SPATIAL-TEMPORAL TREND ANALYSIS OF RAINFALL EROSIVITY AND EROSIVITY DENSITY OF TROPICAL AREA IN AIR BENGKULU WATERSHED, INDONESIA

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Abstract: There have been many studies on rainfall erosivity and erosivity density (ED). However, it was not widely developed in Indonesia as a tropical country and has unique precipitation patterns. They are indicators for assessing the potential risk of soil erosion. The Air Bengkulu Watershed is undergoing severe land degradation due to soil erosion. This study aimed to analyze spatial-temporal in rainfall erosivity and ED based on monthly rainfall data (mm). The data used consisted of 19 weather stations during the period 2006–2020 and which are sparsely distributed over the watershed. The analysis was done by using Arnold's equation. Then, the trend was tested using parametric and non-parametric statistics, and analysed with linear regression equation, and Spearman's Rho and Mann Kendall's tests. The spatial distribution of both algorithms was analysed using the inverse distance weighted (IDW) method based on the geographic information system (GIS). Unlike previous research findings, The long-term average monthly rainfall erosivity and ED revealed a general increase and decreasing trend, whereas it was found to be non-significant when both indices were observed. However, these results indicate a range from 840.94 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1}, 552.42 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1} to 472.09 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1} in that November month followed by December and April are the most susceptible months for soil erosion. Therefore, The upstream area of the region shows that various anthropogenic activities must be managed properly by taking into account the rainfall erosivity on the environment and that more stringent measures should be followed in soil and water conservation activities.

Keywords: erosivity, IDW, tropical, watershed

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Introduction

In most areas of the world, the current watershed conditions are deteriorating. Population density around it grows faces an excellent weight, as does the extensive use or exploitation of natural resources causing the watershed's condition to deteriorate. The Air Bengkulu watershed acts as a catchment area to support community life in Bengkulu Tengah Regency and Bengkulu City, Indonesia. However, based on data from the Center for Watershed Management and Protected Forests (WMPF) Ketahun revealed damage to the watershed with an area of 626,000 ha of critical land and 99,000 ha of very critical land (Satmaidi et al. 2018). This impacts the ability of watersheds

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to store water and increases the volume of water resulting in floods and landslides every year (Mase 2020). Then, the community complained about the poor water quality and relatively small quantity, with Total Suspended Solid (TSS) levels exceeding the quality standard (50 mm · dm^{-3}), namely 219.20 mm · dm^{-3} (dry season) and 175.75 mm · dm^{-3} (rainy season) (Supriyono, Utaya 2019). High rainfall at the study site causes soil erosion with surface runoff which triggers flood disasters (Ma et al. 2020) and decreases water quality (Mahmud et al. 2019). This is due to the conversion of forest areas for mining and plantation activities upstream of the Air Bengkulu watershed (Gunawan et al. 2020).

The importance of erosion assessment as an indicator parameter for critical land requires a complex analysis. However, it can be identified by conducting rainfall erosivity and erosivity density (ED) tests. The rainfall erosivity indicator is a multi-annual average index that assesses the effects of rainfall on sheet and rill erosion by measuring the kinetic energy and intensity of precipitation. It can be investigated using rainfall data (Zokaib, Naser 2011). However, the estimation of rainfall erosivity is constrained in most soil erosion research due to a lack of long-term time series rainfall data with sufficient temporal precision (<60 min). Equations have been created to predict rainfall erosivity based on rainfall data with a lower temporal resolution using the second approach (also known as the empirical approach).

Monthly rainfall data provided information on rainfall patterns related to climate change and the potential risk of soil erosion on land changes and land use (Ma et al. 2014). The amount of rainfall determines the strength of the rain dispersion on the soil, the strength of the surface runoff, and the level of erosion damage that occurs (Arsyad 2012). Research conducted by Hudson (1976), Wischmeier and Smith (1978) shows that rainfall erosivity is an interaction between storm's total kinetic energy (E) and its maximum 30-min rainfall intensity (I_{30}) and soil surface, showing the potential ability of rain intensity to cause soil erosion and destruction of soil aggregates. The strength of soil crushing energy influences the kinetic energy on the size of the raindrops and the speed at which the rain falls to the ground (Wild 1985, Godone, Stanchi 2011, Morgan, Nearing 2011).

Literature review

A discourse analysis of several studies based on the research location for a contrastive study of rainfall erosivity and ED has been carried out. Erosivity modelling of annual precipitation in Europe is presented on a regional scale to analyze soil loss and soil erosion (Panagos et al. 2017). Furthermore, the spatial distribution of rainfall erosivity trends shows an increasing trend of rainfall erosivity from winter to summer in Western to Eastern Europe (Ballabio et al. 2017). Subsequent research also highlighted that the monthly rainfall erosivity map that depicts the spatial and temporal variability could explain the concentration of erosive events and identify the monthly periods to assess soil loss and conservation action measures (Diodato, Bellocchi 2012).

Research on the Himalayan watersheds in Asia shows that the study of rainfall erosivity uses parametric statistics with correlation and linear regression for trend assessment. The study results of this research on rainfall erosivity with annual rainfall have a moderate to a strong relationship, and there is an insignificant increasing or decreasing trend (Ma et al. 2014). However, according to Singh and Singh (2020), these findings show that July is the most vulnerable month for soil erosion in the Suketi River watershed, the Himalayan followed by August and June, and the lower reaches (Northern) being the most vulnerable. Then, research in the Baram River in Sarawak (Malaysian, Borneo) by Vijith and Dodge-Wan (2019) explained that the spatial pattern of rainfall erosivity trends approaches with statistical parametric and nonparametric (linear regression, Superman's Rho, and Mann Kendall). The highest observed has an increasing trend in the Northern Zone and a decreasing trend in the Southern Zone. However, the Baram River in Sarawak research is limited to the spatial distribution of rainfall erosivity and ED based on seasons and years.

Since 1974, Indonesia has been conducting experiments to study rainfall parameters with soil erosion for land criticality assessments. It is found that the rainfall intensity value of 30 min is a show of kinetic energy from the rainfall erosivity map for the island of Java, Indonesia (Asdak 2014). This value would certainly not be appropriate if it is applied to all Provinces in Indonesia. The importance of this research is because Indonesia ranks third in the world for critical watershed land conditions (Asdak 2014). Furthermore, research in the Merawu watershed, Central Java, Indonesia, highlighted that the different equations of rainfall erosivity models could explain actual erosion with an accuracy of 81.13% (Sulistyo 2011).

Erosion research at the study site found that the period of soil erosion occurred. The highest surface erosion rate of the Air Bengkulu watershed occurred in February (0.421 mm $\cdot$ month^{-1}) and the smallest in September (0.023 mm $\cdot$ month^{-1}) (Tunas 2005). This is exacerbated by the damage to the watershed that occurs due to coal mining activities accompanied by changes in the function and designation of Protected Forests in the upstream part of the Air Bengkulu watershed into Permanent Production Forests (Satmaidi et al. 2018). Then the discussion in the downstream watershed stated that there had been erosion and sedimentation in general, which if not handled can experience inundation due to extensive floods, such as the Bengkulu City flood in 2019 (Mase 2020).

Although there has been researched on the potential for erosion with rainfall erosivity based on the research location regionally and the watershed discussed above, several literature studies that have described the assessment of rainfall erosivity are presented with trend analysis and spatial-temporal distribution on an annual, seasonal and monthly basis. However, there is no current comparative research on the development of soil erosion, especially regarding the erosivity approach of monthly rainfall erosivity in the watershed which is tropical Indonesia. This is because the dynamics of the atmosphere are influenced by rainfall caused by trade winds, monsoon winds, and the influence of various local conditions (Eddy, Lestari 2007).

The Air Bengkulu watershed has changed dramatically in recent years due to the rapid expansion in coal mining activities, intensive agricultural practices with sharp increases. In addition, the soil has been exacerbated by tracks, paths and poor access for coal truck mobilisation as the impact of soil compaction because the presence of the trail will have a much greater impact on increasing water flow. Forests continue to be cut down for agricultural activities and infrastructure development and the expansion of mining areas. These anthropogenic activities greatly influenced the rate of soil erosion along with natural agents such as topography, slope, amount, duration, and intensity of rainfall, soil types, geological formations, and types of land use. Based on these observations, areas prone to soil erosion in the fragile Air Bengkulu watershed need to be studied.

Therefore, it is essential to study the spatial-temporal trends of the monthly rainfall erosivity. Because during the last decade, no research on the potential for soil erosion has been carried out in the Air Bengkulu watershed based on rainfall erosivity. This is done to analyse the monthly erosive period for spatial distribution rainfall erosivity and ED and to improve our understanding of the evolution of rainfall erosivity in the Air Bengkulu watershed, particularly concerning rainfall events.

Objective

The main objective of this study was to assess the rainfall erosivity of precipitation and moreover detailed studies on the distribution of spatial and temporal rainfall erosivity and monthly erosivity in Indonesia in general and the Air Bengkulu watershed, in particular, are lacking. The followings are questions as guidelines to achieve the goal:

- How is the rainfall erosivity based on the monthly rainfall data in the Air Bengkulu watershed?
- What is the trend of the rainfall erosivity based on the weather station in the Air Bengkulu watershed?
- What is the spatial distribution based on the monthly rainfall erosivity data in the Air Bengkulu watershed?
- What are the trends and spatial distribution based on the monthly ED data of the Air Bengkulu watershed?

Materials and methods

Study area Air Bengkulu watershed

The Air Bengkulu watershed astronomical location stretches between longitudes 102°14'48.962" to 102°35'5.992" East, and between latitudes 3°37'8.705" to 3°50'30.802" South. The distribution of annual rainfall between 2900 and 3600 mm can be seen in Figure 1. The rainfall occurs throughout the year and is based on climate classification classified as climate type A (Wet Tropical) with a humidity of 70–87% (Case et al. 2007). The mean annual temperature is 25–32°C with monthly rainfall 230–620 mm, and the number of rainy days ranges from 10 to 23 days. Geographically, the Air Bengkulu watershed is located in Bengkulu Province, precisely on the west coast of Sumatra Island, Indonesia. Administratively, Central Bengkulu Regency and Bengkulu City have an area of 50,049 ha (Sulistyo et al. 2020). The watershed consists of three sub-watersheds, namely Susup River, Rindu Hati River, and Bengkulu River (Supriyono, Yanmesli 2016). Topographically, it is located on hills with a steep slope approaching the summit. The upstream of the Air Bengkulu watershed occupies the Western side of the Bukit Barisan which stretches from the Northern tip to the south of the island of Sumatra. Meanwhile, the downstream is a plain area directly opposite the Indian Ocean.

Data sources

In this study, the monthly rainfall data for the recording period from 2006 to 2020 were retrieved from 19 weather stations in the Air Bengkulu watershed. Monthly rainfall is the amount of daily rainfall in 1 month of observation at a specific weather station. Monthly temporal rainfall is obtained from data provided by the Class I BMKG Station in Pulau Baai Bengkulu. The data variation of each weather station shows the monthly rainfall measurement period, presented in Table 1. Data analysis of rainfall calculations was carried out using the Microsoft Excel program. Then, the data is processed to obtain the monthly rainfall erosivity value, statistical trends and mapped with a geographic information system (GIS).

Based on the average of 19 weather stations, the highest rainfall in the Air Bengkulu watershed in November is presented in Figure 2. Above-average monthly rainfall data is shown in November, December, and April (NDA), namely the average rainfall 352.60–432.42 mm. The sea surface temperature influences this in the tropics

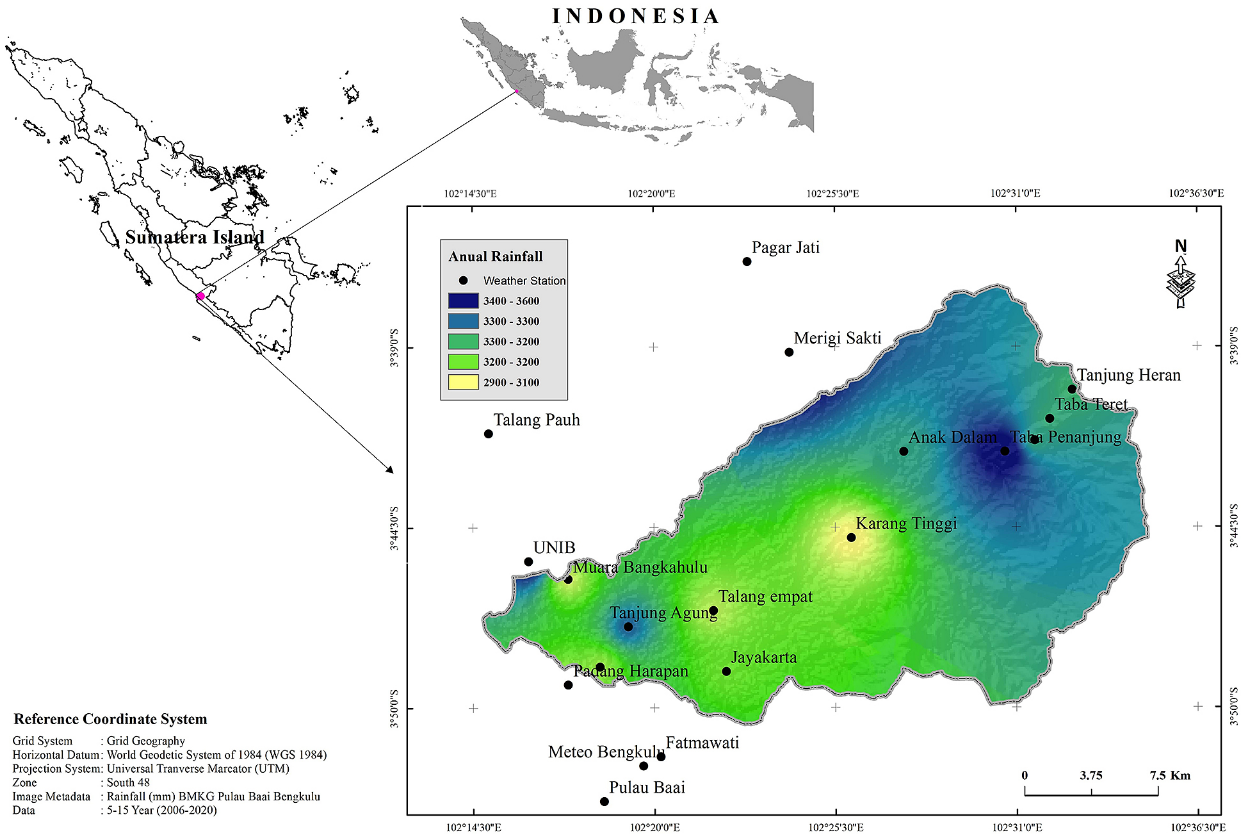

Fig. 1. Spatial distribution of mean annual rainfall and stations used for calculating the rainfall erosivity and the erosivity density (ED) in Air Bengkulu watershed.

vary in both space and time scales. The intense interaction between the atmosphere and the oceans in the Indian Ocean region produces a *dipole mode* phenomenon which is defined as a symptom of anomalous sea surface temperature.

The Western part of the Air Bengkulu watershed, which directly faces the Indian Ocean, is heavily influenced by sea breezes. It experiences humid air for most of the year. This *dipole mode* phenomenon can also be found in the Southern Indian continent. High rainfall is inversely proportional to the sea surface temperature anomaly in Indonesian waters in West Sumatra (Hermawan, Komalaningsih 2008). The Indian Ocean plays a vital role in determining the supply of water vapour during the monsoon cycle, which can affect the rainfall pattern in the Air Bengkulu watershed. The lowest monthly rainfall in June, July, August, September (JJAS) shows a rainfall of 162.75–192.82 mm.

Table 1. Characteristics of gauging weather stations used in this study (acc. BMKG Station Class I Pulau Baai, Bengkulu).

No	Station	Coordinates		Length of record		Elevation	Month Rainfall			
		Latitude	Longitude				min	max	μ	σ
		[S]	[E]	Period	Years	[m]	[mm]			
1	Anak Dalam	−3.70339	102.46	2010–2020	11	149	27	601	256	131
2	Jayakarta	−3.815	102.37	2008–2020	13	39	20	763	261	154
3	Merigi Sakti	−3.65281	102.4022	2011–2020	10	149	10	854	303	157
4	Taba Penanjung	−3.70339	102.5112	2006–2020	15	149	19	773	312	158
5	Karang Tinggi	−3.74707	102.4333	2013–2020	8	84	13	717	253	141
6	Pagar Jati	−3.60677	102.381	2010–2020	11	136	49	476	249	93
7	RM Liku Sembilan	−3.69774	102.5264	2014–2020	7	149	114	478	261	84
8	Tanjung Heran	−3.67209	102.5454	2014–2020	7	149	102	550	268	105
9	Taba Teret	−3.68685	102.5339	2014–2020	7	149	128	509	261	93
10	Talang empat	−3.78407	102.3635	2010–2020	10	30	49	667	257	113
11	Muara Bangkahulu	−3.768	102.29	2010–2020	11	30	11	606	231	125
12	Padang Harapan	−3.82169	102.29	2011–2020	10	30	6	834	249	156
13	Meteo Bengkulu	−3.863	102.328	2011–2020	10	30	5	591	249	143
14	Tanjung Agung	−3.79222	102.3204	2010–2020	11	29	23	927	297	176
15	UNIB	−3.75894	102.27	2011–2020	10	8.5	16	585	262	143
16	Pulau Baai	−3.881	102.308	2006–2020	15	20	14	609	266	136
17	Talang Pauh	−3.694	102.25	2011–2020	10	24	11	1033	294	192
18	Disperta Bengkulu	−3.81271	102.3061	2016–2020	5	8.5	75	491	247	93
19	Fatmawati	−3.85826	102.3368	2011–2020	10	24	5	764	263	156

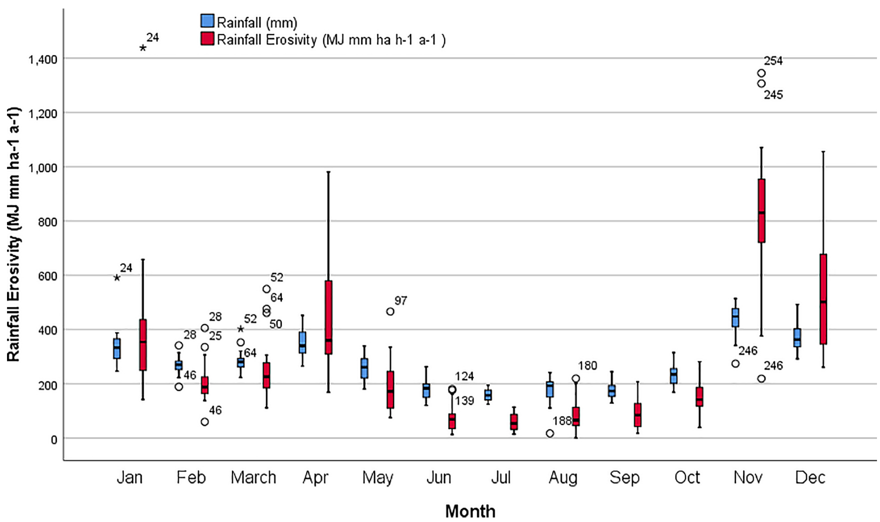

Fig. 2. The boxplots indicate the trends for rainfall and rainfall erosivity related to the monthly models. Its's displayed in figure rainfall (blue), rainfall erosivity (red) in the Air Bengkulu watershed.

Table 2. Homogeneity test (Bartlett's test) and statistic Shapiro-Wilk's (SW) parametric test on the weather stations.

No	Station	Homogeneity			Normality		
		Rainfall	Rainfall erosivity	Erosivity density	Rainfall	Rainfall erosivity	Erosivity density
1	Anak Dalam	S	NS	NS	S	S	S
2	Jayakarta	S	NS	NS	S	S	S
3	Merigi Sakti	S	NS	NS	S	S	S
4	Taba Penanjung	S	NS	NS	S	S	S
5	Karang Tinggi	NS	NS	NS	S	S	S
6	Pagar Jati	S	NS	NS	S	S	S
7	RM Liku Sembilan	S	NS	NS	S	S	S
8	Tanjung Heran	NS	S	NS	S	S	S
9	Taba Teret	S	NS	NS	S	S	S
10	Talang empat	S	NS	NS	S	S	S
11	Muara Bangkahulu	S	NS	NS	S	S	S
12	Padang Harapan	S	NS	NS	S	S	S
13	Meteo Bengkulu	S	NS	NS	S	S	S
14	Tanjung Agung	S	NS	NS	S	S	S
15	UNIB	NS	S	NS	S	S	S
16	Pulau Baai	NS	S	NS	S	S	S
17	Talang Pauh	S	NS	NS	S	S	S
18	Disperta Bengkulu	S	NS	NS	S	S	S
19	Fatmawati	S	NS	NS	S	S	S

Significant (S) and Non-significant (NS).

The rainfall data were tested for homogeneity using the Bartlett test, and the same method was used to evaluate the homogeneity of variance for the data obtained from the data difference stations for 5–15 years of rainfall data. The residuals were checked for normality and homogeneity to ensure that they met the analysis of variance's assumptions. The Shapiro-Wilk (SW) test (Shapiro, Wilk 1965) was used to confirm normality, while the Bartlett test was used to confirm homogeneity (Bartlett 1992). The application of the Bartlett (B) and SW tests made it possible to evaluate the homogeneity of variance and normality for rainfall, erosivity rainfall and ED of data on the weather station scale presented in Table 2. However, the rainfall data for each extreme weather station is for that. Test the data transformation using the Two-Step Approach for Transforming Continuous Variables to Normal (Templeton 2011).

Estimation of rainfall erosivity (R Factor)

Understanding the rainfall erosivity and the ED in space and time is very important to predict the potential risk of water erosion. This study calculates the rainfall erosivity using an equation developed by Wischmeier and Smith (1978), furthermore this equation is also developed using monthly and annual rainfall data (Arnoldus et al. 1980). The Arnold equation shows that reliable rainfall erosivity studies explain the relationship between rainfall and soil erosion processes Yu (2005) also uses similar methods to (Mondal et al. 2016, Singh, Singh 2020). Eq. (1):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{1.5\,log\left(\frac{P_i^2}{P}\right) - 0.08188} \tag{1}$$

where:
- R – rainfall erosivity (MJ $\cdot$mm^{-1} $\cdot$ha^{-1} $\cdot$h^{-1} $\cdot$a^{-1});
- P_i – monthly rainfall (mm);
- P – annual rainfall (mm).

Estimation of ED

The ED is expressed as the ratio of erosivity to precipitation to rainfall, which measures erosivity per unit of rainfall (mm) (Panagos et al. 2015). The assessment results then can explain the occurrence of rainfall, which shows the erosivity of the most erosive rainfall. Eq. (2):

$$ED = \frac{R_i}{P_i} \tag{2}$$

where:
- *ED* – monthly erosivity density ($MJ \cdot ha^{-1} \cdot h^{-1}$),
- R_i – monthly rainfall erosivity ($MJ \cdot mm^{-1} \cdot ha^{-1} \cdot h^{-1} \cdot a^{-1}$),
- P_i – monthly rainfall (mm).

Statistical analysis trend test

After producing a monthly rainfall erosivity assessment of each weather station, different statistical analyses were carried out to identify trends and their statistical significance, using linear regression, Spearman's Rho test, and Mann Kendall test. Linear regression is the simplest and best parametric method for estimating the relationship between variable rainfall and rainfall erosivity. This regression line is a straight line contained in a scatter diagram, which shows a relationship between the two variables (Morgan, Nearing 2011, Ballabio et al. 2017, Singh, Panda 2017). In most statistical analyses of trend determination, the Spearman's Rho test statistic is supported by the best method of test results. The z_{sd} value will provide whether the observed data has a statistically significant trend. If $z_{sd} > 0$, that indicates a positive trend and <zero for a negative trend based on statistical significance. For most statistical analyses of trend determination, the Spearman's Rho test statistic is supported by the Mann Kendall test statistic, the best complementary method available for cross-validation of test results. Mann (1945) and Kendall (1948) proposed a nonparametric test based on ratings to detect linear and non-linear trends and are widely used to detect randomness in rainfall erosivity and ED data (Mohtar et al. 2015, Shin et al. 2019, Liu et al. 2020, Zhu et al. 2021).

Spatial interpolation method

The monthly erosivity value from 19 weather stations was used to obtain the spatial distribution in the Air Bengkulu watershed using the interpolation method. Interpolation is a mathematical function algorithm to estimate the value at locations where data is not available or often called resampling (Tokola 2000, Hanel et al. 2016). The inverse distance-weighted (IDW) interpolation analysis was chosen because this model is often used in estimation exploration activities, and the calculation process is simpler and easier to understand (Hanel et al. 2016).

IDW is an interpolation method to estimate a rainfall erosivity value and ED at the research location which is not sampled based on monthly rainfall erosivity data and has good accuracy (Vijith, Dodge-Wan 2019). Monthly erosivity values were mapped spatially using GIS (Xu et al. 2019). The analysis was carried out by observing the gradation of the resulting map colour so that the erosive period could be identified (Borrelli et al. 2017). However, the value of the unsampled point is assumed to be the distance-weighted average of the values of nearby sampled points in IDW interpolation. Except that nearer points should be closer to the value of the interpolated position than more distant points, this approach does not consider any spatial relationships, including the effects of topography. This has been done by (Xu et al. 2019) choosing the IDW method to calculate the spatial distribution of rainfall erosivity at a station based on weather station data.

Results

The monthly rainfall erosivity at weather stations

The value of rainfall erosivity in the temporal period of 2006–2020 shows the average monthly rainfall is presented in Figure 2. A graphical display of the rainfall erosivity summary is shown, where the horizontal central line within the box represents the median, the upper and lower horizontal lines enclosing the box are at the upper and lower quartiles, respectively, and the whiskers extend to the two extreme observations. Shown boxplots, the horizontal line within the box indicates within the present box indicates the mean. The illustrative dataset rainfall erosivity Air Bengkulu watershed at weather station recorded.

The monthly period of maximum rainfall erosivity occurs in November, which is the highest peak of rainfall. Monthly erosive periods occur in November, December, and April (NDA) or wet months, with variations in the rainfall erosivity index of:

840.94 $MJ \cdot mm^{-1} \cdot ha^{-1} \cdot h^{-1} \cdot a^{-1}$,
552.42 $MJ \cdot mm^{-1} \cdot ha^{-1} \cdot h^{-1} \cdot a^{-1}$,
472.09 $MJ \cdot mm^{-1} \cdot ha^{-1} \cdot h^{-1} \cdot a^{-1}$.

Meanwhile, the minimum rainfall erosivity is in July. The lowest erosive monthly period occurs in June, July, August (JJA) with a rainfall erosivity value of 87.55–105.46 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1}.

Trend of monthly rainfall erosivity at weather stations

The results of the rainfall erosivity research link the values of r^2 and r_s to conclude that the data has a trend. The results show that rainfall erosivity is a relationship between rainfall erosivity and the conditions of monthly rainfall in the Air Bengkulu watershed (Table 3). Statistical analysis with correlation analysis assesses the extent to which the strength between the variables affects. The results of the study obtained significant with a significant level of 0.001, the influencing variable and having a solid relationship between the rainfall erosivity variable and monthly rainfall.

The monthly rainfall erosivity trend for 19 weather stations shows a positive trend, which means that the data is increasing in the Air Bengkulu watershed. This indicates that the results of the slope (b_1) value between 1975 and 3950 from the regression explain the assumption that bulk erosivity has an increasing trend Pagar Jati station with the lowest score and Anak Dalam station with the highest score. The regression parameter value also explains the coefficient of determination (r^2), showing 0.91–0.99. This means that 91–99% of the variation in monthly rainfall is related to and affects the rainfall erosivity. Slope assessment (b_1) can be used to detect trends in rainfall erosivity in the Air Bengkulu watershed.

Spearman's Rho analysis can be observed from the lowest to the highest with a Z score a value of 38.109 and 115. 928 at Tanjung Heran and Talang Pauh stations. Then, H_o rejects and shows that the data has an increasing and significant trend at a significant value of 0.001. However, in the analysis of the Man Kendall test, the results show that the Z score is between −0754 and 0.825. H_o was accepted and stated that the trend was insignificant. This test also explains that 11 weather stations are trend increasing and 8 stations are trend decreasing. Therefore, the percentage of monthly rainfall erosivity was 57.89% increasing and 42.11% decreasing.

Spatial distribution of monthly rainfall erosivity

Data analysis from the interpolation stage can be seen from the colour gradation that shows

Table 3. Test statistical analysis results for monthly rainfall erosivity.

No	Station	Eq. Regression			Spearman's Rho		Mann Kendall		Trend
		r^2	β_1	β_0	r_s	Z_{sr}	s	Z_s	
1	Anak Dalam	0.971*	3.950	−762.095	0.983*	60.572	−205	−0.223	Decreasing
2	Jayakarta	0.953*	3.021	501.154	0.974*	53.353	993	0.825	Increasing
3	Merigi Sakti	0.948*	3.535	−720.338	0.984*	59.739	303	0.374	Increasing
4	Taba Penanjung	0.964*	2.730	509.743	0.986*	78.670	725	0.485	Increasing
5	Karang Tinggi	0.983*	3.651	−637.470	0.993*	81.075	159	0.090	Increasing
6	Pagar Jati	0.966*	1.975	−553.189	0.981*	57.431	−36	−0.040	Decreasing
7	RM Liku Sembilan	0.980*	2.476	−457.674	0.994*	81.778	−354	−0.754	Decreasing
8	Tanjung Heran	0.990*	2.529	−450.889	0.997*	115.928	−171	−3.65	Decreasing
9	Taba Teret	0.989*	2.509	−449.931	0.997*	115.928	−55	−0.119	Decreasing
10	Talang empat	0.972*	2.998	−529.242	0.992*	89.252	−134	−0.145	Decreasing
11	Muara Bangkahulu	0.921*	2.251	−296.683	0.978*	53.249	713	0.762	Increasing
12	Padang Harapan	0.937*	3.426	−539.441	0.979*	51.945	339	0.418	Increasing
13	Meteo Bengkulu	0.949*	2.832	−440.186	0.978*	50.712	254	0.313	Increasing
14	Tanjung Agung	0.974*	3.740	−726.421	0.988*	72.653	8	0.007	Increasing
15	UNIB	0.962*	2.900	−498.657	0.981*	54.694	182	0.224	Increasing
16	Pulau Baai	0.956*	2.739	−462.022	0.980*	65.519	125	0.083	Increasing
17	Talang Pauh	0.910*	2.640	−431.255	0.962*	38.109	131	0.161	Increasing
18	Disperta Bengkulu	0.971*	2.414	−392.646	0.996*	84.156	−24	−0.053	Decreasing
19	Fatmawati	0.983*	3.422	−585.485	0.990*	75.910	−161	−0.200	Decreasing

* – statistically significant trend level (α = 0.01).

monthly rainfall erosivity presented in Figure 3. There is a colour gradation from yellow to blue. The colour gradation that has more yellow colour indicates the lower value. In comparison, the blue colour gradation indicates a higher value. The spatial distribution of the monthly rainfall erosivity explains that the upstream watershed of Air Bengkulu, with the rainfall erosivity,

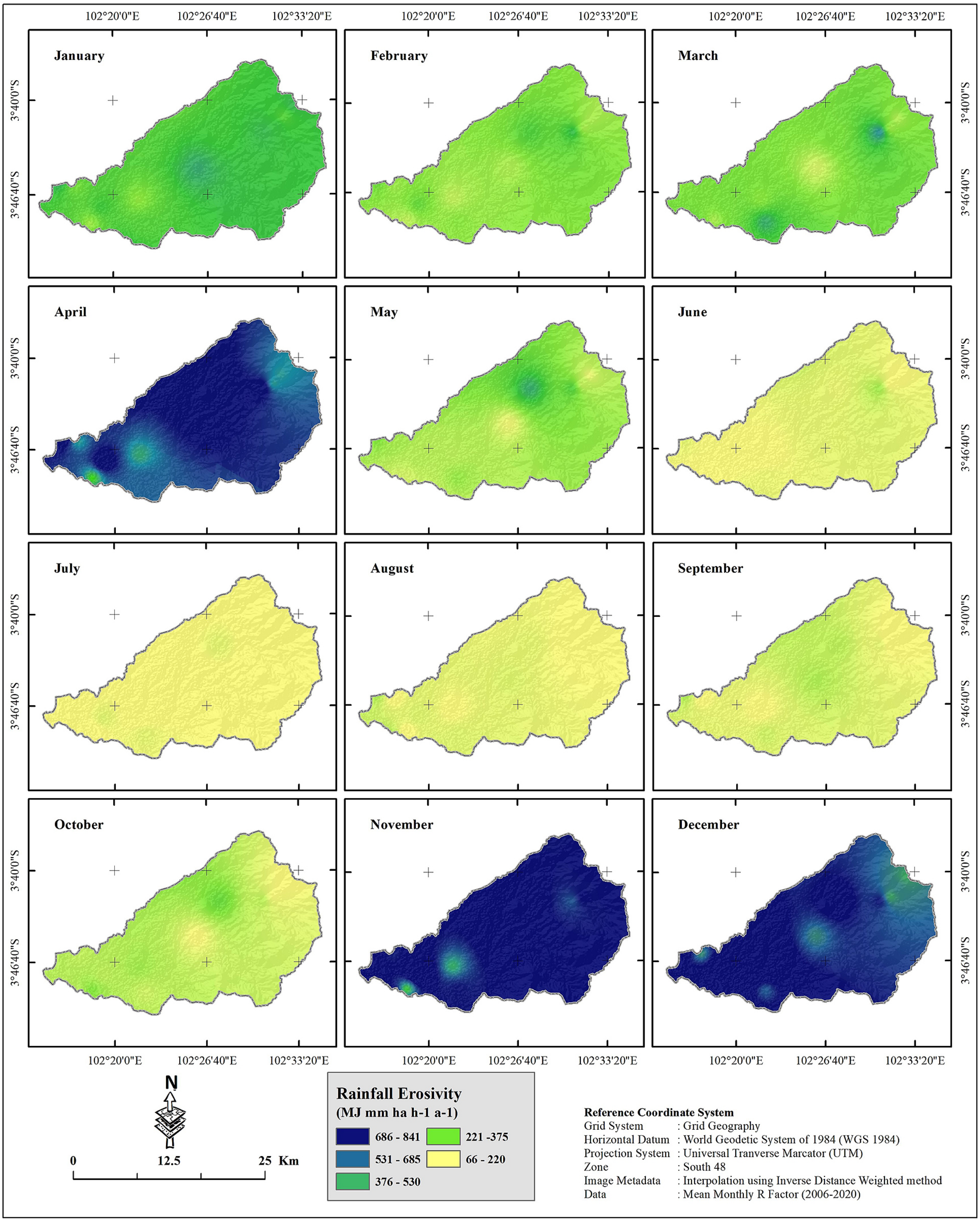

Fig. 3. Map of monthly rainfall erosivity in the Air Bengkulu watershed (same range from 66 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1} to >841 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1}) using the IDW interpolation method.

continues to increase. The homogeneous colour gradation occurs in November, when it turns blue, and in July it turns yellow.

This shows that the erosive period, namely November, December, and April are the most vulnerable. But the months of June, August, and September will witness the lowest periods of the erosion process. But the months of January, February, March, May, and October, the spatial distribution of rainfall showed heterogeneous colour gradations throughout the watershed. However, the Taba Penanjung station shows consistency and continues to increase with increasingly green colour gradations in the Northeast area of the Air Bengkulu watershed.

Trend and Spatial distribution of ED

Analysis of the average ED of 19 weather stations in the Air Bengkulu watershed is for graphic comparisons of a ED of monthly data boxplots presented in Figure 4. The ED for the erosive months in November, December and April, (NDA) with ED values between 1.12 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1}, 1.59 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1} and 1.23 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1}, 1.12 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1}. This value is directly proportional to the rainfall erosivity and indicates that rainfall is a potential disaster risk.

Based on Table 4 shows the value of the coefficient of determinant between 0.795 and 0.989. This means that 79.5–98.9% density erosivity strongly influences both variables, namely rainfall erosivity and monthly rainfall. Further test with the Spearman's Rho assessment is directly proportional to a value between 0.904 and 0.994. This also shows that monthly rainfall has a strong relationship with the calculation of rainfall erosion at the rainfall station in the Air Bengkulu watershed.

ED trend assessment in the regression equation shows that the slope assessment (b1) slope

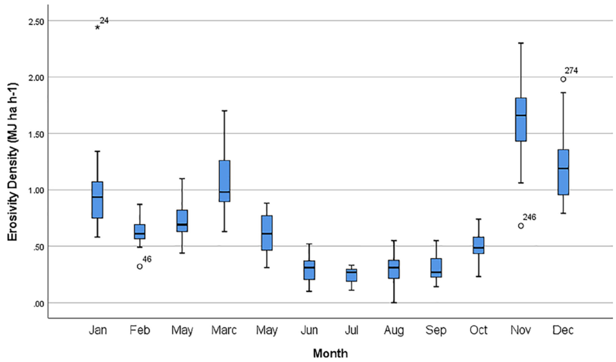

Fig. 4. The boxplots indicate the trends for erosivity density (ED) as the ratio of rainfall erosivity (interpolated erosivity map based on IDW) with monthly rainfall data in the Air Bengkulu watershed.

Table 4. Test statistical analysis results for monthly erosivity density (ED).

No	Station	Eq. Regression			Spearman's Rho		Mann Kendall		Trend
		r^2	β_1	β_0	r_s	Z_{sr}	s	Z_s	
1	Anak Dalam	0.938*	0.005	−0.698	0.963*	40.427	−436	−0.473	Decreasing
2	Jayakarta	0.879*	0.005	−0.498	0.929*	31.512	−10	−0.381	Decreasing
3	Merigi Sakti	0.911*	0.005	−0.666	0.964*	39.215	147	0.181	Increasing
4	Taba Penanjung	0.937*	0.004	−0.524	0.972*	55.033	416	0.278	Increasing
5	Karang Tinggi	0.969*	0.006	−0.731	0.986*	57.025	28	0.047	Increasing
6	Pagar Jati	0.923*	0.006	−0.668	0.956*	37.012	−69	−0.075	Decreasing
7	RM Liku Sembilan	0.970*	0.005	−0.469	0.989*	60.176	−287	0.612	Increasing
8	Tanjung Heran	0.984*	0.005	−0.643	0.994*	81.788	−147	0.314	Increasing
9	Taba Teret	0.989*	0.005	−0.657	0.993*	75.664	−24	0.053	Increasing
10	Talang empat	0.949*	0.005	−0.680	0.980*	55.934	−104	−0.112	Decreasing
11	Muara Bangkahulu	0.863*	0.005	−0.400	0.949*	34.188	396	0.423	Increasing
12	Padang Harapan	0.881*	0.005	−0.516	0.950*	32.909	137	0.168	Increasing
13	Meteo Bengkulu	0.887*	0.005	−0.455	0.953*	34.024	188	0.321	Increasing
14	Tanjung Agung	0.942*	0.005	−0.716	0.974*	48.831	−29	0.032	Increasing
15	UNIB	0.913*	0.004	−0.505	0.957*	35.684	75	0.092	Increasing
16	Pulau Baai	0.907*	0.005	−0.545	0.961*	46.232	−22	−0.015	Decreasing
17	Talang Pauh	0.795*	0.004	−0.301	0.904*	22.871	151	0.186	Increasing
18	Disperta Bengkulu	0.967*	0.005	−0.592	0.993*	75.664	−19	0.042	Increasing
19	Fatmawati	0.960*	0.005	−0.623	0.978*	50.712	147	0.181	Increasing

* – statistically significant trend level ($\alpha = 0.01$).

value (b1) is 0.004–0.005. Even though the slop value is <1, it is positive, so there is an increasing trend. Spearman's Rho shows that five rainfall stations have decreased with a Z score of −0.473 to −0.015. This result rejects H_o and accepts H_1, which means that the ED distribution data at weather stations have a strong relationship, and the data has an increasing trend. The test results

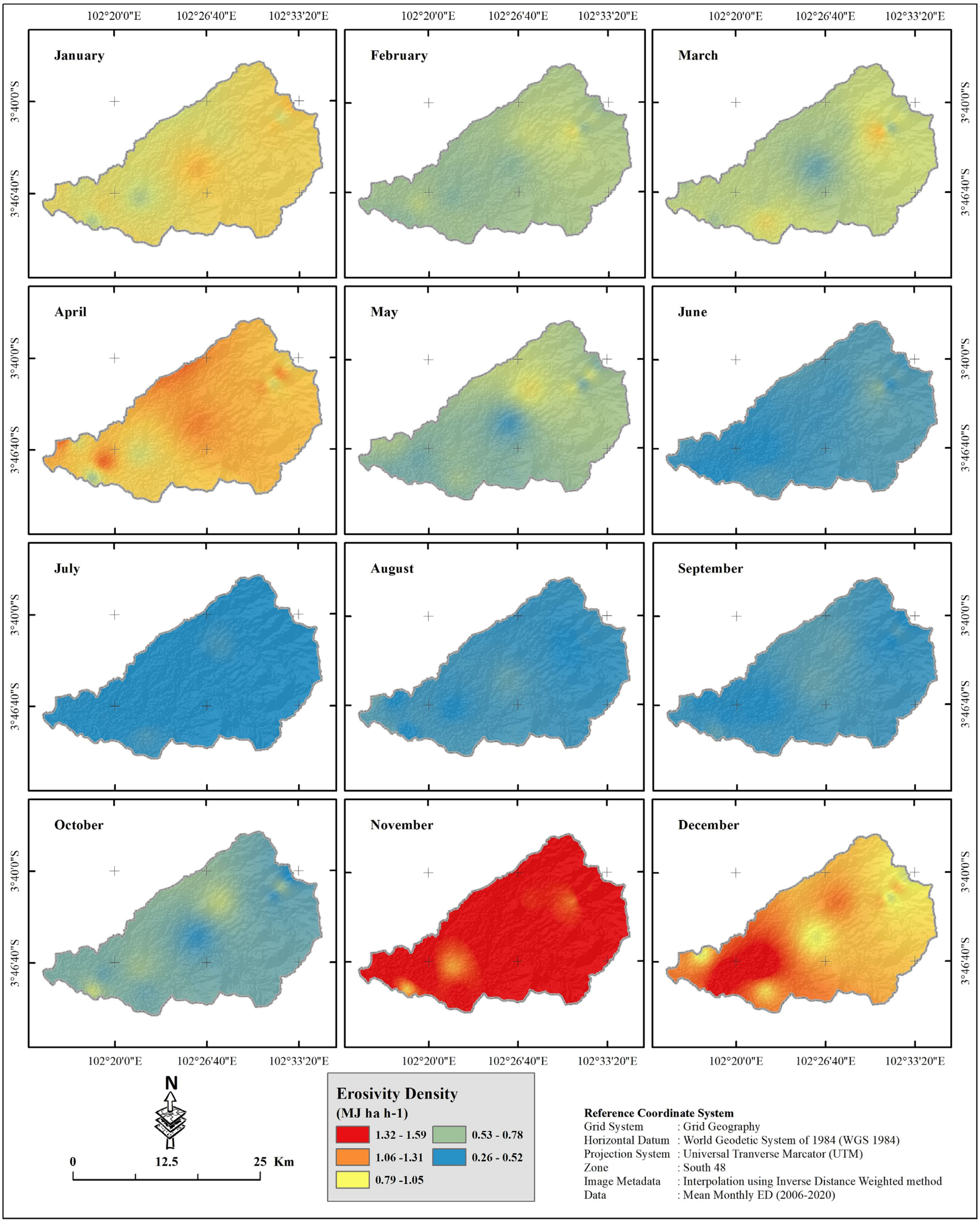

Fig. 5. Map of monthly erosivity density (ED) of the Air Bengkulu watershed (same range from 00.26 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1} to > 1.59 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1}) using the IDW interpolation method.

also explain that 14 stations are trend increasing and 5 stations are trend decreasing. Therefore, there was a 73.68% increasing and a 26.32% decreasing monthly ED.

Based on Figure 5, the spatial distribution of ED shows that the most erosive occurs in November. This is indicated by gradations of red and identified potential hydrometeorological disasters. However, at the Talang Empat and Padang Harapan rainfall stations, there is a yellow gradient in the West and Southeastern locations of the Air Bengkulu watershed. Meanwhile, in December, the red gradient is concentrated in the downstream part of the watershed. January and April heterogeneous spatial distribution of yellow, red, and red colour gradations concentrated in the North and Southeast of the Air Bengkulu watershed. The lowest ED is in June, July, August, and September is shown in blue gradations.

Discussion

Erosion of monthly rainfall at rainfall stations

It can be stated that rainfall erosivity occurs in erosive periods in November, December, and April (NDA). This implies that the erosion of rainfall is directly proportional to rainfall. Meanwhile, the erosive rainfall erosivity is lowest in June, July, and August (JJA). In the months of rainfall events can have a direct influence on rainfall erosivity. However, the difference in the occurrence of rainfall gives rise to the characteristics of typical precipitation (Diodato, Bellocchi 2012). So that the value seems overestimated or underestimated to the value of rainfall erosivity. It has been revealed data information that the erosion of rainfall is underestimated at the rainfall weather station in Karang Tinggi, there is a low value of rainfall erosivity caused by inconsistent indications of rainfall recording by observers or the occurrence of errors in the equipment used.

The occurrence of rain is influenced by several factors, including latitude, altitude, and distance from the sea (Terassi et al. 2020). The Air Bengkulu watershed has a fairly diverse topography. This topographical diversity results in heterogeneous physical conditions between regions and is directly affected by the western part bordering the Indian Ocean. The heterogeneity that occurs at the study site causes an uneven distribution of rainfall events. Therefore, it is necessary to instal rain stations that are evenly distributed and represent rain events in various topographical forms.

Therefore, it is necessary to directly integrate watershed management with rainfall characteristics and pay attention to rainfall erosivity, triggering potential erosion and land criticality disasters. Therefore, management in soil and water conservation planning pays attention to this month. This is done by considering changes in the watershed landscape towards land use activities, including forest (production, protection, and conservation), agriculture, plantations, mining. Furthermore, the information which is generated through this study compiling with other supportive, data will facilitate towards taking up long-term flood/erosion protection measures at the research site along the Padma river (Billah 2018). that the slightest erosion information on the variables studied can be used as material for land conservation planning in the watershed by policymakers.

It is necessary to do conservation because of changes in the watershed landscape to reduce the danger of erosion in the monthly period of rainfall erosivity in November. In accordance with Arsyad (2012) the erosion rate that will occur can be estimated, and the erosion rate can still be tolerated. In that case, a policy on land use can be determined. However, in recent decades, land changes in the upstream watershed have triggered runoff on land without ground cover vegetation (Letsoin et al. 2020). Soil conservation measures with the application of wise land use, especially on steep slopes and riverbanks with lots of plants using candlenut (*aleurites moluccanus*), jackfruit (*artocarpus heterophyllus*), breadfruit (*artocarpus heterophyllus*), and durian (*durio zibethinus*), can improve the quality of the watershed landscape with a sustainable agroecosystem plan scenario applying organic fertilisers, multi-crop options, small mounds for sediment trapping and water harvesting with small ponds (Barchia et al. 2020). Soil conservation and land-use measures are implemented to reduce the rate of erosion to be less than the erosion rate that can still be tolerated.

Furthermore, when compared with monthly rainfall erosivity studies, the findings, such as in the Suketi River watershed at Himalaya, show that farmers know erosive months. That is to support in terms of best agricultural technique management (Singh, Singh 2020). Like agriculture in the Wei watershed in China, knowledge of rainfall erosivity information can help manage erosion prevention in sustainable agricultural systems (Zhang et al. 2021). It is strengthened by the findings made by (Duulatov et al. 2021) in improving soil conservation to ensure the sustainability of future agricultural products with operational management and agricultural planning. Then, the rainfall erosivity is mapped in mainland Africa as material for policy planning in compiling land and water resources management. (Fenta et al. 2017).

Erosivity trend of monthly rainfall at rainfall stations

The results showed that the rainfall erosivity trend with the linear regression equations and Spearman's Rho test was significant with a significance level of 0.001. However, after doing the Mann Kendall test, it is insignificant. This rainfall data to support this research is incomplete and discontinuous. The incompleteness of this precipitation data can also be used as a separate study related to less efficient data inventory. The quality of precipitation data is very important, if there is a lot of unfilled rainfall data, it will not be good to support research related to rainfall erosivity. This causes uncertainty in determining the trend of rainfall erosivity and rainfall density. Trend analysis is an analytical method aimed at estimating or forecasting future erosivity of (Ma et al. 2014, Schmidt et al. 2016, Vijith, Dodge-Wan 2019, Zhu et al. 2021).

Therefore, to forecast well, it requires a wide variety of information (data), which is quite a lot and observed in a relatively long time of rainfall data and associated with several variables that affect rainfall. The analysis results show the fluctuations that occur and what factors influence it to estimate the rainfall erosivity pattern for spatial and temporal scales (Diodato, Bellocchi 2012). Therefore, in calculating rainfall erosivity, high temporal resolution precipitation data is needed at an intensity of 30 min for an extended period (Panagos et al. 2017). It is suggested that the period for rainfall erosivity data is at least 22 years (Panagos et al. 2016a, b).

Theoretically, in time series analysis, the most determining factor is the quality or accuracy of the information or data obtained and the time or period the data was collected. The more data that is collected, the better the estimation or forecasting will be obtained. Conversely, if less data is collected, the estimation or forecasting results will get worse. Estimating monthly rainfall erosivity based on data is problematic and highly biased since rainfall intensity is usually inconsistent (Nearing et al. 2017, Lee, Hsu 2020). However, the findings of this study explain that rainfall affects the rainfall erosivity which indicates a monthly erosive period and is prone to hydrometeorological disasters. (Baumann et al. 2002, Hanel et al. 2016, Djalante et al. 2021, Duulatov et al. 2021).

Although the two statistical analyses show significance, however, accuracy results show an insignificant trend in the Men Kendall test. The same research was carried out in Johor Bahru, where there was a decline, and there was no significant trend during the study period (Mohtar et al. 2015). However, a map of the incidence of soil erosion that can cause soil loss from hillslopes by water, A subsequent study recently Nearing et al. (2017) highlighted rainfall erosivity trend noted that watersheds in the American Southwest show significant under-predictions of erosivity. However, Zhang et al. (2010) reported a significant increasing trend in rainfall erosivity although an insignificant trend in the total rainfall amount was detected. Then, the same thing is also shown that the Suketi River Western Himalayan catchment watershed, India shows that no trend shows a significant value (Singh, Singh 2020). Therefore, in general, it is necessary to assess the rainfall erosivity in this regard due to changes in the global climate. It is also because of climate change in the United States to update maps and information regularly. The rainfall erosivity values for the Eastern United States were calculated using data from 1936 to 1957 (Yin et al. 2017).

Spatial distribution of erosivity of monthly rainfall

The results showed that the spatial distribution of the Air Bengkulu watershed, the rainfall erosivity of the Northeastern, is an erosive area. However, It has been revealed that the resulting interpolation map tends to be rough and centred on the weather station. This is due to limitations in the number of weather stations, installed weather stations that are not in accordance with the physical conditions of the area, limited installation costs and equipment maintenance that requires continuous observers.

Geographically, the upstream watershed area with a slope of 45% is located on the west side of the Bukit Barisan mountains range along the Sumatra island route. Therefore, this area is most vulnerable to erosive processes. Areas that receive more rainfall as an orographic rainfall climatic phenomenon (Bagwan 2020) increase evaporation at an altitude of 100 m. The surface temperature will drop by 0.6°C. Spatially, the IDW method best explains the monthly rainfall erosivity based on weather station plots. however, it has been revealed that the findings of the Air Bengkulu River Basin in the middle show an underestimating result because the colour gradation of the map presented is drastically rough.

This shows that further studies are needed as to why this is so, namely by adding weather station plots. so it was revealed that the Karangtinggi Weather Station underestimated the results of interpolation of rainfall erosivity. However, this research is still not related to how topographical parameters can affect the value of rainfall erosivity. The colour gradation of the middle of the watershed shows an underestimating value. Furthermore, the map produced at the research site is satisfactory enough to determine the distribution of the rainfall erosivity. Thus the findings of the resulting map can provide a reliable estimation of the rainfall erosivity index and an essential prerequisite for the successful identification of areas at risk of soil erosion where soil conservation practices are required. (Borrelli et al. 2016).

The upstream area of the Air Bengkulu watershed is an area that influences the interaction of rainfall erosivity events downstream. Changes in the landscape of the upstream watershed causing heavy rainfall, causing runoff to carry material over the ground. Deforestation of the upstream watershed is used for mining activities and changes in land cover for socio-economic activities such as the formation of community forests, plantations (Andriansyah, Mustikasari 2011, Supriyono et al. 2017, Satmaidi et al. 2018, Gunawan et al. 2020). The Value 80% of Rindu Hati's protected forest area has been turned into agricultural and plantation land (Belladona, Nasir 2019). Meanwhile, the downstream area of the Air Bengkulu watershed states that the result of the erosion process is sedimentation which causes the river flow to experience a vast inundation impact due to flooding, such as the 2019 Bengkulu Flood (Mase 2020).

In other research locations, the rainfall erosivity is influenced by geographical conditions. For example, in the Wei River watershed in China, it is highlighted that spatial differences change under the influence of topography and geomorphology (Zhang et al. 2021). The coefficient of variation is usually higher in upland areas than in lowland areas, indicating that as elevation increases, the spatial variability of regional rainfall in the horizontal dimension increases, and the erosivity of rainfall changes drastically. Research conducted by Borrelli et al. (2016) of rainfall erosivity trends can determine the spatial distribution of research locations for both soil and water conservation planning.

Trend and spatial distribution of ED

The findings of the ED trend between 0.26 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1} and 1.59 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1} were insignificant. The pattern of ED increased by 73.68%, and the pattern decreased by 26.32%. An ED value >1 means that rainfall causes erosivity to the rainfall and triggers an erosive month (Oliveira et al. 2013, Mondal et al. 2016). In addition, areas with high rainfall erosivity and ED may be associated with landslide activity and risk of soil erosion (Panagos et al. 2016a, b). The upstream watershed, with its soil slope and geological conditions, may be more conducive to soil erosion than landslide activity influenced by rainfall and rainfall erosivity. However, the downstream watershed has erosive rainfall, making this area vulnerable to floods and sedimentation disasters (Mase 2020).

Important information about the rainfall erosivity and the ED is the time of year at the maximum and minimum points. The same rainfall intensity produces different effects on soil erosion. It directly depends on different factors, such as land cover in a watershed that changes throughout the month (Vijith, Dodge-Wan 2019). Knowledge of the highest ED is essential for management practice. It allows optimisation of management measures for soil and watershed conservation (Andriyani et al. 2017, Nasir et al. 2020). The spatial distribution of monthly rainfall erosivity in the catchment area has been presented in Figure 5, which shows the spatial distribution of ED. The intensity of rain erosivity occurs in November, December, April, and the lowest is in June, July, August. Based on the data, selective erosion control measures can be done, such as reduced tillage, leaving crop residues in agricultural areas, changes in crop or crop rotation to attenuate the impact of rainfall on soil and vegetation by increasing the soil.

The comparison of the study of rainfall ED trend and spatial distribution can significantly determine the location of the disaster. The conversion of land from rubber plantations to oil palm plantations has led to deforestation (Barchia et al. 2020). Changes occur in the upstream watershed of the Air Bengkulu. Therefore, the high rainfall in April 2019 was flooded (Mase 2020). This proves that rainfall events affect. According to the facts in the field, it shows that the ED of monthly rainfall can explain the vulnerability of erosive processes and hydrometeorological disasters.

Conclusions

The rainfall erosivity is part of the USLE equation indicator for soil erosion assessment in Indonesia. The spatial distribution and erosivity trends of rainfall as a reliable and proven method can explain the potential risk of erosion for soil and water conservation management in the watershed. This analysis has been revealed as follows: First, the findings of the monthly rainfall erosivity of the most erosive occurred:

- in November: 840.94 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1},
- in December: 552.42 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1},
- in April: 472.09 MJ $\cdot$ mm^{-1} $\cdot$ ha^{-1} $\cdot$ h^{-1} $\cdot$ a^{-1};

second, the rainfall erosivity and ED trends show as a significant trend level (a = 0.01), however, the Mann Kendall test shows insignificance but shows a decreasing and increasing trend patterns; third, the spatial distribution of rainfall erosivity shows that the months of November, December, and April (NDA) are the most erosive. Meanwhile, June, July and August (JJA) are the months with the lowest rainfall erosivity. Finally, the ED is 0.71 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1} from linking between 0.16 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1} and 2.30 MJ $\cdot$ ha^{-1} $\cdot$ h^{-1}.

This study has analysed the monthly rainfall erosivity. but the limitations of rainfall data and the density of weather stations at the research location. So that the resulting map is underestimated at the rainfall station which can affect the rainfall erosivity. However, the findings of this study can present a new map which is an essential source of information for predicting soil erosion in the initial disaster risk investigation in the Air Bengkulu watershed. Several implications for the government in watershed management, recommending WMPF Ketahun Bengkulu and agencies related to watershed management to be responsive and on targeted in carrying out soil and water conservation activities. For the community, it is crucial to carry out agricultural activities in soil cultivation and fertilisation according to procedures by paying attention to the erosive month period to suppress the process of erosion, and the mining sector must apply the principles of sustainable mining strictly with simultaneous supervision.

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Authors' contribution

The authors confirm contribution to the paper as follows conceptualization, methodology, and formal analysis, Supriyono S. includes visualization, investigation, data analyzed and writing original draft preparation, Then Supriyono S., Utaya S., Taryana D., and Handoyo B. includes supervision, writing review, and editing. The Authors have read and agreed to the published version of the manuscript. Then the authors agreed to be responsible for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are properly investigated and resolved.

Conflict of interest

The authors confirm and sign that there is no conflict of interests with networks, organizations, and data centers referred to in the paper.

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