989/90 and moderate drought in 1999 at Sultan Iskandar Muda, moderate drought at Malikussaleh (March to June 2008), moderate drought at Deli Serdang in 2010, as well as the drought from January to June 2006 at FL Tobing. Analysis of spatial patterns revealed that moderate droughts were more prevalent than severe and extreme droughts. These drought assessment results are essential for the mitigation of natural catastrophes.

Keywords

Drought Assessment, Aceh, North Sumatra, Effective Drought Index, Positive IOD-El Niño

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1. INTRODUCTION

Drought is one of the natural disasters that occurs at specific times due to a lack of rainfall. Drought can affect almost all areas of life, including agriculture, health, and even social life (Mondol et al., 2021). Therefore, the determination of drought index as a part of drought mitigation efforts is necessary, one of which is drought assessment based on rainfall.

Drought assessments typically involve a variety of indicators that are adjusted based on local climatic conditions and topography. There are at least 23 indices that are used to identify meteorological droughts using various climatic parameters such as rainfall, humidity, and temperature (WMO, 2016). Effective Drought Index (EDI) is one such index with rainfall as a computational input. Depending on the characteristics of each index, the indices mentioned above have various advantages and disadvantages. The EDI was designed to overcome some of the limitations of the standardized precipitation index (SPI). (Byun and Kim, 2010; Kamruzzaman et al., 2019a; Kamruzzaman et al., 2019b) demonstrated EDI to be more effective in drought detection. One advantage of EDI over SPI is that it can detect long-term droughts that short-term SPI cannot, and conversely, EDI can detect short-term droughts that long-term SPI cannot (Byun and Kim, 2010). Apart from the study by Kamruzzaman et al. (2019a), several others have also used EDI to detect drought. Mondol et al. (2021) used EDI to measure drought in Bangladesh, Adisa et al. (2021) compared performance of EDI and SPI in drought detection in South Africa, and Pinto et al. (2022) used EDI and other indices to detect drought in Chile.

Indonesia is an archipelagic nation with two main seasons: the dry and the wet seasons. Under normal conditions, the dry season begins in summer and ends in autumn. This climate state is influenced by monsoons, the El Niño-Southern Oscillation (ENSO) (Iskandar et al., 2019; Lee, 2015; Tangang et al., 2018), Indian Ocean Dipole (IOD) cycle (D'Arrigo and Wilson, 2008; Kurniadi et al., 2021; Lestari et al., 2018), Madden-Julian Oscillations (MJO) (Hidayat, 2016), and others. For example, a simultaneous occurrence of positive IOD and El Niño cycles results in a prolonged drought, such as the ones witnessed in 1997/98 and 2015/16 (Iskandar et al., 2017; Kirono et al., 1999).

In addition to the dry and wet seasons, Aldrian and Dwi Susanto (2003) described three rainfall patterns in Indonesia. The Sumatra Islands have a semiannual pattern north of the equator and a monsoon pattern in the southern region (Ferijal et al., 2021). This rainfall pattern is influenced by several climatic phenomena in addition to those mentioned above. The rainfalls of northwestern Sumatra are correlated with positive IOD and those of southern Sumatra are correlated with negative IOD (Lee, 2015). North Sumatra, which has a semiannual rainfall pattern, has a rainy season of 48 to 100 days, and this has been on the decline over the past two decades (Ferijal et al., 2021). The situation has definitely affected the dry and wet seasons of Aceh and North Sumatra. But even in this state, research on drought in the region is very limited (Ferijal et al., 2021). Previous studies on drought in Indonesia have been performed more frequently in the central and eastern regions (Avia and Sofiati, 2018; Iskandar et al., 2017; Lestari et al., 2018; Pramudya and Onishi, 2018). In the western Indonesia region, a drought study was conducted in the western region of Sumatra (Daoed et al., 2018), Riau Provinces, and the southern region of Sumatra (Nurdiati et al., 2021). Nurdiati et al. (2021) showed that drought in South Sumatra and Riau provinces is affected by El Niño; however, there is no confirmation about drought in Aceh and North Sumatra provinces. These provinces are at low risk to be affected by El Niño (Supari et al., 2016). Nur'utami and Hidayat (2016) also demonstrated that a positive IOD-El Niño does not affect drought in this region.

This study aims to find out the drought situation in Aceh and North Sumatra using the Effective Drought Index. Rain gauge data have been used for the analyses as they provide an overview of actual drought conditions.

2. EXPERIMENTAL SECTION

2.1 Materials

This study was conducted in the provinces of Aceh and North Sumatra using rainfall data from the meteorology, climatology, and geophysics agency (BMKG): the agency that oversees climate change and rainfall collection. The period covered in this data is 1985–2019. The coordinates of the BMKG rainfall gauges spread across the South Sumatra region are shown in Table 1.

Table 1. Rain Gauge Coordinates

Rain Gauge	Latitude	Longitude
Sultan Iskandar Muda	5.52244	95.41700
Malikussaleh	5.22869	96.94749
Deli Serdang	3.62114	98.71485
FL Tobing	1.55000	98.88000

Based on the coordinates in Table 1, BMKG rain gauge locations were identified by the corresponding serial number and names in the table, as shown in Figure 1.

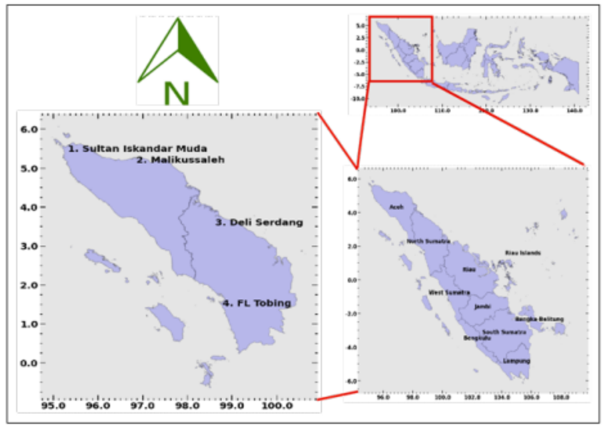

Figure 1. Mark of Rain Gauge

2.2 Methods

EDI was developed by Byun and Wilhite (1999) to identify drought for specific locations and durations. It is the fraction of precipitation required to return from standard deviation (σPRN) to normal precipitation (PRN).

$$EDI_j = \frac{PRN_j}{\sigma(PRN_j)} \quad (1)$$

with

$$PRN_j = \frac{DEP_j}{\left(\sum_{i-1}^{M} \frac{1}{i}\right)} \quad (2)$$

$$DEP_j = EP_j - \bar{EP}_j \quad (3)$$

and

$$EP_j = \sum_{m=1}^{N} \left[\frac{\left(\sum_{i=1}^{m} P_i\right)}{i} \right] \quad (4)$$

$\bar{EP}_j$ is the mean of effective precipitation EP_j in a j month calendar. Effective precipitation is the accumulation of rainfall as a function of time reduction. This function counts decreasing weight of precipitation from the previous i month. Drought classification of EDI is based on threshold as shown in Table 2. In this table, EDI represents wetness and dryness. A disadvantage of EDI is that it does not directly account for temperature effects, as it only includes rainfall in its calculations (WMO, 2016). Another drawback is the difficulty in detecting droughts in areas with high variability in rainfall over a given decade (Park et al., 2022).

In addition, past data on El Niño, La Niña, and Indian Ocean Dipole (IOD) events provided by the Japan Meteorological Agency (https://ds.data.jma.go.jp/tcc/tcc/products/

Table 2. EDI Classification

EDI Values	Category
EDI>2	Extremely Wet
1.55≤EDI≤1.99	Vey Wet
1.0≤EDI≤1.49	Moderately Wet
-0.99≤EDI≤0.99	Near Normal
-1.0≤EDI≤-1.49	Moderately Drought
-1.55≤EDI≤-1.99	Severely Drought
EDI<-2	Extremely Drought

elnino/iodevents.html) and National Oceanic and Atmospheric Administration (NOAA) (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php) were used to analyze drought-related events. These data have been shown in Table 3.

3. RESULTS AND DISCUSSION

3.1 Rainfall Climatology

Figure 2 shows the climate gotten for each rain gauge. As is evident from this figure, the Sultan Iskandar Muda and Malikussaleh rain gauges followed a similar trend in rainfall climatology. This area has little rainfall throughout the year (Darlan et al., 2020), and the rain gauges show one peak in November; however, the climatic phenomena related to this situation are still not clear. Rainfall climatology for SK Deli Serdang shows two peaks appearing in May and September. Despite that, the level of rainfall is low throughout the year as a result of the Bukit Barisan mountains that block the water mass from the Indian Ocean (Hermawan, 2010). In case of SM FL Tobing, two peaks of rainfall are observed in March and November. Unlike the other three rain gauges, this rain gauge experiences high rainfall throughout the year (Iskandar et al., 2011) due to its geographical position on the west coast which is close to the Indian Ocean (Darlan et al., 2020).

3.2 Temporal Assessment

The timeline of EDI is depicted in Figure 3. This graph shows that Sultan Iskandar Muda was out of drought from March 1989 to April 1990; however, this event was overshadowed by an extreme drought (May 1989–February 1990). In addition, this rain gauge station experienced the same drought from March 2002 to January 2003. on the data in Table 3 reveal the occurrence of one La Niña-related negative IOD in 1989/90 and one positive IOD in 2002. Apart from the extreme drought, moderate and severe droughts also occurred from winter 1998 to summer 1999 and from summer to late autumn 2008, with June, July, August, and September 2012 (JJAS) experiencing moderate droughts. As is established, positive IOD and El Niño are climatic phenomena that generate dry season in Indonesia, while negative IOD and La Niña generate wet season. Table 3 shows La Niña events in 1999 and positive IOD events in JJAS 2012. In 1989/90, there was an extreme drought at this rain gauge, even though climate phenomena indicated a negative IOD cycle. Further, despite the occurrence of a negative IOD in 1999, a moderate drought occurred. Also, an extreme drought occurred in the summer to early winter of 2002, and a severe drought in JJAS 2012 was associated with a corresponding phenomenon (positive IOD).

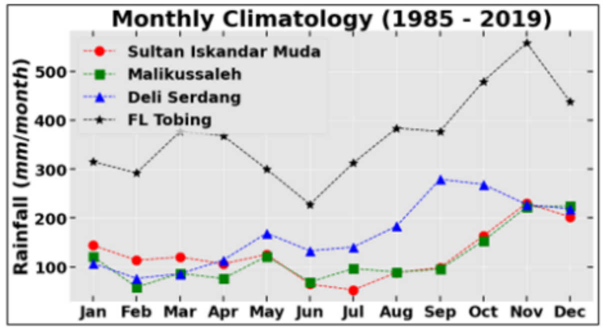

Figure 2. Monthly Climatology of Rainfall

The Malikussaleh rain gauge station recorded a drought from March 2012 to March 2013, with an extreme drought from summer to autumn. This event was related to a positive IOD in 2012. Further, a moderate drought occurred at this rain gauge station from August 2002 to February 2003 and March to June 2008 and fluctuated in late 2019. Although there was a positive IOD in 2008, the moderate drought-related phenomenon from March to June 2008 was not clear.

In Deli Serdang, only one extreme drought was recorded during September 2015, and it was positively associated with positive IOD and El Niño events. El Niño was observed from August 1987 to July 1988, moderate drought variations occurred in early 1991 (not clearly related to climatic phenomena) and 2006, and all seasons (winter to autumn) were experienced in 2010. Whereas in 2006, there was a moderate drought associated with positive IOD, in 2010 a moderate drought occurred with a negative IOD and La Niña. This rain gauge recorded severe droughts from summer 1997 to late spring 1998 and from June to October 2015. These droughts were clearly related to favorable IOD-El Niño.

Similar to the case with other stations, the causative factors behind the drought at the FL Tobing station are not known. The station experienced a drought from February 1990 to March 1991, which lasted until a positive IOD occurred in August 1991. The drought from January 1997 to June 1998 recorded at this station was positively associated with a positive IOD-El Niño. This rain gauge also recorded a moderate drought from June to November 2015, clearly associated with a positive IOD (El Niño).

3.3 Spatial Assessment

The drought frequency in the moderate, severe, and extreme categories is shown in Figure 4. For 35 years, the highest frequency of moderate drought (Figure 4a) occurred at the

Table 3. El Niño, La Niña, and IOD Events (1985–2019)

Climate Events	Years
Positive IOD	1987, 1991, 1994, 1997, 2002, 2003, 2006, 2008, 2011, 2012, 2015, 2019
Negative IOD	1989, 1992, 1996, 1998, 2010, 2013, 2016
El Niño	1986/87, 1987/88, 1991/92, 1994/95, 1997/98, 2002/03, 2004/05, 2006/07, 2009/10, 2014/15, 2015/16, 2018/19
La Niña	1988/89, 1995/95, 1998/99, 1999/00, 2000/01, 2005/06, 2007/08, 2008/09, 2010/11, 2011/12, 2017/18

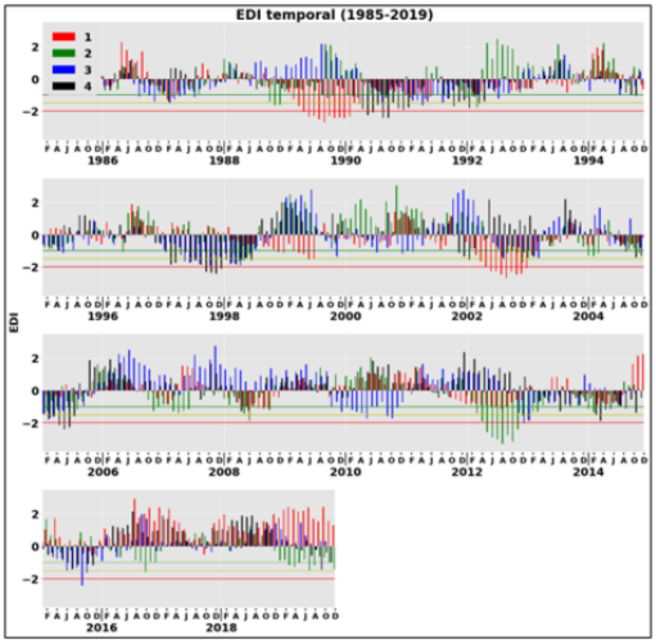

Figure 3. Temporal EDI Assessment of Each Rain Gauge. Red (1), Green (2), Blue (3) and Black (4) are Rain Gauges of Sultan Iskandar Muda, Malikussaleh, Deli Serdang and FL Tobing Respectively. The Green, Yellow and Red Horizontal Lines Represent the Limits of Moderate, Severe, and Extreme Drought

Malikussaleh rain gauge station and was up to more than 45 times. Sultan Iskandar Muda experienced drought about 45 times, FL Tobing about 40 times, and Deli Serdang about 25 times. The most frequent severe drought occurred in FL Tobing (about 22 times), while the lowest was in Deli Serdang (about 5 times). Sultan Iskandar Muda and Malikussaleh occurred about 10 and 15 times, respectively. Over the past 35 years, Deli Serdang experienced extreme drought approximately 18 times. Malikussaleh experienced drought about 2 times and it was of the lowest frequency. Sultan Iskandar Muda and FL Tobing underwent extreme droughts nearly 8 and 10 times, respectively. In general, Sultan Iskandar Muda, Malikussaleh, Deli Serdang, and FL Tobing tend to experience moderate drought.

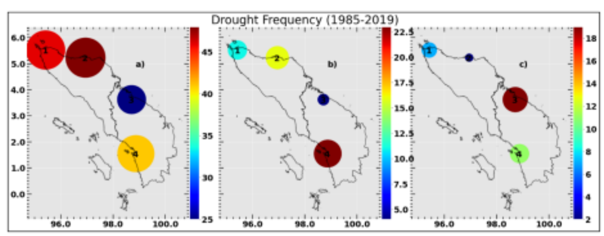

Figure 4. The Moderate (a), Severe (b) and Extreme (c) Drought Frequency of Each Rain Gauge for 35 Years

4. CONCLUSION

The rainfall climatology of the four rain gauges (Sultan Iskandar Muda, Malikussaleh, Deli Serdang, and FL Tobing) varied markedly. This variability is affected by the associated position of FL Tobing and Deli Serdang. FL Tobing is located on the west coast of Sumatra, which is close to the Indian Ocean; on the other hand, Deli Serdang, which is located on the east coast and surrounded by a mass of water from the Indian Ocean, is blocked by the Bukit Barisan mountains. It is still unclear as to what phenomenon causes low annual rainfall in Sultan Iskandar Muda and Malikussaleh. The temporal analysis of drought assessment at four rain gauges in Aceh and North Sumatra revealed that drought at certain rain gauges was not associated with positive IOD-El Niño phenomena, e.g., the extreme drought in 1989/90 and the moderate drought in 1999 at Sultan Iskandar Muda. The moderate drought in Malikussaleh from March to June 2008 was also unrelated to the positive IOD. Similarly, Deli Serdang experienced moderate drought in 2010, and FL Tobing experienced drought from January to June 2006. The results of the spatial analysis indicate that moderate drought occurs more frequently than severe and extreme drought, particularly in the Sultan Iskandar Muda and Malikusaleh rain gauges. Further, a low rainfall is not necessarily associated with extreme drought.

5. ACKNOWLEDGMENT

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