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Characteristics of Extreme Rainfall Events in North Sumatra

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Abstract

Extreme rain is an event that has an impact on various sectors of life. Therefore, this study aims to determine the spatial and temporal characteristics of extreme rain events in North Sumatra Province in the time period between 1991-2020. In accordance with the WMO recommended rain index, the frequency and intensity of rain were calculated using 50 rain stations spread across North Sumatra where the data had passed the quality control test for empty data. Spatial patterns were analyzed by mapping the climatological mean of the indices then for trend patterns were tested using the Mann-Kendal non-parametric test. The results showed that extreme rainfall events with low frequency and intensity occurred on the east coast while high frequency and intensity occurred in mountainous areas. Based on the temporal trend test, it shows that in general an insignificant trend dominates in this area. Significant and consistently increasing trends are only found at several points, namely in the districts of Deli Serdang (5 station), Batu Bara (1 station), Humbang Hasundutan (1 station), Langkat (2 station), Labuhan Batu Utara (1 station), Medan (1 station), Pematang Siantar (1 station) and Serdang Bedagai (1 station). Meanwhile, a significant and consistently decreasing trend was found in Asahan Regency (1 station), Simalungun (2 station), North Tapanuli (1 station), and North Labuhan Batu (1 station).

Keywords: spatial and temporal characteristics, extreme rainfall, North Sumatra

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INTRODUCTION

The conversation about climate change is currently being discussed. Research conducted by the Intergovernmental Panel on Climate Change (IPCC) on global climate change shows that human influence on climate causes changes in the frequency and intensity of extreme weather events (Trenberth et al., 2007). As a result, these events have major economic, social and environmental impacts (Manton et al., 2001). In urban areas, these events often cause flooding problems due to inadequate drainage to accommodate sudden large rainfall events, while in rural areas, the impacts of extreme rainfall can damage crops and livestock (Carvalho et al., 2002). On a global scale, these events are also blamed for the rapidly increasing cost of losses since the 1970s (Menzel ; John et al., n.d.). Serious impacts can be caused by these extreme events in the environmental, economic, social, and other sectors. This has caused the demand for extreme weather information to increase (Klein et al., 2003).

Indonesia is one of the developing countries that is highly affected by extreme climate events, especially North Sumatra. North Sumatra has climate conditions that are influenced by global climate variability conditions such as the Indian Ocean Dipole (IOD) phenomenon, Madden Julian Oscillation (MJO) (Marzuki at al.,2016) and also diverse topographic factors (Prasetyo et al., 2018). These influences are the reason to further investigate extreme climate conditions. The National Disaster Management Agency (2022) noted that there were 240 floods and landslides of various intensities in North Sumatra province in the 2017-2021 period caused by extreme rainfall. Data obtained from the BPS of North Sumatra Province shows that rice crops are ranked first in the largest food crop production at 2,040,500 tons throughout the year (BPS.,2022). Therefore, it is necessary to study whether the extreme rainfall events on a regional scale in North Sumatra Province are changing or not. Changes in these events either in frequency or intensity will have an effect on policy formulation in various sectors, such as agriculture (agricultural product management) and infrastructure (construction management). Without studying this subject, it will not be known whether the current extreme climate conditions still support strategies in these sectors.

Observational studies in several regions show evidence of extreme climate change. Using daily rainfall data from 1931 - 1996, Kunkel et al. [1999], examined trends in extreme rainfall events in the contiguous United States and Canada and found indications of increasing trends in the number of extreme rainfall events over 7 days and 1 year. Studies in several countries show evidence of changes in extreme rainfall events. For example, in Peninsular Malaysia it was found that almost all stations in the eastern region showed a decreasing trend in the frequency of extreme rainfall during the southwest monsoon period. However, the western region shows the opposite result, namely an increasing trend (Suhaila et al., 2010). Manton et al. [2001] found a different trend when examining extreme rainfall events in the Asia Pacific region. An increasing trend was seen in Fiji and French Polynesia. However, Solomon Island, Fiji, New Zealand, Malaysia and Japan showed a decreasing trend. Other countries did not even show a significant trend. For Indonesia, they concluded that the trend of extreme rainfall events is not significant. Unfortunately, they only used six rain stations namely Pangkalpinang, Jakarta, Balikpapan, Manado, Ambon and Palu which of course is not enough to describe climate conditions throughout Indonesia.

The positive trend of extreme climate events has encouraged the development of research on extreme weather or climate events. The Commission for Climatology (CCl)/World Climate Research Programme (WCRP), Climate Variability and Predict-ability (CLIVAR) project's Expert Team on Climate Change Detection and Indices (ETCCDI), an international organization, has developed 27 extreme climate indices based on daily rainfall and temperature data. The extreme climate indices consist of 11 extreme indices for rainfall and 16 extreme indices for air temperature (Dos-Santos at al., 2010).

There have been many studies using climate indices for extreme event analysis, including Klein Tank and Konnen (2003) analyzing trends in rainfall and extreme temperatures in Europe, Brown et al. (2010) studied climate change using climate indices in the northeastern United States 1870-2005, Zhang et al. (2011) used climate indices to monitor extreme changes based on rainfall and temperature data, Yin and Sun (2018) used extreme climate indices to characterize extreme temperatures and precipitation in China, Klein-Tank et al. (2006) analyzed changes in temperature and extreme rainfall in Central Asia and South Asia in the period 1961-2000 and 1901-2000 using the extreme climate index. This study aimed: (1) to examine the trend of extreme rainfall events in North Sumatra for the period 1991-2020 based on the extreme index for rainfall developed by ETCCDMI using the Mann-Kendall method, and (2) to analyze changes in rainfall conditions in North Sumatra in the 30-year period. The results of this study are expected to provide information on areas that have a tendency to experience extreme rainfall and can be used as information for early warning in the face of extreme events so as to minimize the losses caused by these extreme events.

METHOD

The data used in this study are daily observational rainfall data from the Meteorology Climatology and Geophysics Agency spread across North Sumatra. The rainfall data is the result of observations from 50 rainfall observation stations spread across North Sumatra in the 30-year time period, namely 1991-2020, where the data has been tested for data quality. Digital Elevation Model (DEM) in the research area obtained from The Shuttle Radar Topography Mission (SRTM) at https://earthexplorer.usgs.gov/, is used as supporting data in this study for spatial pattern analysis of the extreme index. Testing data quality is important when analyzing time series data. To guarantee data that is ready for analysis, the blank observation data allowed for analysis is 10% (Ngongondo at all., 2011).

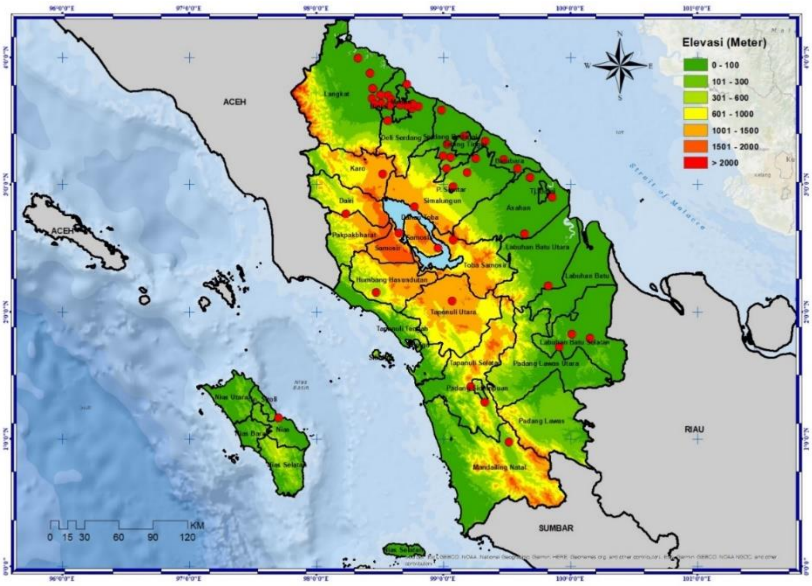

Figure 1. Spatial Map of Rainfall Monitoring Locations Scattered in North Sumatra

Referring to the research by Hernandez et al. (2009) and WMO guidelines (2009), the analysis of extreme rainfall events is expressed by several indices that are widely used to describe extreme weather events. The indices are calculated as annual values for each station. A limit of 1 mm is used to define a rainy day (WMO, 2009; Bodini & Cossu, 2010]. Indices are generally grouped into three categories, namely frequency, intensity and proportion indicators, but only frequency and intensity indicators are used in this study. The determination of the threshold for the 1-year return period was done by sorting the daily rainfall from the largest observation to the smallest. The thirty largest daily rainfall data in the period 1991-2020 were extracted and the smallest of these 30 data was selected as the threshold (Supari et al., 2012)

Table 2. Detail extreme rainfall indices which are used in the study

N	INDEX	DESCRIPTION
Frequency Indicator [adapted from Hernandez et al. 2009; WMO, 2009; BMKG,]		
1	***R20mm***	Number of rainy days with rainfall greater than or equal to 20 mm (moderate rainy days)
2	***R50mm***	Number of rainy days with rainfall greater than or equal to 50 mm (heavy rainfall days)
3	***R90p***	Number of rainy days with rainfall greater than or equal to the 90th percentile
4	***CWD***	Consecutive wet days; maximum length of wet days
Intensity Indicator [Adapted from WMO, 2009]		
5	***RX1d***	Maximum daily rainfall

N	INDEX	DESCRIPTION
6	***RX5d***	Cumulative maximum rainfall of 5 consecutive rainy days
7	***RTOT***	Annual rainfall amount
8	***SDII***	Total annual rainfall divided by the number of rainy days

Sumber: dos Santos, dkk (2010)

Point pattern analysis was chosen as a method to explain the spatial characteristics of extreme rainfall, because rain gauges with high-quality data are not proportionally distributed. The purpose of point pattern analysis is to analyze the geometric structure of patterns formed by randomly distributed objects in one-, two-, or three-dimensional space. Variables are displayed in thematic maps with points and marks. The dot describes the location of the object, while the mark provides additional information, i.e. further characteristics of the object, for example through its type, size, or shape. In this study, the threshold magnitude and trend of the extreme index are mapped at the point where the rain gauge is located. Applications of point pattern analysis in studying extreme rainfall can be found in Kunkel et al. (1999) and Fu et al. (2010).

The trend value of the index is known from the calculation of the slope using the Least Square method, where the value is considered as the average increase or decrease that occurred in variable y (extreme climate index) in the 1991-2020 period. Mathematically, the Least Square method generates a regression through a series of data points. The Least Square method aims to obtain regression coefficients a and b, which make the sum of squared errors as small as possible (Ariantono, 2015). The linear regression equation is as follows.

$$y_i = a + bx_i$$

Where:
x_i = independent variable
y_i = dependent variable
a = the average value in variable y if variable x is 0
b = regression coefficient (slope) of variable x

This calculation was done using the R-Climdex application (downloadable at www.r-project.org). Furthermore, the trend was tested for confidence using the Mann-Kendall test. This method is commonly used to detect trends for data series that are often not normally distributed. WMO also recommends this method for testing trends in climatological data (WMO, 2000). The procedure for Mann-Kendall analysis quoted by HydroGeoLogic, Inc (2005), is as follows.

1. Calculating *Mann-Kendall Statistic*
   The initial value of the Mann-Kendall statistic (S) is assumed to be 0 (i.e. no trend). If the data value of the next time period is higher than the data value of the previous time period, S is increased by 1. Conversely, if the data value of the next time period is lower than the data value of the previous period, S is decreased by 1. The results of all stages produce the final value of S. The formula for calculating S is:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

   Where :

$$sign(x_j - x_k) = \begin{cases} 1, if\,(x_j - x_k) > 0 \\ 0, if\,(x_j - x_k) = 0 \\ -1, if\,(x_j - x_k) < 0 \end{cases}$$

2. Calculate the normalization z statistic test as follows:

$$sign(x_j - x_k) = \begin{cases} \dfrac{s-1}{\sqrt{Var(s)}}, if\ S > 0 \\ 0 \qquad\quad\ , if\ S = 0 \\ \dfrac{s+1}{\sqrt{Var(s)}}, if\ S < 0 \end{cases}$$

3. Calculate the probability associated with this statistical test of normalization, expressed as p-value. The probability density function for a normal distribution with mean 0 and standard deviation 1 is given by the following equation.

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}$$

$$p - value = 1 - f(z)$$

4. Determine the significance level (alpha = *5%*).

Conclusions about trends are determined using criteria, i.e. a trend is said to decrease if Z is negative and is said to increase if Z is positive. The trend is statistically significant if the p-value is less than alpha, otherwise it means that the trend is not significant or there is no trend.

RESULTS AND DISCUSSION

Spatial Characteristics of Extreme Rainfall Events

The extreme threshold calculation based on the 90th percentile in North Sumatra varies from 25 mm to 50 mm. The minimum value is found at Bantun Kerbo (ID:25), while the maximum value is found at Tandem (ID:46). Threshold values for the 1-year return period show varying values with a range of 60 mm to 185 mm, where the minimum value is found at Bantun Kerbo (ID:25) and the maximum value is found at Tiga Panah (ID:69).

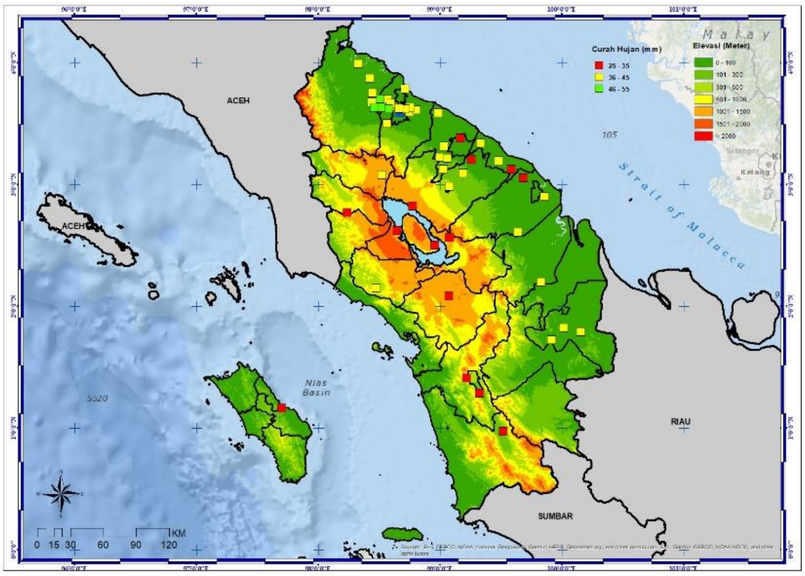

Figure 2. Spatial Distribution Map of Thresholds Based on 90th Percentile in North Sumatra

The spatial distribution of thresholds based on the 90th percentile is shown in Figure 2. On the East coast of North Sumatra and the eastern slope, thresholds are dominated by values in the range of 36-45 mm. Meanwhile, thresholds with values of 25-35 mm were found to dominate in the central region of North Sumatra and some posts in other regions, namely in Nias Islands, Tebing Tinggi, Simalungun, Batubara and Asahan. Other threshold values in the 46-55 mm range were found in the Deli Serdang and Langkat districts. Spatially, it can be seen that the threshold based on the 90th percentile is lower in mountainous areas compared to coastal areas.

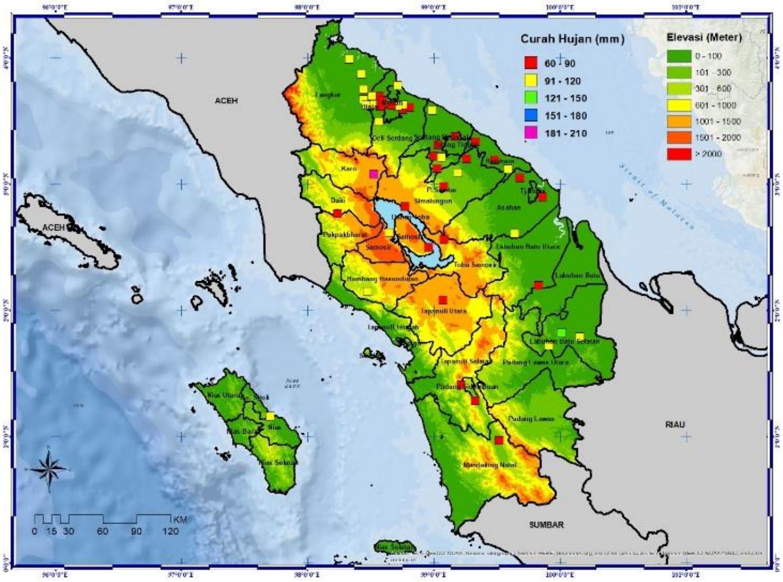

Figure 3. Threshold Spatial Distribution Map Based on 1-Year Return Period

Figure 3 shows the spatial distribution of thresholds for the 1-year return period. In general, the spatial distribution of thresholds for a 1-year return period is in the range of 60-90 mm. The threshold value is 91-120 mm, found in Langkat and Deli Serdang districts. Spatially there is no clear difference in the threshold of one-year return period in the study area.

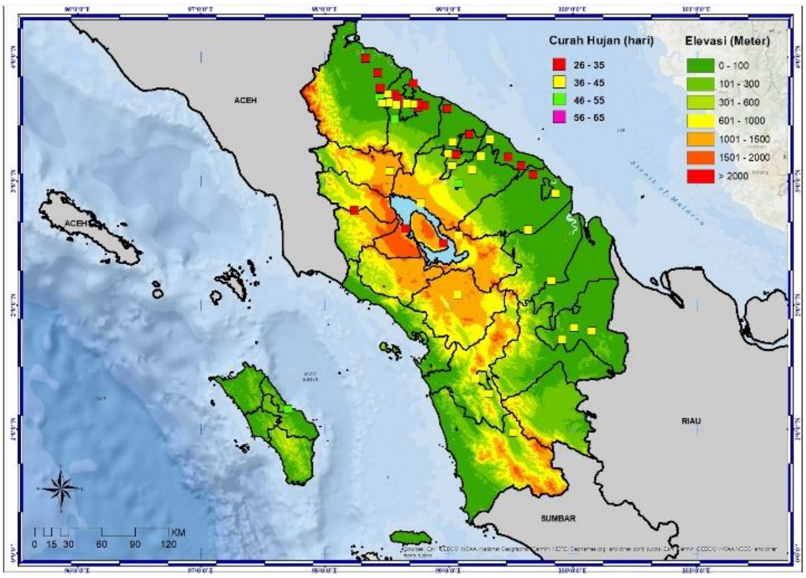

Figure 4. Annual frequency of daily rainfall events exceeding 20 mm

Figure 4 shows the frequency distribution of rainy days with rainfall greater than or equal to 20 mm (R20mm). In the study area the frequency of rainy days with rainfall greater than or equal to 20 mm (R20mm) varies in the range of 26-60 days per year. Rainfall stations/posts with a frequency of 26-35 days per year are generally found on the East Coast of North Sumatra. For other areas on the eastern slope of the province, intermediate frequencies with a range of 36-45 occurrences per year are dominant. There are several posts in the central part of the province that have a frequency of 26-35 days per year such as the Daily Post (ID:160), Onan Runggu Post (ID:162), and Bantun Kerbo Post (ID:25). Spatially there is no clear difference in the frequency of rainfall more than or equal to 20 mm in North Sumatra.

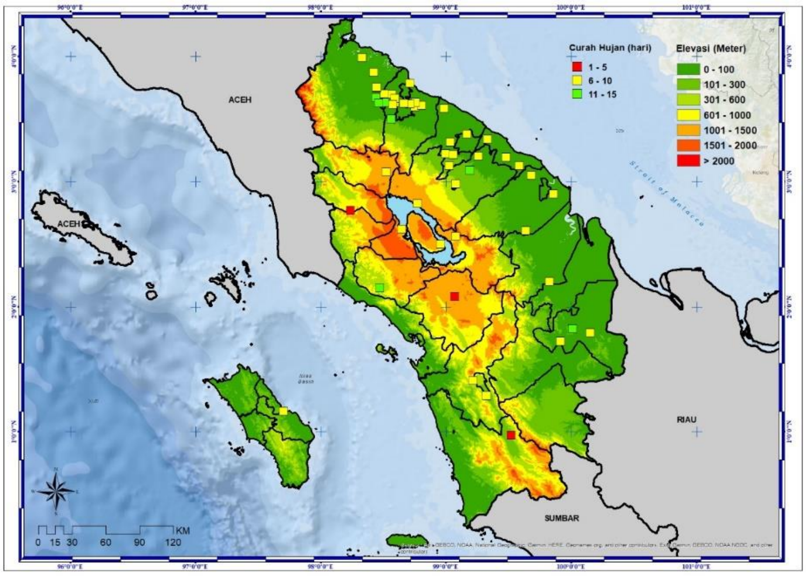

Figure 5. Annual frequency of daily rainfall events exceeding 50 mm (R50)

Figure 5 shows the average frequency of rainy days greater than or equal to 50mm. The frequency of rainy days more than or equal to 50mm with a range of 6-10 days per year dominates in the North Sumatra region. There are only 3 posts that show a frequency of 1-5 rainy days, namely at the Bantun Kerbo post (ID: 25), Sipahutar (ID: 227), and Bange (134). The areas that have a frequency of 11-15 days of rainfall per year are found in the Langkat Regency area. Spatially, it can be seen that the frequency of rainy days greater than or equal to 50 mm increases with altitude.

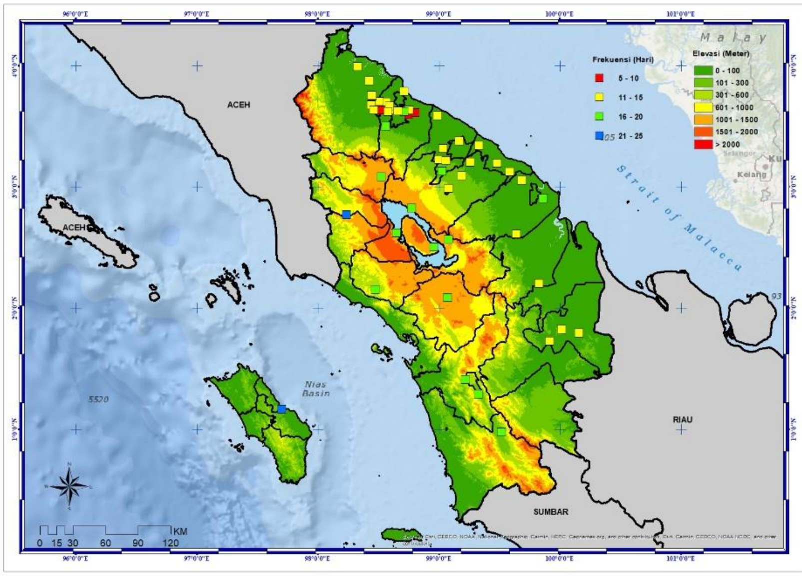

Figure 6. Average Frequency of Rainy Days, with CH ≥ Percentil to 90 mm

The spatial distribution of the average frequency of rainy days with rainfall greater than or equal to the 90th percentile is shown in Figure 7. The east coast appears to have a frequency of rainy days in the range of 11-15 rainy days per year while the mountainous areas have a higher frequency of rainy days in the range of 16-20 rainy days per year. Spatially, the frequency of rainy days greater than the 90th percentile increases with altitude.

Temporal Occurrence of Extreme Rainfall

The temporal trend of the index was assessed using RClimdex 1.0, an RClimDex developed and maintained by Xuebin Zhang and Feng Yang at the Climate Research Branch of the Canadian Meteorological Service. The software provides a Mann-Kendal test to check the trend of the tested series and a slope estimator estimates the magnitude of the trend slope. The significance level (α) was chosen at 5%.

The results of the trend assessment of the number of daily rainfall events exceeding 50 mm (heavy rainfall events) showed that 20 rain observation stations tested showed a negative trend of which 2 were statistically significant. A total of 30 stations showed a positive trend of which 7 were statistically significant.

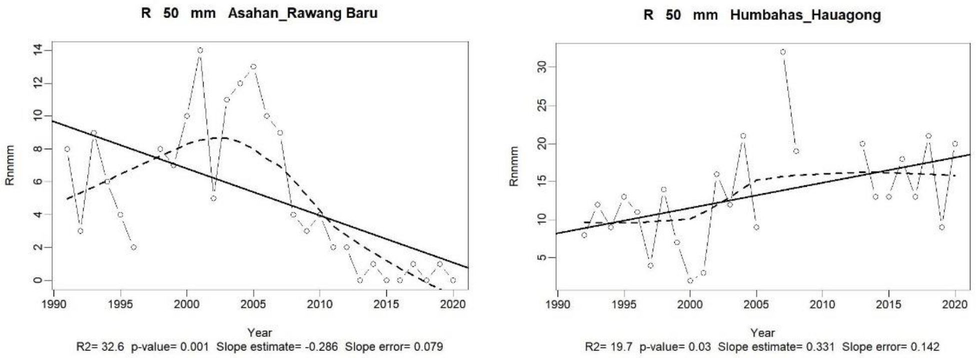

Figure 7. Scatter plot of index R50mm at Station Rawang Baru-left and Huagong-right

The trend assessment for total annual rainfall shows that 18 stations experienced a significant decrease (increase). The total decreasing series both significant and insignificant are 17 stations, while the total increasing series are 33 stations. Examples of trends detected in annual rainfall are shown in Figure 08. A significant upward trend was detected at Bangun Station, Pematang Siantar City while a significant downward trend was found at Tanjung Leidong Station, Labuhan Batu Utara. The gradient of the linear line indicates the magnitude of the temporal change.

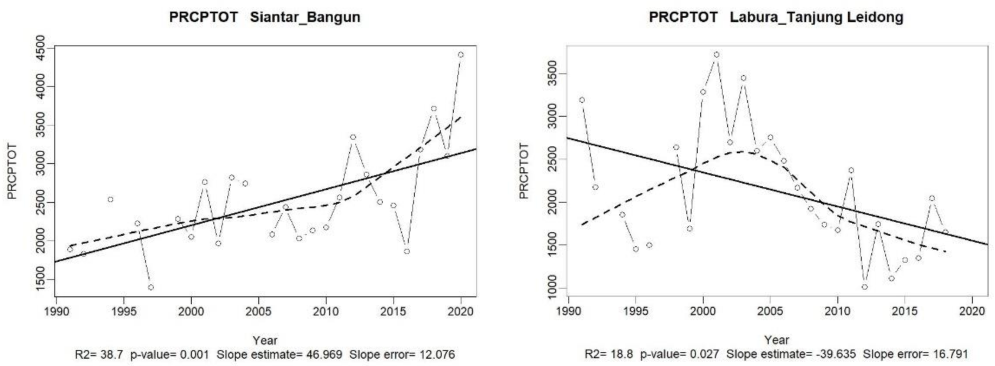

Figure 8 . Temporal change of annual rainfall at Station Bangun, left and Tj Leidong, right

Table 1. Summary of trend assessment for all frequency indicators presented as number of station. Sig. = significant

Index	Decrease			Increase			No Trend
	Not Sig.	Sig.	Total(%)	Not Sig.	Sig	Total(%)	
R20	16	2	36	20	12	64	0
R50	18	2	40	23	3	60	0

R90p	11	3	28	28	7	70	1
CWD	18	4	44	25	1	52	2

A summary of the ratings for all intensity indicators, RX1d, RX5d, RTOT and SDII is shown in Table 2. Similar to the frequency indicators, a non-significant trend was the dominant finding for all intensity indicator indices.

Table 2. Summary of trend assessment for all intensity indicators presented as number of station. Sig. = significant

Index	Decrease			Increase			No Trend
	Not Sig.	Sig.	Total(%)	Not Sig.	Sig	Total(%)	
RX1d	18	4	40	27	1	60	0
RX5d	20	2	44	24	4	56	0
RTOT	13	4	34	19	14	66	0
SDII	14	7	42	17	12	58	0

Spatial Patterns of Detected Trends

The purpose of analyzing the spatial pattern of detected trends is to identify regions where coherent trends are located. The spatial pattern of detected trends for the R20mm index is shown in Figure 10. A cluster of increasing trends (round legend) is seen in the eastern part of the study area especially on the east coast. This area is a highly populated area in deli Serdang district, medan city and binjai city. The area on the eastern slope has a significant increasing trend and the highest is located in Bangun post (ID:159). In the mountainous region there is no significant trend, either a decreasing or increasing trend.

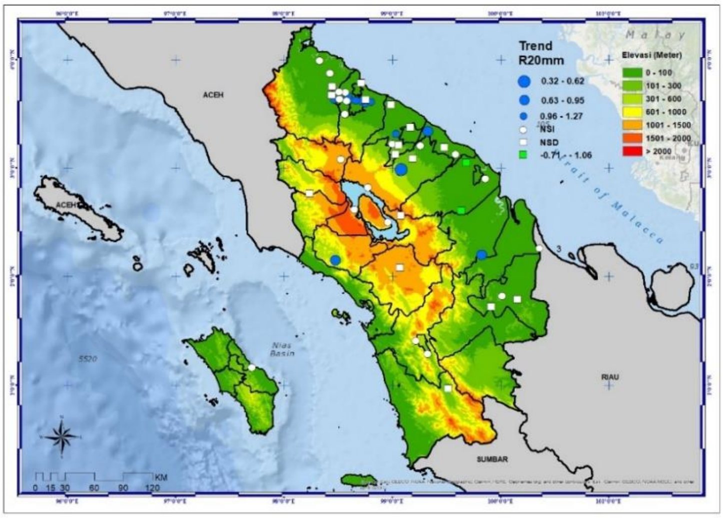

Figure 9. Trend of daily rainfall events exceeding 20 mm. Circle refers to positive trend, square to negative trend. Blue and green legend corresponds to significant trend. Magnitude is given in “events/decade”. NSI = Not Significant Increasing, NT = No Trend and NSD = Not Significant Decreasing

Analysis of the R50mm, R90p and CWD indices shows that the negative and positive trends of the frequency indicators are generally randomly distributed. Annual rainfall is seen to increase in most of the east coast (see Figure 11), especially in the districts of Deli Serdang, Langkat and Medan City. However, the number of stations showing an insignificant trend is much greater than those showing a significant trend. The areas with statistically significant decreasing trends occurred in 4 observation posts, namely Asahan district (Rawang), South Labuhan Baru district (Aek Torop and Tanjung Leidong), and North Tapanuli district (Sipahutar). No significant increasing or decreasing trends were observed in the central region of the study area.

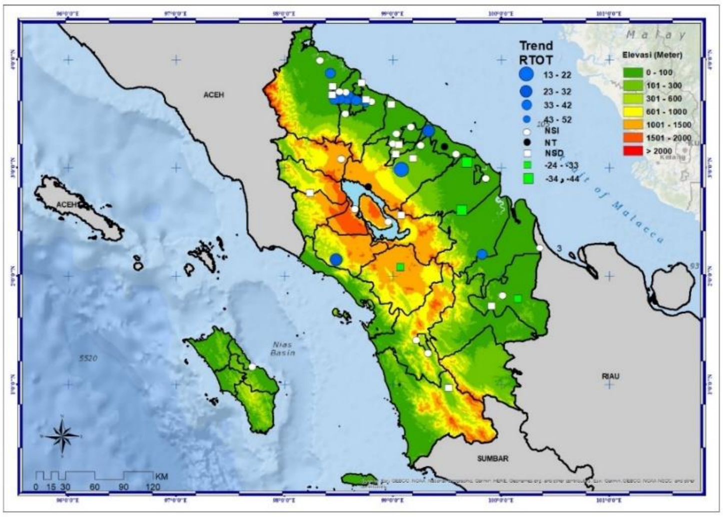

Figure 10. Similar to Figure 9 but for total annual rainfall. Magnitudes are given in "mm/year"

Analysis of daily rainfall observations over the period 1991-2020 in North Sumatra Province shows that the general characteristics of extreme rainfall events can be recognized. The relationship between the fixed threshold and the site-specific threshold of extreme rainfall events used in this study has been detected. By comparing the fixed threshold and the site-specific threshold, it shows that the fixed threshold of 50 mm developed by BMKG may be related to events with a return period of 1 year. For this return period, the average daily rainfall is about 50 mm in the study area. Thus, the 50 mm threshold is reasonable enough to describe the frequency of extreme events that generally occur infrequently.

Table 3. Contingency table showing inter-index relation (R20mm and R50mm) given in the number of gauge. NSD = not sig. decrease, NSI = not sig. increase and, NT = no trend

		Rainfall≥50 mm					
		NSD	*SD*	*NSI*	*SI*	*NT*	*TOTAL*
Rainfall≥20 mm	*NSD*	12	0	4	0	0	16
	SD	1	1	0	0	0	2
	NSI	4	1	12	3	0	20
	SI	1	0	7	4	0	12
	NT	0	0	0	0	0	0
	Total	18	2	23	7	0	50

Based on the summary of the trend assessment for each station given in Table 4, the trend assessment also successfully detected stations with significant and consistent trends for at least two extreme indices. These consistent trends were observed for both significant positive trends and significant negative trends. The stations that showed a significant and consistent increasing trend were Sei Suka Deras (Batubara, ID:17), Bandar Klippa (Deli Serdang, ID:32), Klambir Lima (Deli Serdang, ID:37), Klumpang (Deli Serdang, ID:38), Staklim Deli Serdang (Deli Serdang, ID: 44), Tandem (Deli Serdang, ID:46), Pakkat (Humbahas, ID54), Lobu Rampah (Labura, ID:100), Kwala Bingei (Langkat, ID:115), Tanjung Jati (Langkat, ID:130), Helvetia (Medan, ID:140), Bangun (Pematang Siantar, ID:159), and Bangun Bandar (Serdang Bedagai, ID:170). Details of the extreme indices whose trend assessment shows a significant positive trend can be seen in Table 4.

Table 4. List of stations which are consistently increasing. Sig. = Significant positive

ID	Gauge	R20mm	R50mm	R90p	CWD	RX1day	RX5day	SDII	RTOT
17	Sei Suka Deras	Sig.	-	-	-	-	Sig.	Sig.	Sig.
32	Bandar Klippa	Sig.	-	-	-	-	-	-	Sig.

ID	Gauge	R20mm	R50mm	R90p	CWD	RX1day	RX5day	SDII	RTOT
37	Klambir Lima	Sig.	Sig.	-	-	Sig.	Sig.	Sig.	Sig.
38	Klumpang	Sig.	Sig.	-	-			Sig.	Sig.
44	Staklim Sumatera Utara	Sig.	-	-	-	-	Sig.	Sig.	Sig.
46	Tandem	-	Sig.	Sig.	-	-	-	-	Sig.
54	Pakkat	Sig.	Sig.	-	-	-	-	-	Sig.
100	Lobu Rampah	Sig.	Sig.	-	-	-	-	Sig.	Sig.
115	Kwala Bingei	-	Sig.	-	-	-	-	-	Sig.
130	Tanjung Jati	Sig.	-	-	-	-	-	Sig.	Sig.
140	Helvetia	Sig.	-	-	-	-	-	Sig.	Sig.
159	Bangun	Sig.	-	Sig.	-	-	-	-	Sig.
170	Bangun Bandar	Sig.	-	-	-	-	-	Sig.	-

For a consistently significant downward trend, this study identified 5 rainfall stations namely Rawang Baru (Asahan, ID:8), Bandar Betsy (Simalungun, ID:188), Laras Empl (Simalungun, ID:192), Sipahutar (North Tapanuli, ID:227), and Tanjung Leidong (Labura, ID:103).

Table 5. List of stations which are consistently decreasing. Sig. = Significant negative

ID	Gauge	R20mm	R50mm	R90p	CWD	RX1day	RX5day	SDII	RTOT
8	Rawang Baru	Sig.	Sig.	-	-	Sig.	Sig.	Sig.	Sig.
188	Bandar Betsy	-	Sig.	-	-	Sig.	-	-	-
192	Laras Emplasmen	-	-	-	-	Sig.	-	Sig.	-
227	Sipahutar	-	-	-	Sig.	Sig.	Sig.	-	Sig.
103	Tanjung Leidong	Sig.	-	-	Sig.	-	-	-	Sig.

The spatial distribution of the stations showing consistent trends is presented in Figure 11. Consistent negative trends are seen in Asahan, North Tapanuli, and North Labuhan Batu districts. No significant positive trends were found in these districts. This could pose a serious problem in the future in terms of drought probability, especially in Asahan where at least 6 indices showed a significant decrease. While a significant positive trend was found for at least 6 indices found in Deli Serdang namely at the Klambir Lima rain station and 4 other stations showed a significant positive trend. This could potentially lead to a high risk of hydrometeorological disasters for the area. For Medan City, flooding may be a serious threat as Medan City is a densely populated urban area and most of the area is surrounded by Deli Serdang Regency. As for Humbahas, the consistently significant positive trend may lead to a high frequency of landslides as the area is located in the Mountains.

In general, for both frequency and intensity indicators, insignificant trends are the dominant temporal changes. Only a few stations show significant trends. This finding is consistent with the study of extreme rainfall events conducted by Supari, [2012] on Java Island. They found that only a few stations showed significant trends while the dominant ones were insignificant trends. By taking a location in the Java Island region, this study confirms that the trend of extreme rainfall events in this region is not very clear. The current study also agrees with the study of Manton et al, (2001) who examined trends in the Asia Pacific region. They found that the extreme rainfall index showed less spatial consistency in the region studied.

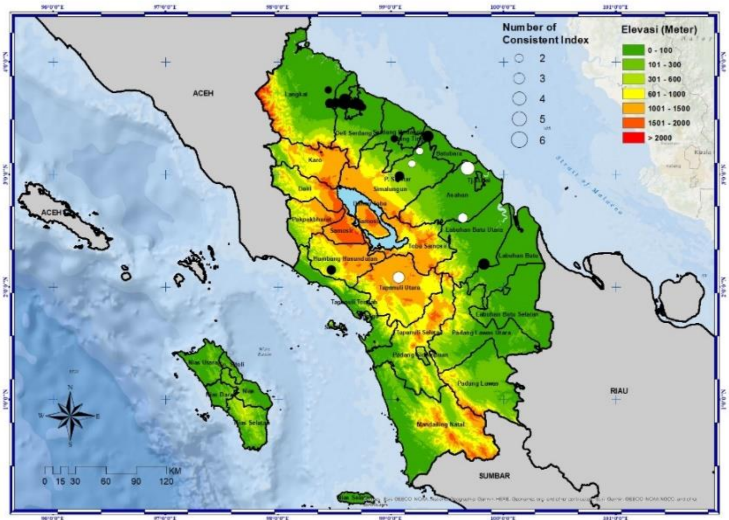

Figure 11. Stations showing consistent trend. Open circles symbolize negative trend, filled circles for positive trend

Areas that have more severe extreme rainfall should be prioritized to minimize risks such as Pakkat blood of Humbahas Regency which has a diverse topography making the area prone to landslides. For Medan City (Helvetia Station), this condition can be serious because the trend is detected to increase significantly considering that it is also located directly adjacent to Deli Serdang Regency which can cause water delivery from areas where rainfall is significantly increased. Then, the Asahan area, which has a significant trend of rainfall decreasing throughout the year, requires anticipation of future preparations so that the impact of drought can be anticipated.

CONCLUSION

Some of the usual findings can be summarized from this research as follows: (1) Spatially, it can be seen that the threshold based on the 90th percentile is lower in mountainous areas compared to coastal areas; (2) Spatially, there is no obvious difference in the threshold of one-year return period in the study area; (3) Spatially there is no clear difference in the frequency of rainfall more than or equal to 20 mm in North Sumatra; (4) Spatially visible areas of rainy day frequency greater than or equal to 50 mm increase with altitude; (4) Spatially, it is seen that the frequency of rainy days greater than the 90th percentile increases as the altitude of the place increases; (5) The spatial pattern of extreme rainfall events in North Sumatra Province for both frequency and intensity indicators is not clearly visible between mountainous areas and coastal areas; (6) In general, the trend of extreme rainfall events detected from this study is dominated by insignificant trends. However, some areas with consistently significant trends can be recognized. On the east coast, significant postive trends were consistently found in Deli Serdang, Medan City, Langkat, Batubara, Labuhan Batu Utara and Serdang Bedagai districts. The same was also found in Humbahas District, in Pakkat, the Central part of the province. On the other hand, significant negative trends were consistently seen in Asahan and North Tapanuli. In Simalungun Regency, a consistently significant positive trend was identified along with a consistently significant negative trend.

RECOMMENDATION

Based on the limitations of the study, the following recommendations are formulated for further assessment of extreme rainfall: (1) Because the number of rainfall observation stations in North Sumatra that have empty data is too much, finding other more complete data sources is needed so that the resulting trend is even more accurate; (2) The need for additional rainfall observations especially in mountainous areas and the west coast. So that in the future it can be clearly seen the spatial pattern of extreme rainfall in North Sumatra; (3) The use of rainfall data from satellites needs to be an option in examining the characteristics of extreme rainfall in North Sumatra considering the quantity of good observation data is not much.

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