Umiati_2019_Spatial analysis and monitoring of drought using

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Journal of Physics: Conference Series **1367** (2019) 012088 doi:10.1088/1742-6596/1367/1/012088

Spatial analysis and monitoring of drought using Standardized Precipitation Index in East Java

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Abstract. Drought hazard index monitoring is important in the process of disaster risk reduction, as part of efforts to control drought. The purpose of this study was to determine the drought index based on precipitation. The location of this study is in the East Java region. The method used in the research is the Standardized Precipitation Index (SPI) method. The data needed is rainfall data obtained from the TRMM satellite. The data is then analyzed using R to obtain a drought index value. The results showed that Banyuwangi Regency became a district with a moderate drought hazard index with the highest value, which is 52.3% or 0.523 on a scale of 0-1 in accordance with SPI. Mojokerto City is a district with a low drought hazard index with the lowest value, which is 28.4% or 0.284 on a scale of 0-1 according to SPI.

1. Introduction

Drought is one of the most complex phenomena on earth that is able to influence various aspects of life such as social, economic and environmental life in various regions, especially arid and semi-arid regions [1]. In the environmental aspect, drought has an impact on reducing soil moisture that affects agriculture, reduced groundwater reserves, and river discharge [2]. Meanwhile, on social and economic aspects, drought is associated with the failure of the water resources system to meet water demand. This has an impact on increasing conflict among water users, decreasing public safety and security, decreasing health, quality of life and increasing psychological pressure on the community ([3;[4]).

Drought disasters generally occur due to the decrease in the amount and intensity of rainfall over a long period of time, but the real causes of drought are more due to high climate variability and the intensity and duration of diverse rainfall ([5];[4]) The high climate variability causes extreme dryness and extreme wetness. Where when dry extracts occur, the potential for drought in the dry season is even greater. And vice versa, if there is extreme wetness, the potential for the occurrence of floods will be even greater [6].

Drought disaster monitoring currently plays an important role in efforts to reduce the risk of drought, especially for areas prone to drought [7]. Monitoring of drought can be done through various types of drought indices, one of which is the Standardized Precipitation Index (SPI). SPI is a method of determining the drought index developed by McKee in 1993 [1]. In this method, the data used is in the form of monthly rainfall data which is processed with a gamma probability distribution, which is then transformed into a normal distribution so that the average index value for each location and the desired period becomes zero [8]. SPI has several advantages that make it one of the most frequently used indices

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in determining drought hazards. Some of these advantages include only requiring rainfall data in its calculations and the results can be compared with other regions that have different climate zones [9]. In addition, SPI also has good consistency in terms of statistics and has good ability in predicting the effects of drought in the short and long term on various time scales with only monthly rainfall data ([1];[10]).

In the area which is the place of research, East Java is one of the regions in Indonesia which is a region prone to drought. Based on the results of the disaster risk assessment prepared by BNPB in 2015, East Java ranked first after West Java in the number of drought risk exposure. East Java recorded losses due to the drought, with details of 35,247,898 people exposed to drought, economic losses totaling 19,657,247,000,000 rupiahs, and 306,793 hectares of environments exposed to the risk of drought. Meanwhile, in 2018 there were droughts in 11 provinces with 111 districts/cities, 888 sub-districts and 4,053 villages which made 4.87 million affected people. Of the 11 provinces, East Java is one of the provinces experiencing a fairly wide drought.

The magnitude of the impact of the drought is due to a lack of information about which areas have high drought threat levels or indices. Research on monitoring the drought index with the SPI index has actually been carried out by several previous researchers. Some of them are Ihsan et al [11] who examined the monitoring of meteorological drought in the Citarum area using the SPI method. Then Mayasari et al [12] conducted a determination of the drought index analyzed based on rainfall patterns using the SPI method with the case study area in the Bangga River Basin. Although there have been many studies regarding the determination of the drought index, there have been no studies specifically addressing the determination of drought indices on a provincial scale with the SPI method. This study aims to analyze the drought index that occurred in the East Java region using the SPI method. It is expected that the drought hazard index monitoring research can provide information to the relevant agencies that are authorized to make decisions so that the impact caused by drought can be minimized.

2. Data and Study Location

East Java is one of the provinces in Indonesia which is located between 111.0 ′ EL to 114.4 ′ EL and latitude 7.12 "SL and 8.48‘ SL. East Java Province itself is divided into 38 districts or cities with details of 29 districts and 9 cities.

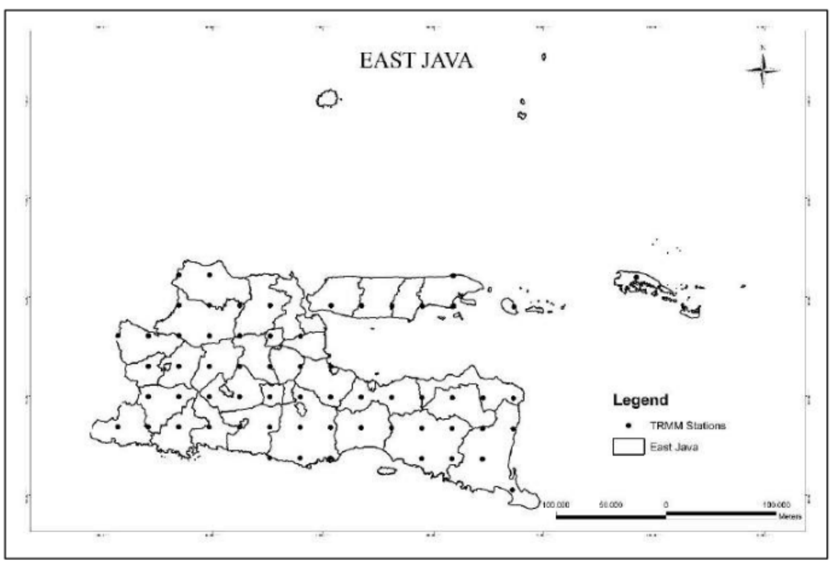

Figure 1. Research Location (source : author)

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Based on data from the Indonesian Ministry of Internal Affairs, East Java has 8028 villages with a registered population of 39,921,952 people with an area of 46. 428, 57 km2.

The data used in this study is monthly rainfall data obtained from measurements of the satellite Tropical Rainfall Measuring Mission (TRMM) over a period of 20 years starting in January 1998 until December 2018. TRMM satellites are satellites developed to measure rainfall in the area tropical, for example, Indonesia. Initially, TRMM satellites were the result of collaboration from the US National Aeronautics and Space Administration with Japan's National Space Development of Japan NASDA which is currently changing its name to JAXA (Japan Aerospace Exploration Agency) ([13];[14]). There are 61 TRMM stations located in East Java Province with an uneven distribution of numbers in each district or city.

3. Method

Calculation of SPI values based on the number of gamma distributions is defined as the function of frequency or chance of occurrence as follows [15]:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha} T(\alpha)} \int_0^x t^{\alpha-1} e^{\frac{-x}{\beta}} dx \tag{1}$$

α> 0 is a form parameter
β> 0 is a scale parameter
x> 0 amount of rainfall (mm)

The values of α and β are estimated for each rain station using the following formula [14]:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{2}$$

$$A = ln\ ln\ (\underline{x}) - \frac{\Sigma ln(x)}{n} \tag{3}$$

Or

$$\alpha = \frac{\underline{x}^2}{s^2} \tag{4}$$

$$\beta = \frac{\underline{x}}{\alpha} \tag{5}$$

$$s = \sqrt{\frac{\Sigma(x - x^2)}{n-1}} \tag{6}$$

n = amount of rainfall observation data
for x > 0
for x = 0 then the value of G (x) becomes:

$$H(x) = q + (1 - q)\ x\ G(x) \tag{7}$$

Where:
q = number of rainfall events = 0 (m) / amount of data (n)

The SPI value is a transformation from the gamma distribution (G (x)) to a normal standard with a mean of 0 and a difference of 1, or using the formula below [14]:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for : } 0 < H(x) \leq 0.5 \tag{8}$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for : } 0{,}5 < H(x) \leq 1.0 \tag{9}$$

$$t = \sqrt{ln\left(\frac{1}{(H(x))^2}\right)} \qquad \text{for}: 0 < H(x) \leq 0.5 \qquad (10)$$

$$t = \sqrt{ln\left(\frac{1}{(1-H(x))^2}\right)} \qquad \text{for}: 0,5 < H(x) \leq 1.0 \qquad (11)$$

Where
c0 = 2.515517
c1 = 0.802853
c2 = 0.010328
d1 = 1.432788
d2 = 0.189269
d3 = 0.001308

After obtaining the SPI value, the next step is to make a map of the drought threat with the following stages:

a) Identify in each year the drought occurrence data in the study area so that certain months of drought can be chosen.
b) Describe the results of the interpolation of the SPI value into 2 classes, namely the value <-0.999 is dry (1) and the value> 0.999 is not dry (0)
c) Results of classifying SPI-3 values in each year the data is overlaid as a whole (accumulated all years)
d) Calculate the dry class frequency (1) with a minimum frequency of 5 times in the time period the data is used as the reference for the lowest drought event
e) Perform a linear transformation of the frequency value of drought to a value of 0 - 1 as the drought hazard index

4. Results and Discussion

4.1. SPI Distribution

In this study, the rainfall data used as the basis for calculating the SPI value in the East Java region came from the Tropical Rainfall Measuring Mission (TRMM) with a data year of 20 years starting from 1998-2018. The TRMM Satellite (Tropical Rainfall Measuring Mission) collaborates with two national space agencies, namely the National Aeronautics and Space Administration (NASA) of the United States and the National Space Development of Japan (NASDA) from Japan which is now transformed into the Japan Aerospace Exploration Agency (JAXA). TRMM Satellite (Tropical Rainfall Measuring Mission) itself is a weather/climatology satellite used to measure rainfall in the tropics ([13];[14]). After rainfall data is obtained, then the SPI value is calculated for each month at each TRMM location in the East Java region. The example of the calculation of the SPI value in one of the TRMM locations is shown in Figure 2 below:

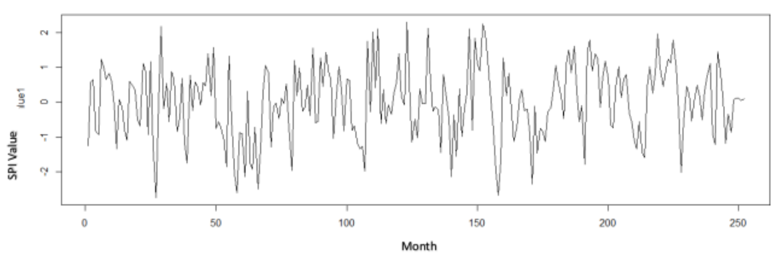

Figure 2. The plotting graph of the SPI value.

Figure 2 is the result of the calculation of the value of rainfall each month which is converted into a value on a scale that matches the classification of values in SPI. In SPI there are 7 classifications where each classification describes the conditions of drought. In the month that shows a positive SPI value, it shows that the rainfall value for the month above is average and enters into a wet condition, whereas in the month that has a negative SPI value it shows that the month's rainfall is below average and enters in a dry condition.

4.2. Drought Hazard Classification

4.2.1. SPI Value Classification. After obtaining the SPI value every month in the data collection period, then the SPI drought conditions are classified according to the SPI value. Details of the classification of SPI drought conditions can be seen in Table 1 below:

Table 1. SPI Value Classification.

SPI Classification	
SPI Value	Classification
≥ 2	Extremely Wet
1.5 up to 1.99	Very Wet
1 up to 1.49	Moderately Wet
-0.99 up to 0,99	Near Normal
-1 up to -1.49	Moderately Dry
-1.5 up to -1.99	Severely Dry
≤ -2	Extremely Dry

4.3. SPI Frequency Distribution

After calculating the SPI value of each data year for each point, then calculate the frequency of each SPI classification for each TRMM point. The example of the calculation of the number of frequencies for each SPI classification can be seen in Figure 3.

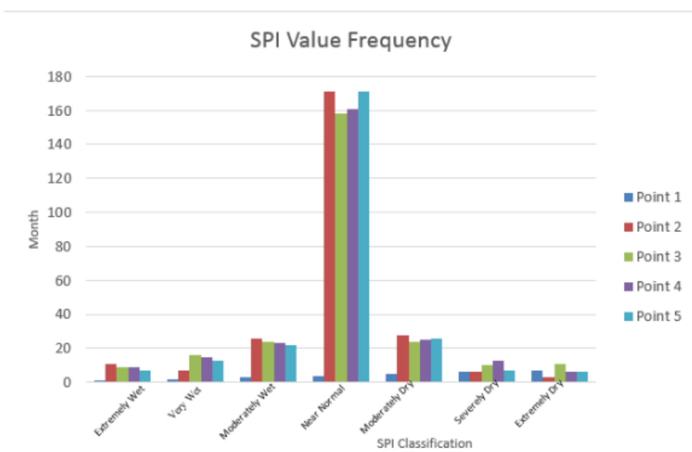

Figure 3. Graph of the comparison of the number of months in each SPI classification.

Figure 3 above is a graph of the comparison of the number of frequencies for each SPI classification for 5 points or the location of a TRMM taken. In this study, the classification taken to determine the dryness index is the classification of moderately dry, severely dry and extremely dry. This is because the three classifications are classifications that can generally be said as dry classifications. Although each classification has a different level of drought. In the moderately dry classification, the point experiencing the driest months is point 5, while for the point experiencing the lowest dry month is point 2. For severely dry classifications, the point with the driest months is point 3, while the point with the least amount the dry month is point 1. Furthermore, for the extremely dry classification, the driest point is point 2, while the point with the least number of dry months is points 1 and 5.

4.4. SPI Spatial Distribution

Then a linear transformation is carried out towards the frequency of drought to be a value of 0 - 1 as the drought hazard index. The frequency values carried out by linear transformation are from classifications moderately dry, severely dry and extremely dry which are added together. The result is a drought hazard index on a scale of 0-1 based on SPI.

Based on the drought hazard distribution map in figure 4, it can be seen that the districts that have the highest category of drought hazards with the highest score are Banyuwangi Regency, which is followed by Nganjuk Regency and Kediri Regency. In other words, the three districts have a higher chance of drought disasters compared to other districts or cities in East Java. This means that drought mitigation efforts can be focused and increased again in Banyuwangi, Nganjuk and Kediri Regencies.

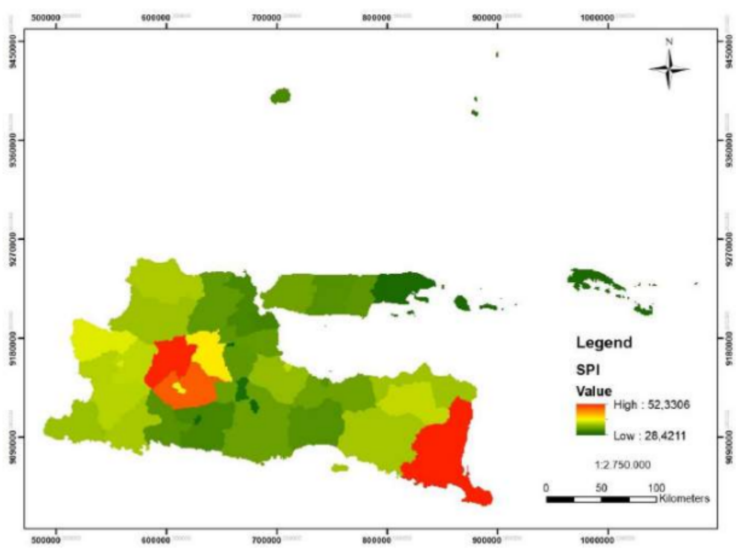

Figure 4. Drought distribution map of dangers in East Java.

4.5. Drought Hazard Index

Table 2 is a breakdown of the average drought hazard index value based on the SPI value for each district or city in East Java. Table 2 shows that there are 25 districts and cities that have a Moderate drought hazard index. Of the 25 districts or cities, Banyuwangi Regency is a district with a Moderate drought hazard index with the highest value, which is 52.3% or 0.523 on a scale of 0-1 in accordance with SPI. Mojokerto Regency is a district that has a Moderate drought hazard index with a low value of 33.1% or 0.331 on a scale of 0-1 according to SPI. Furthermore, there are 13 districts or cities that have

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a low drought hazard index. Pamekasan Regency becomes the district with the Low drought hazard index with the highest value, namely 33.0% or 0.33 on a scale of 0-1 according to SPI. Then, the City of Mojokerto became a district with a Low Drought Hazard Index with a low value, which was 28.4% or 0.284 on a scale of 0-1 according to SPI.

Table 2. Drought Hazard Index.

No	Regency / City	Province	Average Drought Index (%)	Danger level
1	Banyuwangi	East Java	52.3	Moderate
2	Nganjuk	East Java	52.1	Moderate
3	Kediri	East Java	49.6	Moderate
4	Jombang	East Java	41.7	Moderate
5	Kediri City	East Java	40.0	Moderate
6	Ngawi	East Java	39.1	Moderate
7	Madiun City	East Java	39.0	Moderate
No	Regency / City	Province	Average Drought Index (%)	Danger level
8	Pasuruan City	East Java	38.0	Moderate
9	Bondowoso	East Java	37.8	Moderate
10	Madiun	East Java	37.7	Moderate
11	Ponorogo	East Java	37.4	Moderate
12	Magetan	East Java	37.2	Moderate
13	Tuban	East Java	36.9	Moderate
14	Trenggalek	East Java	36.6	Moderate
15	Jember	East Java	36.5	Moderate
16	Situbondo	East Java	36.2	Moderate
17	Bojonegoro	East Java	36.1	Moderate
18	Pacitan	East Java	36.0	Moderate
19	Pasuruan	East Java	35.6	Moderate
20	Probolinggo	East Java	33.9	Moderate
21	Bangkalan	East Java	33.9	Moderate
22	Malang	East Java	33.7	Moderate
23	Sidoardjo	East Java	33.3	Moderate
24	Lamongan	East Java	33.2	Moderate
25	Mojokerto	East Java	33.1	Moderate
26	Pamekasan	East Java	33.0	Low
27	Tulung Agung	East Java	32.7	Low
28	Probolinggo City	East Java	32.6	Low
29	Lumajang	East Java	32.5	Low
30	Sampang	East Java	32.4	Low
31	Gresik	East Java	31.9	Low
32	Blitar	East Java	31.7	Low
33	Surabaya City	East Java	31.5	Low
34	Batu City	East Java	29.5	Low

35	Sumenep	East Java	29.4	Low
36	Blitar City	East Java	29.0	Low
37	Malang City	East Java	29.0	Low
38	Mojokerto City	East Java	28.4	Low

5. Conclusion.

The level of drought based on SPI is divided into 7 classes, three of which fall into the general category of drought, namely the class is moderately dry, severely dry, and extremely dry.

In determining the danger level of drought based on SPI in each regency or city in East Java, it is performed using the average function, this is due to the point or location of the TRMM station whose numbers are spread unevenly for each district or city. So that there are districts or cities that have more than one TRMM, on the other side, the station there are districts or other cities that do not have TRMM stations at all.

Of the 25 districts or cities, Banyuwangi Regency is a district with a Moderate drought hazard index with the highest value, which is 52.3% or 0.523 on a scale of 0-1 in accordance with SPI. Mojokerto Regency is a district that has a moderate drought hazard index with a low value of 33.1% or 0.331 on a scale of 0-1 according to SPI. Furthermore, there are 13 districts or cities that have a low drought hazard index. Pamekasan Regency becomes the district with the low drought hazard index with the highest value, namely 33.0% or 0.33 on a scale of 0-1 according to SPI. Then, the City of Mojokerto became a district with a low Drought Hazard Index with a low value, which was 28.4% or 0.284 on a scale of 0-1 according to SPI.

Acknowledgments

10

Financial support for completing this research is graciously provided by the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia with contact number: 176/SP2H/LT/DPRM/2019

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