Model of rainfall erosion index for predicting the potential erosion rate by using a rainfall simulator

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Abstract. The intent of this research is to investigate the rainfall erosion index that has the highest correlation to the surface runoff volume and the amount of soil erosion. In addition, the aim of this research is to determine the effective rainfall erosion index to predict soil erosion based on observations. This research was conducted in a hydrology laboratory by using a rainfall simulator. The three methods that were used for analysing rainfall erosion were the formulas of EI₃₀ by Bols, Utomo, and Lenvain. The result is expected to become a consideration in selecting the model of rainfall erosion index due to the rainfall factor as the input of soil erosion prediction. This research provides a temporary hypothesis for obtaining the value of the rain erosivity index with a different value from previous studies with EI₃₀, which leads to the latest model for estimating and predicting from the Bols equation. Based on this research, the rain erosivity index was obtained with a predicting value and final equation of EI₃₀ = 5.128 x (Rain)^1.26 x (Days)^0.47 x (Maxp)^0.53 x (High)^0.61 with the explained value from research analysis being EI₃₀ = 5.128 x (50.002)^1.35 x (23)^0.47 x (622)^0.53 x (12)^0.61. Analysis was then performed with trial and error, and the conclusion of this research is a high rain erosivity index.

Keywords: surface run-off, rainfall intensity, erosion index

1. Introduction
Erosion occurs due to the destruction of the soil mass by raindrops and surface runoff. Raindrops and surface runoff carry energy that can destroy soil aggregates. Thus, the conversion is important to be performed, such as by reducing the amount of peak energy (rainwater or surface runoff), increasing soil aggregate resistance, and improving soil protection. The reduction of the amount of destructive energy can be accomplished through protecting the soil mass from direct raindrops or surface runoff erosion, increasing the soil infiltration capacity, and increasing the hardness in the soil surface. These methods are intended to reduce the speed and volume of rainwater and surface runoff, eliminating their capabilities to erode the soil [2, 8, 11, 12]. Efrodina [5] studied the land erosion in the Dawas watershed in South Sumatra, in which the amount of rainfall will cause an increase in the erosion and sedimentation from year to year. Based on the research of Maurice O. Kodio and Boniface [10], there is a relationship between erosion with the existing land cover, and thus the type of appropriate land cover/vegetation for erosion prevention can be identified.
A research conducted by Felix K. Salako [6] in Southern Nigeria demonstrated that the rainfall intensity factor with time duration variations (EI_{30} and EI_{15}) will produce kinetic energy by the amount of rainfall, which can affect the amount of land erosion. This was further analysed by using USLE. On the other hand, another research in the southern region of Spain proved that the effect of rain with EI_{30} and EI_{60} can cause large amounts of erosion on land, coupled with the occurrence of high daily precipitation in the region. Thus, the kinetic energy generated from rain and its precipitancy results in the Exponential Modelling in its application [4].

Some studies by far still show leading results in the value of the erosion due to the influence of rainfall intensity with EI_{15}, EI_{30}, and EI_{60} in certain areas. One of which is a research performed in Korea [7], with the results being various erosion values affected by rain with EI_{30} that occurred in four different seasons. In addition, a research conducted by Luis Augusto DiLoreto; Ricardo Santos; Eduardo Guimaraes [9] in Brazil also resulted in several erosion categories on land with the EI_{30} rainfall intensity factor with the addition of several erosivity variables; erosion was identified as the categories of low, medium, medium-high, high, and very high.

This study involves the examination of a rain erosion model that has never been implemented in previous studies. The research is carried out by applying several variations of rainfall intensity with different rain erosivity indices (EI) and adds one parameter based on the others research [13, 19, 20]. In addition, this study also refers to the rain erosivity index (EI_{30}) which has been previously studied [13, 19, 20].

2. Methods

2.1 Materials and Methods
To predict the level of land criticality due to rain erosion at an early stage, modelling was performed by conducting physical model experiments in the laboratory using a rainfall simulator. This was followed by making a map of the land unit through overlaying of the slope map, the landform map, the land use map, and the land map. From the results of the map overlay, critical areas and places that must be surveyed and used as research locations were identified. In this case, map overlay processing was performed with the Geographic Information System (GIS) method. The next step was to analyse the rainfall in the field by using secondary data. Analysis of rain erosivity was performed with calculations using the equation [19, 20], as well as EI_{30} [13]. From these three methods, a more suitable and similar study location was found, which allowed the erosion rate to be predicted with USLE [14, 15, 16]. Finally, an erosivity model was developed based on the results of the study that had been verified and calibrated for implementation in other research locations if needed.

2.2 Study Location
For this study, the City of Batu was selected as the research location, with a focus on the upper Brantas watershed. The City of Batu has an area of 202 km² with a population of 200,000 inhabitants. The city is located between the Malang-Jombang and Malang-Kediri crossings. The length of the Brantas River is 320 km with a watershed area of 14,103 km², which covers 25% of the area of the Province of East Java, or 9% of the area of the island of Java. The 14,103 km² area of the Brantas River has more than 100 small watersheds that flow to the southern coast of Java. The total population living in the Brantas River region is almost 50% of the total population in East Java (18,995,043 of the total of 38,847,561 people) with an average population density of 1,272 people/km². In addition, the upstream part of the Brantas watershed was also used for the research application with a physical model, which was conducted at the Hydrological Laboratory of Brawijaya University, Malang.

2.3 Data Collection
The data collected in this study involved primary data including Erosion (E) and Time (t) values, with variations of rain (i) of ten minutes with six different rain times. A barrier wire was added as an assumption of additional vegetation parameters, as different rain heights (H), with three vegetation
heights from the ground surface with different spacing conditions. The analysis method in this research utilized the statistic modelling system with additional parameters. From statistic modelling with linear regression correlation, a large correlation value (R) was found to improve the Bols equation for EI30 [3, 17, 18]. The Bols equation in this research is $EI_{30} = 5.128 \times (\text{Rain})^{1.26} \times (\text{Days})^{0.47} \times (\text{Maxp})^{0.53} \times (\text{High})^{0.61}$. Some values were substituted from the analysis primary data. The result is the discovery of a new and improved equation.

3. Results and Discussion

3.1 Rainfall Intensity and Duration

In a watershed, there are several factors that have unique characteristics, and thus each watershed will give different responses to the same rain input. In wet tropical locations such as Indonesia, erosion by effect from water (runoff) is an important factor in soil damage. Some climate factors that can cause erosion are rainfall, temperature, wind, moisture, and sun radiation. From these five factors, rainfall is the most important factor. The effect of rainfall intensity on surface runoff depends on the infiltration capacity. If the rainfall intensity exceeds the infiltration capacity, the amount of runoff on the surface will increase according to the increase in rainfall intensity. However, the magnitude of the increase in runoff is not proportional to the increase in effective rain caused by the effects of inundation or storage on the ground surface. In each watershed, there is a duration of critical rain. If the rain duration is less than the critical duration, then the runoff surface boundary will be the same and does not depend on the intensity of the rain. If the rain duration is longer, then runoff will be longer. The rainfall duration will also result in a decrease in infiltration capacity. For a long duration of rainfall, surface runoff will be greater even though the intensity is relatively moderate.

3.2 Data Analysis

The previous rainfall index causes soil moisture levels to be high, which causes flooding to easily occur because these conditions reduce the infiltration capacity. Likewise, if soil moisture increases and reaches the field capacity, then percolation occurs and the infiltration will reach the groundwater surface; hence subsurface runoff as base flow becomes enlarged. During the period of reduction in soil moisture by evaporation, heavy rainfall will not result in an increase in runoff over the surface. This is due to the infiltrated rain being retained as soil moisture. Conversely, if soil moisture increased due to previous heavy rain, then rain with small intensity can sometimes cause flooding. The treatment of the factors causing erosion in this study is the assumption of a stable condition and no change in parameters. The parameters that were changed were only rainfall and the duration of rainfall, in order to see the amount of runoff and erosion on the study site.

| Time | Rainfall | (Os) | R. Linear | R. Exponent |
|------|----------|------|-----------|-------------|
| 10   | 100      | 5.76 | 0.9796    | 0.8815      |
| 20   | 200      | 11.52|           |             |
| 30   | 250      | 14.40|           |             |
| 40   | 300      | 17.28|           |             |
| 50   | 350      | 20.16|           |             |
| 60   | 400      | 23.04|           |             |

Table 1 shows prediction results with height parameter $(H1) = 30$ cm vegetation in the research. These were taken from analysis of primary data from recorded durations of time and rainfall amounts. Then, runoff can be predicted by the relationship of the value of linear correlation and value of exponent correlation.
Table 2. Rainfall with parameter H2

| Time | Rainfall | (Qs) | R. Linear | R. Exponent |
|------|----------|------|-----------|-------------|
| 10   | 131      | 7.545| 0.9987    | 0.965       |
| 20   | 220      | 12.67|           |             |
| 30   | 310      | 17.85|           |             |
| 40   | 415      | 24.36|           |             |
| 50   | 520      | 31.96|           |             |
| 60   | 621      | 35.77|           |             |

Table 2 shows prediction results with height parameter (H2) = 60 cm vegetation in the research. These were taken from analysis of primary data from recorded durations of time and rainfall amounts. Then, runoff can be predicted by the relationship of the value of linear correlation and value of exponent correlation.

Table 3. Rainfall with parameter H3

| Time | Rainfall | (Qs) | R. Linear | R. Exponent |
|------|----------|------|-----------|-------------|
| 10   | 120      | 6.912| 0.9989    | 0.9581      |
| 20   | 215      | 12.38|           |             |
| 30   | 305      | 18.72|           |             |
| 40   | 410      | 23.61|           |             |
| 50   | 518      | 29.83|           |             |
| 60   | 622      | 35.82|           |             |

Table 2 shows prediction results with height parameter (H3) = 90 cm vegetation in the research. These were taken from analysis of primary data from recorded durations of time and rainfall amounts. Then, runoff can be predicted by the relationship of the value of linear correlation and value of exponent correlation.

3.3 Rainfall Erosivity Index

Based on the data of rainfall erosion, when factors other than rainfall are not observed and considered to be constant, the groundwater flow is directly proportional to the parameters of the rainstorm, and identified as EI [20]. The relationship between soil loss and this parameter is linear, and individual rainfall event is correlated directly. Based on the research data, the erodibility (K) value of land ranges from 0.26 to 0.29, with a slope of one type (Ls) which is steep and rather steep at a slope of 30 degrees with a yield of 16-25%. Based on vegetation analysis, where the category of open land with a value (C) is equal to 1.0, the obtained erosion level is close to severe conditions, with the amount of erosion ranging from 60 to 480 tons/ha/year.

3.4 The Model of Rainfall Erosivity Index (EI\text{50})

The rain erosivity index (EI\text{50}) that had been developed through the equation was EI\text{50} = 6.119 \times (\text{Rain}) 1.21 \times (\text{Days}) 0.47 \times (\text{Maxp}) 0.53, with R being the rainfall annual average rainfall, D being the number of annual average of rainy days, and M being the maximum average rainfall of 24 hours per month for a period of one year [1, 13, 19, 20].

If the Bols equation can show that the magnitude of erosivity that occurs on land is influenced by the amount of rain that occurs during 30 minutes, then with a longer duration of rain observed in the study (R), a greater number of days (D), and a greater magnitude of the maximum rain value (M), the magnitude of erosivity becomes greater, and the inverse is true. In this research, a new equation model was developed regarding the Rain Erosivity Index Model by varying the rain duration (I) with the addition of the rainfall height parameter (H).
This parameter was used to prove that if the value of rainfall is small (R), with a small number of days (D) and the smallest value of maximum rain (M), there is a smaller amount of erosion that occurs on the land. When the rainfall height value increases (H), the resulting erosivity value will also be smaller. On the contrary, with a greater value of rain (R), and a higher value of rain height (H), then the resulting value of erosivity will also be greater. In this study, it can be assumed that H represents the plants around the land as the surface cover with high, medium, and low categories.

**Fig. 1.** Correlation between rainfall and time with H1

**Fig. 2.** Correlation between rainfall and time with H2

**Fig. 3.** Correlation between rainfall and time with H3
Figures 1, 2, and 3 shows the large and small value correlation analysis; the large value correlation is appropriately selected. From the results of primary data analysis of Tables 1, 2, and 3, these are followed by the linear value correlation results in the figures. The results of data analysis leads to the selection of value correlation with the parameter H3 because the R² Linear value is large and will be good if integrated into the Bols equation.

4. Conclusion
This research provides a temporary hypothesis for obtaining the value of the rain erosivity index with a different value from previous studies with EI30, which leads to the latest model for estimating and predicting from the Bols equation. Based on this research, the rain erosivity index was obtained with a predicting value and final equation of EI30 = 5.128 x (Rain)1.26 x (Days)0.47 x (Maxp)0.53 x (High)0.61 with the explained value being EI30 = 5.128 x (50.002)1.35 x (23)0.47 x (622)0.53 x (12)0.61, for which the conclusion of this research is a high rain erosivity index.

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