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ANALYSIS OF RAINFALL EROSIVITY INDEX USING THE BOLS AND LENVAIN METHODS

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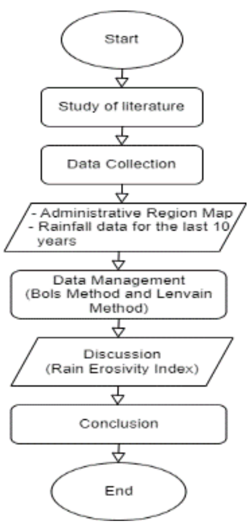
Graphical abstract



Abstract

Indonesia has a tropical climate, which causes variations in the intensity of rainfall. With a high level of rainfall intensity, Indonesia is vulnerable to soil erosion. The ability of rainfall to cause erosion is called erosivity. The aim of the study was to determine the rain erosivity index as a potential erosion control plan. The employed methods were the Bols and Lenvain methods involving the rainfall consistency test, analysis of average rainfall, and analysis of the erosivity index of rain. The results indicate that only Penengahan Station was eligible for the rainfall analysis with determination coefficient values (R2) of 0.9904 and 0.9889 with the Bols and Lenvain methods respectively. The annual average erosivity index value with the Bols method was 1762.23, while with the Lenvain method, it was 1280.19. With the results in mind, it is safe to infer that the use of the Bols equation is safer to apply to a plan concerning erosion potential mitigation caused by rainfall in the sub-sub watershed area of Khilau as the Bols method yielded a larger value.

Keywords: Rainfall, Erosivity Index, Soil Erosion, Bols Method, Lenvain Method, Khilau Watershed

1.0 INTRODUCTION

The tropical climate causes variation in the rainfall intensity in Indonesia. The high level of intensity underlies Indonesia's vulnerability to soil erosion. The adverse impact is not only on agricultural productivity, but also on the quality of downstream rivers and aquatic ecosystems (Dominati et al., 2010; Lukic et al., 2010; Omar, 2018; Lukic et al., 2019). In addition, changes in land use also greatly affect the process of erosion (Li et al., 2019; Borelli et al., 2020). Land use is an action that greatly influences the functions of a watershed water system (Pratama et al., 2016). In different cases of land use, the processes of erosion intensity are also different. A lack of attention to land use concepts and the effectiveness of methods led to more severe soil damage and further effects on water resources.

Erosion can cause soil damage, especially right where the erosion occurs, in the forms of the loss of fertile soil top layer for plant growth and reduced soil ability to absorb and hold water (Arsyad, 2012). Silt can also be caused by erosion, resulting in siltation of reservoirs, irrigation canals, and other bodies of water (Stewart et al., 2008; Yousef, 2014; Hartono, 2016). Therefore, analyzing the erosivity index of rain is essential in understanding the effects of rainfall on erosion.

Erosivity is the rainfall potential ability to cause erosion (Utomo, 2016). Erosivity of rainfall is one of the most important parameters for describing erosion processes and proposing conservational actions by means of erosion prediction models (Panagos et al., 2017; Yue et al., 2020). The most widely used erosion prediction model is known as the Universal Soil Loss Equation (USLE)which comprises six factors, i.e. rainfall erosivity (*R*), soil erodibility (*K*), slope length (*L*), slope steepness (*S*), vegetation cover (*C*), and erosion control practices (*P*) (Schmidt et al., 2016). Rain Erosivity Index (*R*) can show significant regional differences as a result of the amounts of rainfall, rainfall intensity, and seasonal characteristics (Strohmeier et al., 2016). Thus, the value of the *R* factor is used not only to evaluate erosion susceptibility, but also as an appropriate index to select areas of flood and drought (Panagos et al., 2015). Several methods can be employed to determine an erosivity index. This research applied the Bols and Lenvain methods.

This research is expected to find novelty about the level of erosivity index in an area that is influenced by the intensity and variation of rainfall and altitude of the place itself. This occurs in the research area which is a catchment area located adjacent to the Grand Forest Park, Lampung Province, so it becomes very strategic in conserving biodiversity and requires adequate monitoring, estimation and evaluation (Ratih et al., 2021; Nawras et al., 2022). The protected forest of this area is also used as a mixed plantation where, up to now, further research at the level of rain erosivity is still required as this information is very much needed to be the basis for further research at an even higher level. Given all that, the purpose of this study was to determine the values of the rain erosivity index with the Bols and Lenvain methods as a plan for potential erosion control in the Khilau watershed sub-watershed.

2.0 METHODOLOGY

2.1 Study Area

-The research location was the Khilau sub-sub watershed, Way Bulog sub-watershed, Way Sekampung watershed, Lampung Province. Most of these watersheds are in Pesawaran District and some are in Pringsewu District (see in Figure 1).

The data of this research were the rainfall data from 3 predetermined rain stations; Penengahan Station, Sukajaya Station, and Way Lima Station. The used rainfall data were 10 years' daily rainfall data from January 2013 to December 2022 obtained from the Mesuji Sekampung River Basin Center (BBWS). In this study, the analysis of the rain erosivity index involved two methods, Bols and Lenvain methods.

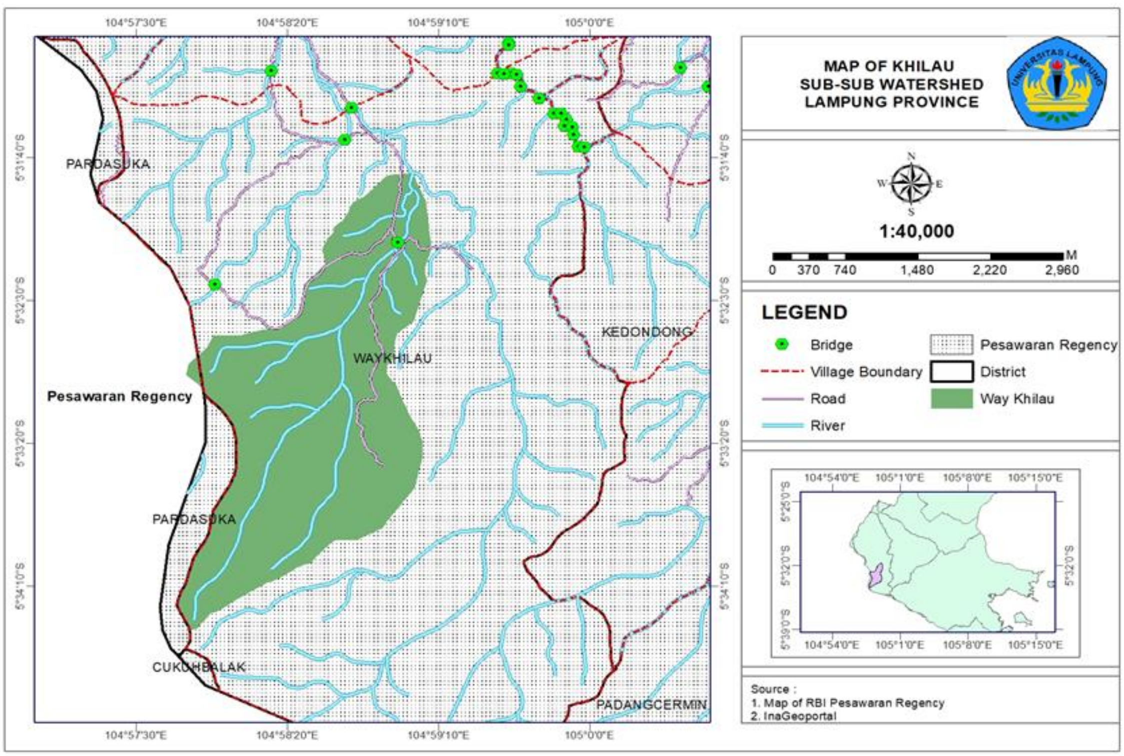


Figure 1 Map of the Khilau watershed, Lampung Province

2.2 Rainfall Consistency Test

Consistency test refers to the testing of field data correctness not affected by error during measurement. Before being used, the data should be checked for further hydrological analysis. Error is potentially caused by human, equipment, and location factors. If error occurs, the data is called inconsistent. Rain data is called consistent if it is measured and calculated thoroughly, accurately, correctly, and in accordance with the phenomenon when the rain occurs. Several ways to check the quality of rainfall data are: (a) carrying out field checks, (b) carrying out checks at the data processing office, (c) comparing the rainfall data with the climate data of the same location, and (d) performing the multiple mass curve analysis (Soewarno, 2000).

One way to test the consistency of rainfall data is performing the double mass curve analysis. This test figures out whether there has been a change in the environment or a change in the way of measuring. If the test results state that the rainfall data at a station is consistent, it means there has been no change in the environment and measurement during the recording of the data and vice versa. The accuracy of the calculation resulting in a hydrological forecast plays a vital role. This accuracy depends on the consistency of the data itself. In a series of rain observation data, non-homogeneity can arise and result in a mismatch deviation. The mismatch deviation obtained from non-homogeneity calculation is possibly generated by several factors; (a) change in the station location, (b) change in the data collection system, (c) change in the climate, and (d) change in the environment (Searcy and Hardison, 1960).

This method compares the cumulative annual rainfall at Station Y with that at the reference station, Station X. The reference station usually has the average value of those at several nearby stations. The cumulative value is described in the x-y-Cartesian coordinate system, and the formed curve is examined to see changes in the inclination (trend). If the formed line is straight, it means the recording at Station Y has been consistent. If the inclination of the curve breaks or changes, it means the recording at Station Y has been inconsistent and requires correction. The correction is made through the following equation (equation 1) (Asdak, 2007):

$$Yz = (tg\,\alpha \; x \; Y) / tg\,\alpha_o \quad (1)$$

Where *Yz* is the corrected rain data (mm), Y is the observed rain data (mm), *tg α* is the inclination before a change, and *tg αo* is the inclination after a change

2.3 Average Rainfall Analysis

Due to topographical conditions and a sufficient number of rain stations, the Thiessen Polygon method is used to determine the area of a rain station.. These polygons are created by connecting one station to another and then drawing perpendicular bisectors (Derakhshana et al., 2011). This method is used for the calculation of the weight of each station representing the surrounding area. This method is applied when the distribution of rain under review is unbalanced. The procedures of average rainfall calculation are (1) drawing rain stations on the map of the area under review, (2) connecting the stations with straight lines to form a triangular shape, (3) forming each side of the triangle with a heavy line, so the lines meet each other and are shaped like a polygon surrounding each station and each station represents the area formed by the polygon, and (4) measuring the area of each polygon and multiplying the result by the depth of rain. The results of the calculation are then divided by the total area under review. The average rainfall of each rainfall station can be calculated using Equation (2) as stated in Wanie et al. (2021) as follows:

$$P = \frac{P1\,A1 + P2\,A2 + P3\,A3 \ldots\ldots + Pn\,An}{A1 + A2 + A3 + \cdots + An} \quad (2)$$

Where *P* is the average rainfall, *P1* is the daily rainfall value of the first station, *A1* is the area of the Thiessen polygon at the first station, *Pn* is the daily rainfall value at the *n*-station, and *An* is the width of the Thiessen polygon area at the *n*-station.

2.4 Determination of Rain Erosivity Index

The erosivity of rain partially occurs due to the fact that raindrops fall directly onto the ground and make a flow of water over the soil surface. The erosivity index of rain is the erosion ability at a place. Khilau watershed is a humid area with a high rainfall intensity, the erosivity index value is calculated using two methods which are very appropriate for Indonesia due to its tropical climate (Permenhut, 2009).

The Bols method is recommended if the monthly rainfall average, number of rainy days and maximum daily rainfall average in a certain month are known. This method is based on data gathered over 38 years at 47 rain measuring stations on Java Island.. The rain erosivity index using Bold method can be computed via Equation (3) as stated in Asdak (2007).

$$R_B = 6{,}119 \; x \; (Rain)^{1{,}211} \; x \; (Days)^{-0{,}474} \; x \; (MaxP)^{0{,}526} \quad (3)$$

where Rm is the erosivity index of the monthly rainfall, Rain is the monthly rainfall average (cm), Days is the average number of rainy days per month (days), and Max P is the maximum rainfall average within 24 hours per month (cm).

The Lenvain method is applied when only average monthly rainfall is available [19]. Using the Lenvain method, the *R* factor is calculated using rainfall data collected from several regions in Java. The erosivity index formula using Lenvain method is represented by Equation (4) as mentioned in Asdak(2007).

$$R_L = 2{,}21 \; x \; P^{1{,}211} \quad (4)$$

in which *Rm* is the erosivity index of monthly rainfall, P is the average monthly rainfall (cm). With the Bols and Lenvain methods, the annual rainfall erosivity is obtained by adding up the erosivity indexes of monthly rainfall in a range of twelve months, from January to December, as seen in Equation (5)

$$R = \sum (Rm) \quad (5)$$

where *R* is the annual rainfall erosivity index, *Rm* is the monthly rainfall erosivity index. After calculating the data, an analysis of the relationship between the rain erosivity index and the average rainfall is performed for the comparison of the two methods.

3.0 RESULTS AND DISCUSSION

3.1 Recapitulation of Average Daily Rainfall

In this study, rain data are obtained from the closest rain stations in the Khilau sub-watershed areas such as Penengahan, Sukajaya, and Way Lima.. Table 1 displays the recapitulation of average daily rainfall of each station over a period of 10 years from 2013 to 2022. It can be seen that Penengahan Station has the greatest average daily rainfall with 1956.55 mm., Meanwhile, the lowest average daily rainfall of 1612.01 mm is observed at Sukajaya Station.

Table 1 Recapitulation of Average Daily Rainfall (2013-2022)

Rain Stations	Rainfall (mm)
Penengahan	1955.55
Sukajaya	1612.01
Way Lima	1758.92

3.2 Variation of Rainfall Consistency Test

The consistency tests of the rainfall data at Penengahan, Sukajaya, and Way Lima Stations are plotted in Figures 2 to 4. The rainfall data at all stations are almost similar where the coefficient of R^2 is approximately equal to 1.This indicates that the recorded rainfall data at the three stations are consistent and, therefore, feasible for a further hydrological analysis.

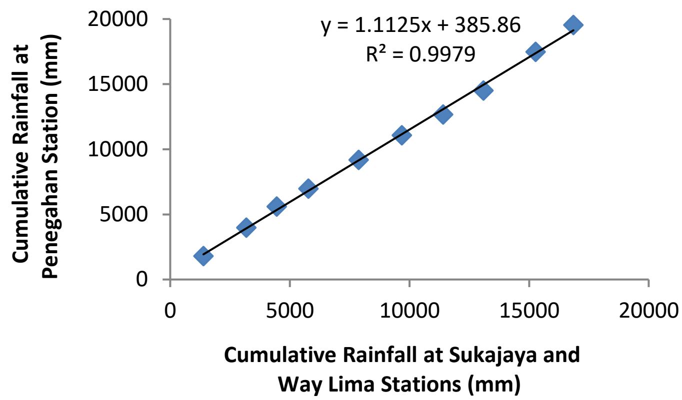


Figure 2 Rainfall Consistency Test at Penengahan Station

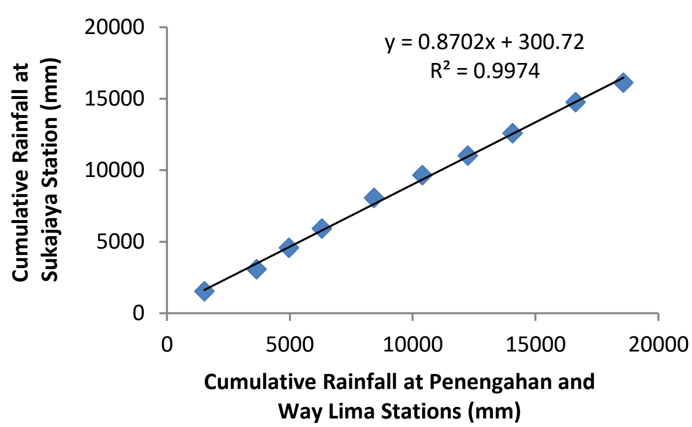


Figure 3 Rainfall Consistency Test at Sukajaya Station

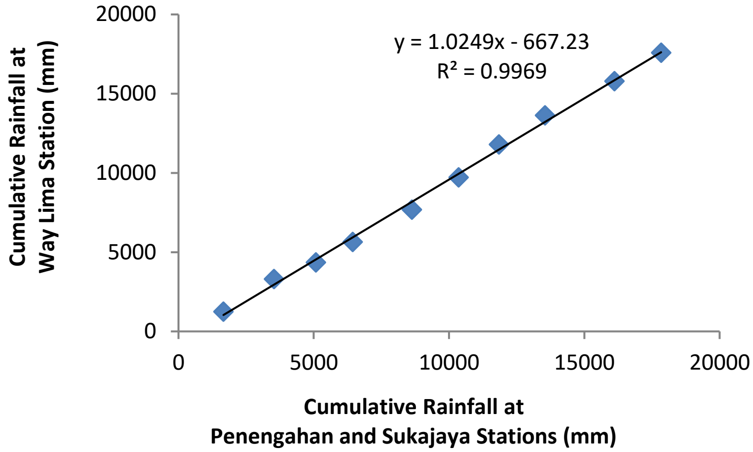


Figure 4 Rainfall Consistency Test at Sukajaya Station

3.3 Rain Erosivity Index

The results of the Thiessen Polygon indicate that the influence of the rain area of the Khilau sub-watershed only existed at Penengahan Station, with a rainwater catchment area of 100%. So, this study performed an erosivity index analysis with the rainfall data at Penengahan Station. The results of the calculation of the average annual rainfall, rainy days, maximum rainfall in the watershed and those of the rain erosivity index with the equations of the Bols and Lenvain methods are shown by Tables 2 to 5.

Table 2 Average Monthly Rainfall at Penengahan Station

Month	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average Rainfall (cm)
	(mm)										
Jan	240	435	251	190	311	90	143	506	523	273	29.62
Feb	194	139	150	291	203	283	161	242	359	395	24.17
Mar	165	64	217	219	165	273	225	268	387	168	21.51
Apr	229	155	165	140	236	64	210	145	442	144	19.3
May	62	93	100	68	153	132	195	109	167	99	11.78
Jun	33	47	111	83	59	148	113	76	229	60	9.59
Jul	5	152	44	35	113	99	0	26	138	24	6.36
Aug	3	141	129	11	151	61	0	14	118	169	7.97
Sept	6	52	24	35	193	161	90	0	145	117	8.23
Oct	165	178	36	17	123	123	15	17	83	154	9.11
Nov	333	247	104	139	295	236	197	10	169	88	18.18
Dec	361	498	269	149	213	211	263	425	196	388.5	29.73

Table 3 Average Rainy Days at Penengahan Station

Month	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average Rainy Days
Jan	16	16	15	11	8	5	6	17	17	11	13
Feb	7	6	6	8	9	13	8	9	15	14	10
Mar	31	2	9	7	8	13	9	14	17	5	12
Apr	9	9	10	6	9	5	7	8	18	7	9
May	2	5	5	5	6	9	7	5	7	5	6
Jun	2	2	6	6	3	6	7	4	10	6	6

Jul	1	12	3	2	5	5	0	1	6	2	4
Aug	1	6	5	1	6	4	0	1	4	5	4
Sep	0	3	1	2	7	8	5	0	8	6	4
Oct	9	9	3	1	6	4	1	2	5	9	5
Nov	16	16	5	4	12	9	9	1	9	5	9
Dec	15	21	12	9	11	8	9	13	9	14	13

Table 4 Average Maximum Rainfall at Penengahan Station

Month	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average (mm)	Average (cm)
Jan	32	51	32	48	79	27	43	62	57	72	50.3	5.03
Feb	42	55	39	70	45	82	27	86	45	52	54.3	5.43
Mar	58	57	57	50	46	74	51	48	48	48	53.7	5.37
Apr	97	32	24	42	61	21	58	57	52	60	50.4	5.04
May	23	35	48	25	63	29	47	42	42	34	38.8	3.88
Jun	23	42	57	20	40	62	25	30	43	27	36.9	3.69
Jul	5	28	20	20	35	42	0	26	42	14	23.2	2.32
Aug	3	73	73	11	41	23	0	14	42	50	33	3.30
Sep	6	37	24	30	36	50	36	0	30	29	27.8	2.78
Oct	62	35	12	17	42	52	15	9	32	28	30.4	3.04
Nov	42	32	45	38	50	55	60	10	36	28	39.6	3.96
Dec	45	47	75	32	43	95	53	90	42	59	58.1	5.81

Table 5 Computed Rain Erosivity Index for Bols and Lenvain Methods

Month-	Rain (cm)	Days (days)	Max P (cm)	Bols Method (R_B)	Lenvain Method (R_L)
Jan	29.62	13	5.03	260.36	221.69
Feb	24.17	10	5.43	239.82	168.13
Mar	21.51	12	5.37	190.04	143.48
Apr	19.30	9	5.04	175.50	123.81
May	11.78	6	3.88	106.93	88.26
Jun	9.59	6	3.69	81.18	47.83
Jul	6.36	4	2.32	46.73	27.36
Aug	7.97	4	3.30	74.01	37.19
Sept	8.23	4	2.78	70.26	40.85
Oct	9.11	5	3.04	75.01	44.60
Nov	18.18	9	3.96	160.03	114.14
Dec	29.74	13	5.81	282.35	222.86
Annual Average Rain Erosivity Index (*R*)				1762.23	1280.19

3.4 Annual Average Erosivity Index

The findings revealed that the annual average erosivity indexes using Bols and Lenvain methods were 1762.23 and 1280.19, respectively. With this in mind, it is inferable that the Bols formula is safer to use for erosion estimation and from the perspective of the level of accuracy, the Bols method is also recommended since it involves more factors in its equation, such factors of rain erosivity as the average rainfall, number of rainy days, and maximum rainfall.

It is also an implication of the calculation results that, with both the Bols and Lenvain formulas, the highest and lowest annual amounts of rainfall produced the highest and lowest rain erosivity indexes. In addition, the rainy days and lowest maximum rainfall also indicated the lowest values with these two different formulas. This proves that high annual rainfall leads to a high annual rainfall erosivity index. The relationships between the accumulated daily rainfall and the rain erosivity with the Bols and Lenvain methods are presented by Figure 5.

With the Bols method, the relationship between the rainfall and the rain erosivity can be represented by the equation y = 9.5772x – 9.219 with a determination coefficient (R^2) of 0.9904, while with the Lenvain method, the equation 8.2181x – 27.242 with a determination coefficient (R^2) of 0.9889 constitutes the relationship. Taking this into account, it is obvious that the Bols and Lenvain methods are equally good to employ as the two equations generated good positive relationships or considerably strong relationships between the rainfall and the rain erosivity since the R^2 values were close to 1. Then again, it is reasonable to infer a higher coefficient of determination (R^2) provided a higher level of safety. So, it is found that the novelty is the application of the Bols method is more advisable for the planning of potential rainfall-driven erosion mitigation in the watershed area.

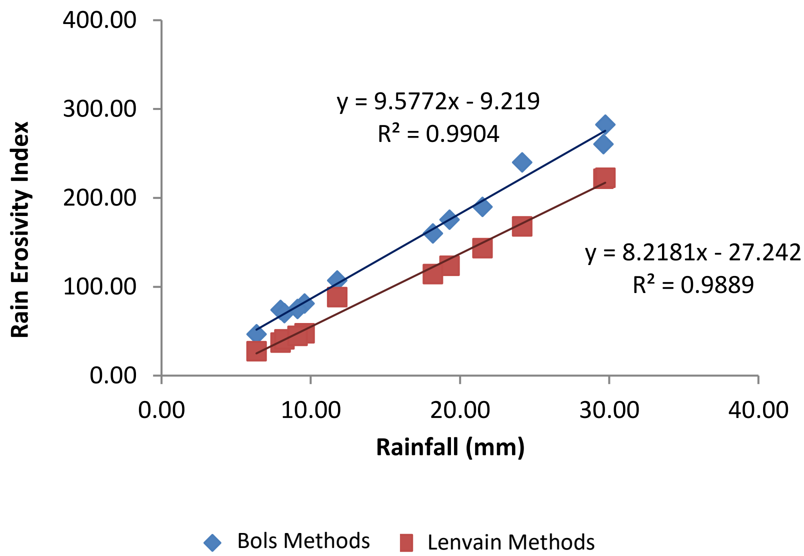


Figure 5 Relationships between Rainfall and Rain Erosivity Index using Bols and Lenvain Methods

The results above indicate that the greater the rain intensity, the greater the produced kinetic energy (erosivity index value). This agrees with Dijk, who asserts that rain intensity greatly affects the kinetic energy of rain, but a large amount of rainfall does not necessarily result in a high level of erosion or a high rain erosivity value since natural rain does not always underlie soil erosion (Dijk et al., 2002). Low-intensity rain lasting for a very long time nevertheless produces a tremendously large amount of runoff, which, in turn, gives rise to erosion. On the contrary, very short-lasting high-intensity rain does not bring about erosion.

4.0 CONCLUSIONS

The rain erosion index is a measure of the ability of rain to cause erosion. In calculating erosion, several important parameters are needed, one of which is the erosivity index to measure the ability of rain to cause erosion. In addition, the Bols method produced a larger determination coefficient (R^2), making the Bols equation safer to apply to the mitigation planning of potential rainfall-triggered erosion in the Khilau sub-watershed area.

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