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Sensitivity Analysis of the Revised Universal Soil Loss Equation's Rainfall Erosivity Factor (R-Factor)

[1] Samuel Law Lik Ging, [2] Kuok King Kuok
[1] Swinburne University of Technology,[2] Swinburne University of Technology
[1] SLaw@swinburne.edu.my, [2] kkuok@swinburne.edu.my

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Abstract:
The Erosion and Sedimentation Control Plan (ESCP) is undoubtedly useful for mitigation of soil erosion at construction sites and agricultural areas. However, the ESCP computational factors of the Manual Saliran Mesra Alam 2nd Edition (MSMA 2) are only for application in the Peninsula, and such factors are not available for Sarawak and Sabah. This research aims to carry out the sensitivity analysis of the R-Factor of the Revised Universal Soil Loss Equation (RUSLE). In this research, a study site was identified, and the actual equatorial characteristics of the study area were used as inputs. The Sensitivity analysis were carried out within specific typical equatorial rainfall intensities of 2,000-6,000 mm/yr. Based on the findings, it is found that the degree of sensitiveness of R factor 0.34%. The findings could be used as supplementary information for Sarawak Urban Stormwater Management (SUStoM) for a development project. By knowing the sensitiveness of R-factor of the study area, the same methodology can be applied to achieve better outcomes of reduction in soil loss for a better environmental quality in Sarawak.

Keywords: *Revised Universal Soil Loss Equation (RUSLE), Equatorial Characteristics, Rainfall Erosivity Factor (R), Annual Soil Loss, Sensitivity Analysis.*

I. INTRODUCTION

Sarawak has the biggest territory among the Federation Partners of Malaysia is well-known not just because of living style of citizens but also the nature assets such as rainforests and caves that act as the main pillars to support the financial status. Sarawak with 124,450 km^2, which is about 37.5% of Malaysia's total land area and with a population of approximate 2.8 million in Sarawak [1]. The high rainfall volume in Sarawak has been causing significant erosion problem to hill and mountain slopes that have been noticed especially at areas without proper management of stormwaters and runoffs due to flash flooding in certain areas with rapid development citations. It is high time that this issue should be resolved to minimize losses by adopting better and more cost-effective erosion control and drainage systems.

The Department of Irrigation and Drainage (DID) of Sarawak introduced the design standards called Sarawak Urban Stormwater Management (SUStoM) Guidelines to replace MSMA 2nd Edition for design of drainage systems. The main objective of SUStoM is to reduce flooding by integrating with the structural designs and Best Management Practices (BMPs), i.e., to "Control-at-Source" [2]. With respect to MSMA 1st Edition, MSMA 2nd Edition and SUStoM, one of the most crucial demerits of the guidelines is the omission on the details of the probable consequences of surface runoffs that would lead to possible land slide due to rill and gully erosion.

Hypothetically, the rate of erosion can be estimated by using RUSLE, and the RUSLE's R-factor is extremely sensitive to annual rainfall intensities of the regions understudy; annual rainfall intensity at temperate region of <2000 mm/yr versus equatorial's 2000-6000 mm/yr. Sensitivity analysis on RUSLE's R-factor can be accomplished by varying the annual rainfall intensity within a specific range. The significance of this study is to determine the sensitiveness of a development area understudy for allocation of most cost-effective erosion control technologies or methodologies.

II. Literature Review

The term "Erosion" usually refers to describe the wearing down of a landscape and soil erosion can be defined as the detachment or entrainment of soil particles by raindrop impact, and later transported by surface runoff and deposited at downslope. Soil erosion-sedimentation is one of the natural processes that happens everywhere on the ground surface. It is a process of transportation, erosion, compaction and deposition of sediment [3]. With a rapid increase in urbanization activities for construction purposes or the expansion of agriculture lands, loss of soils and land area are the major economic losses that would cost a lot to the inhabitants and would impact the ecosystem.

Rainfall erosivity index, R-Factor can be expressed as R-Factor = EI_{30} where E = Rainfall Energy and I_{30} = Rainfall Energy [4]. Rainfall intensity can vary with respect to climatic and geological conditions of the study area. It is noteworthy that a considerable number of previous researches and studies on the application of R-Factor to suit the local requirements have been cited. Figure 1 shows the plot of the co-relationship of rainfall intensity (mm/hr) versus kinetic energy contents ($Jm^{-2}mm^{-1}$) [5].

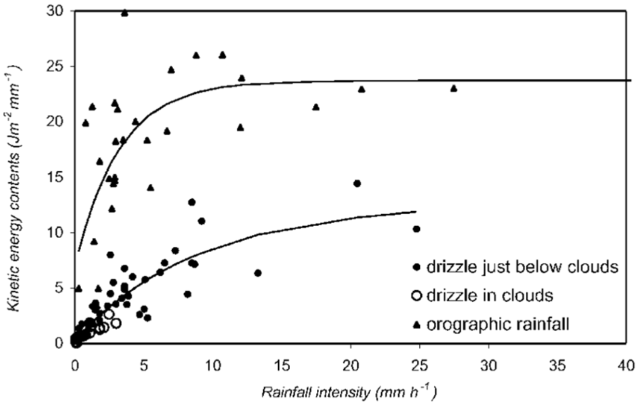

Fig. 1 Rainfall Intensity versus Rainfall Kinetic Energy [5]

A few researchers proposed different R-Factor equations based on the locality and actual conditions of the regions. However, a more reasonable approximation of R-Factor of a specific area would require comprehensive rainfall intensity data of the area understudy. Table 1 shows the R-Factor equations proposed by a number of researchers who carried the research on R-Factor correlated with EI_{30} [6]. Table 2 shows the definitions of other factors required by RUSLE [4].

TABLE 1. Rainfall Erosivity Factor (R) by Different Researchers [6]

Sources	Year	Place	Equation	Remarks
Wischmeier W.H. & Smith D.D.[7]	1958 1978	United States	$R = EI_{30}$	$E = 0.1187 + 0.0873\log I_{30}$
Morgan R.P.C. [8]	1974	Peninsular Malaysia	R = 9.28P – 8838.15	P = Annual precipitation
Lal R. [9]	1976	Nigeria	$R = AI_m$	A = Rainfall amount of single

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				rainfall event I_m = Maximum 7.5 minutes rainfall Intensity
Roose E. [10]	1977	West Africa	$R = (0.5 \pm 0.05) P$	P = Annual precipitation
Bols P.L. [11]	1978	Indonesia	$R = 2.5P^2/100 \times (0.073P+0.73)$	P = Annual precipitation
Moore R.R. [12]	1979	East Africa	$R = 0.029(3.96P + 3122) - 26$	P = Annual precipitation
Ulsaker L.G. & Onstad C.A. [13]	1984	Kenya	$R = AI_{30}$	A = Rainfall amount of single rainfall event
Renard K.G. & Freimund J.R. [14]	1994	United States	$R = 0.0483P^{1.61}$	P = Annual precipitation
Yu B. & Rosewell C.J. [15]	1996	Southeastern Australia	$R = 0.0483P^{1.61}$	P = Annual precipitation
Ha N.T. [16]	1996	Vietnam	$R = 0.548P - 59.9$	P = Annual precipitation

TABLE 2. DEFINITIONS OF FACTORS FOR RUSLE [4]

Factors	Terminology	Definition
K	Soil Erodibility Factor	Measurement on susceptibility of soil particles based on ability of rainfall on detachment and transportation of soil particles.
LS	Topography Factor	Slope length and slope gradient of study area
C	Vegetative Cover Factors	Ratio for soil under specified crop to the loss from bare soil/the type of vegetation at site
P	Erosion Control Practice Factor	Coefficient for the management of the site/the ratio of soil erosion rate provided with specific surface condition

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III. METHODOLOGY

For RUSLE, the main factors consist of R, K, L, S, C and P. In this research, R factor is investigated, and simulations are made for the sensitivity analysis. The study area (red dotted spot) is located at Santubong of Sarawak, a tourist spot with high visitor's rate (Figure 2). It is located at rural area with reserved natural environments and some unique plants and animals could be found such as rare proboscis monkey, mangrove swamps, fireflies and others [17]. Figure 2 shows the map of Sarawak and the red line demarcated area denotes the study site (Figure 3). Based on previous researches of the area, the parameters and characteristics of Santubong area, which are the inputs are shown in Table 3. The input values are the optimal configuration for the calculation of sensitivity analysis.

Fig. 2 Map of Sarawak

Fig. 3 Locality Plan of the Site

TABLE 3. INPUTTED VALUE IN RUSLE SPREADSHEET

Parameters	**Value**	**Factor**	**Input Value**
Mean Annual Rainfall	3000mm/yr	R	3000 mm/yr
Length of Hill Slope	200–250 m	L	225 m
Width of Site	1100m	w	1.1 km
Gradient of Hill Slope	7.5%	S	7.5%
Soil Types	Rjn – Rajang	K	0.3
Soil Support Practice	None	P	1
Future Land Use	Old shifting Agriculture	C	0.38

Once the values of the required data are determined factors, soil loss can be estimated by using the Revised Universal Soil Loss Equation (RUSLE) as shown in the following equation [18].

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where,
A = Soil loss per unit area (tones/acre/year)
R = Runoff factor
K = Soil erodibility factor
LS = Slope length-steepness factor
C = Cover management factor
P = Support practice factor

For sensitivity analysis, the values from estimated soil loss amount by RUSLE is required to calculate average annual total solid concentration in Equation 4 [7], and the simulated percentage of sensitivity in Equation 5. The following equations 2, 3 and 4 show the procedures of the required computations.

$$AAR(\text{m}^3) = \text{Mean Annual Precipitation (m)} \times \text{Total Development Area (m}^2) \quad (2)$$

Where,
AAR = Average Annual Rainfall
R = Runoff factor
K = Soil erodibility factor

$$AASLD\ (\text{t}) = \text{Average Annual Soil Loss per Unit Area (t/ha/yr)} \times \text{Development Area (ha)} \quad (3)$$

Where,
AASLD = Average Annual Solid Loss from Development

AATSC (mg/l) = *AASLD* (mg) / *AAR* (l) (4)

Where,
AATSC = Average Annual Total Solid Concentration

The rainfall intensity over the study area of 3000 mm/year is considered as the "Actual Value" denoted as V_O. To determine the sensitivity of R-Factor, rainfall intensities from 2,000mm/year to 6,000mm/year at 100mm/year intervals are used to determine the Average Annual Total Solid Concentrations (AATSC). The degrees of sensitivity are computed to determine sensitivity differences at incremental rainfall intensity of 100 mm/yr intervals within the range between 2000 mm/yr and 6000 mm/yr. The degree of sensitiveness of R-Factor (expressed in % Sensitivity) can be computed by using Equation 5.

$$\% \text{ Sensitivity} = [(V_S - V_O) / V_O] \times 100\% \quad (5)$$

Where,
V_S = Computed *AASTC* by Using Varying Rainfall Intensities (2000-3000 mm/yr at rainfall intensity of 100 mm/yr intervals)
V_O = Observed Onsite *AATSC* with respect to Actual Rainfall Intensity Onsite at 3000 mm/yr.

IV. Results

Table 4 shows the simulated R-Factor sensitivity analysis (%) conducted by using RUSLE spreadsheet by adjusting the rainfall from the range of 2000 mm/year to 6000 mm/year at rainfall intensity of 100 mm/year intervals. With 3000 mm/year as the actual or observed average annual rainfall intensity, the computed differences in sensitiveness expressed in percentages are shown in Table 4, and the degree of sensitivity (% Sensitivity) computed to determine sensitivity differences for different ranges of the R-Factor are graphically plotted in Figure 4.

TABLE 4. R-FACTOR SENSITIVITY ANALYSIS (%)

Factor						Estimated Soil Loss	Sensitivity Analysis
R	K	L	S	C	P	(t/ha/yr)	(%)
2000	0.30	225	7.5	0.38	1.00	1350	-0.17
3000	0.30	225	7.5	0.38	1.00	2028	0.00
4000	0.30	225	7.5	0.38	1.00	2707	0.08
5000	0.30	225	7.5	0.38	1.00	3385	0.13
6000	0.30	225	7.5	0.38	1.00	4064	0.17

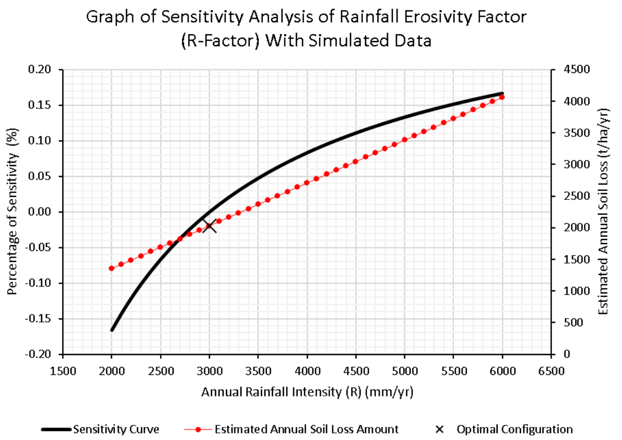

Fig. 4 Estimated Soil Loss and R-Factor Sensitivity Analysis

The results show that the percentage of sensitivity falls within the range of -0.17% and +0.17%, where it is generally considered as "insignificant" level of contribution to soil loss amount. The estimated annual soil loss amount increases with incremental annual rainfall intensity; a steady increment from 1350 t/ha/yr to 4064 t/ha/yr with respect to actual or observed onsite soil loss of 2028 t/ha/yr. Possible reasons of increment is due to the high rainfall runoff that would result in higher surface water volume. Higher volume of runoff would mean higher tendency of soil particles being carried away from the soil surface.

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Generally, the results depict a stable increment, but it is only ideal with the same environmental conditions where all other factors would remain unchanged while simulating the R-factor. The coverage of the study area would affect the simulated outcomes of R-Factors sensitiveness based on the adjustment of rainfall due the to the change in runoff area, where the results might not be consistent and higher chance of errors would occur; comparison between the varying study area size and change in rainfall intensity. It can be concluded that the changes of rainfall based on the conditions in the simulations have negligible or extremely insignificant on the estimated soil loss amount.

V. Conclusion

From this study, the following conclusions can be drawn: (1) Based on the problem statement, the issues of incomplete calculations on ESCP of site in Sarawak had started to do an approach in this research by having the implication of R-factors from MSMA 2nd Edition with relation to Sarawak and RUSLE is adapted for the calculations which could help in the estimation of soil loss onsite, (2) from the hypothesis, the estimation of rate of erosion had been calculated by having RUSLE with related parameters for R-factor that suits the study area located in Sarawak, and (3) the simulations and analysis had been done on the given parameters and simulated data, where the simulated result is compared by the estimated soil loss amount and resulted in a percentage of 0.34% in sensitivity analysis for R-factor.

VI. Future Recommendations

There are some recommendations could be considered to improve this spreadsheet for future development purposes. (1) The collections and the updating of data on the individual data can be widen and improved with more researches and studies on the factors to get more precise outcomes for the spreadsheet, (2) other than RUSLE, the spreadsheet could have more future expansion, such as adding in detention pond calculations as an extension to the spreadsheet, (3) for the practicality of this spreadsheet, it is good to apply and test-run with calculations on the soil loss of the smaller site as pilot project to improve the spreadsheet, and (4) the layout and data input of the spreadsheet could be more user friendly and more types of equations of soil loss can be included.

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