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Effects of Rainfall Intensity, Kinetic Energy and Slope Angle to the Upslope, Downslope, and Lateral Slope Components of Splash Erosion in Hillslope Agriculture: A Case in Badiangan, Ajuy, Iloilo

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ABSTRACT

This study was conducted in Barangay Badiangan, Ajuy, Iloilo City, Philippines (11°10'N, 122°58'E) to determine the effects of rainfall intensity and other rainfall-derived parameters on the directional components of splash erosion in hillslopes. There are five experimental set-ups with slope angles ranging from 0% to 48% were tested under natural rainfall conditions using a modified splash collector. The data collected show~~s~~ that kinetic energy, slope, and rainfall intensity have shown significant effects on splash erosion. The models obtained using regression analysis are $Q_{det} = 0.0093(KE^{0.80})$ and $Q_{trans} = 0.060(KE^{0.107})(S^{0.700})(I_{20}{}^{0.700})$. The model equation performance has been validated using the Standard Error of Estimates with values of 12 and 9.4 for splash detachment and splash transport, respectively. The constants used for kinetic energy in detachment and slope in transport align with the research by Quansah (1981) for sandy soil, which is similar (the characteristics) to the soil at our research site. Additionally, rainfall intensity, especially with a 20-min duration, generated the best model as it yielded the lowest SEE value for all cases.

INTRODUCTION

Soil erosion is one of the most serious global and ecological environmental crises in progress today, resulting from the interaction of the soil itself, climate, relief, surface cover, and land use practices (Hoyos & Waylen 2005, Renschler et al. 1999). The problems caused by soil erosion include decreased soil fertility, increased landslide activity, reservoir sedimentation, contaminant diffusion, rocky desertification, and ecosystem disturbances, all of which significantly impact human development (Bai et al. 2013, Jiang et al. 2014, Syvitski et al. 2005).

Splash erosion, which is the first stage of interrill erosion, involves soil detachment and transport resulting from raindrop impact (Kinnell 2005, Morgan 2005), which can destroy soil structure, increase runoff turbulence, and enhance sediment delivery (Dussaillant 2011, Ma et al. 2015). Generally, raindrop kinetic energy (KE) is accepted as the best predictor of rainfall erosivity that can define the ability of raindrops to detach soil particles (Fernández-Raga et al. 2010, Hammad et al. 2006). In splash erosion, to overcome the particle weight and the cohesive force binding the particles together for detachment and transport, some of the important factors to consider are the rainfall intensity-kinetic energy relationship, the slope steepness, and transportability.

Rainfall intensity and the kinetic energy of a rainfall event are important parameters in erosivity (Fornis et al. 2005, van Dijk et al. 2002). The erosive force of rainfall involves the detachment of soil particles by the kinetic energy from falling raindrops and the transport of these soil particles through surface runoff (Vrieling et al. 2014). Rainfall kinetic energy has been known to cause erosion, especially in tilled bare land, since vegetation intercepts the impact of rain and protects the soil surface as well as intercepts runoff (Zuazo & Pleguezuelo 2008).

According to Parsons et al. (1991), although there is some controversy, most authors suggest that the intensity of splash erosion increases with slope. Many studies have been conducted to evaluate the relationship between splash and slope since the influence of slope angle on soil detachment is of importance in soil conservation (Aissa et al. 2014, Bryan 1979, Torri & Poesen 1992). If the soil has no slope, material splashes away from the point of impact randomly in the surrounding area (Kinnell 2005). In a sloped soil surface, material splashed downslope travels further than those upslope, resulting in the net downslope migration of detached material. That downslope migration increases as the slope gradient increases, but it takes many drop impacts to cause much material to move downslope in most cases (Quansah 1981).

The transport of detached soil particles, according to Kinnell (2005), may occur as a result of raindrops and flow acting either singly or together. He further identified detachment and transport systems; included here is the raindrop detachment with transport by raindrop splash (RD-ST) system. This system is due to the energy from raindrop impact, which causes the breakdown of soil particle bonds that hold them together, resulting in the transportation of particles from the raindrop impact site (Kinnell 2005).

Soil properties and rainfall physical parameters, including rainfall intensity, kinetic energy, and their various interactions, were studied as this research aims to investigate the effects of rainfall parameters at variable slope angles on the directional components (upslope, lateral, and downslope) of splash erosion characteristics. This investigation seeks to help prevent further degradation of the soil. We constructed an experimental setup on hillslopes from the agricultural lands of Badiangan, Ajuy, and Iloilo to develop a model that predicts the net amount of splash erosion downslope as a function of rainfall parameters and the slope of the ground surface. This information can estimate the quantity of splash erosion, which is the initial stage of soil erosion on slopes (Shanshan et al. 2018).

MATERIALS AND METHODS

Study Site

Iloilo Province, situated in the center of the Philippine archipelago as shown in Fig. 1, occupies the southern and northeastern portions of Panay Island. The topography of Iloilo Province varies from flat lands and rolling hills to mountain peaks and ranges.

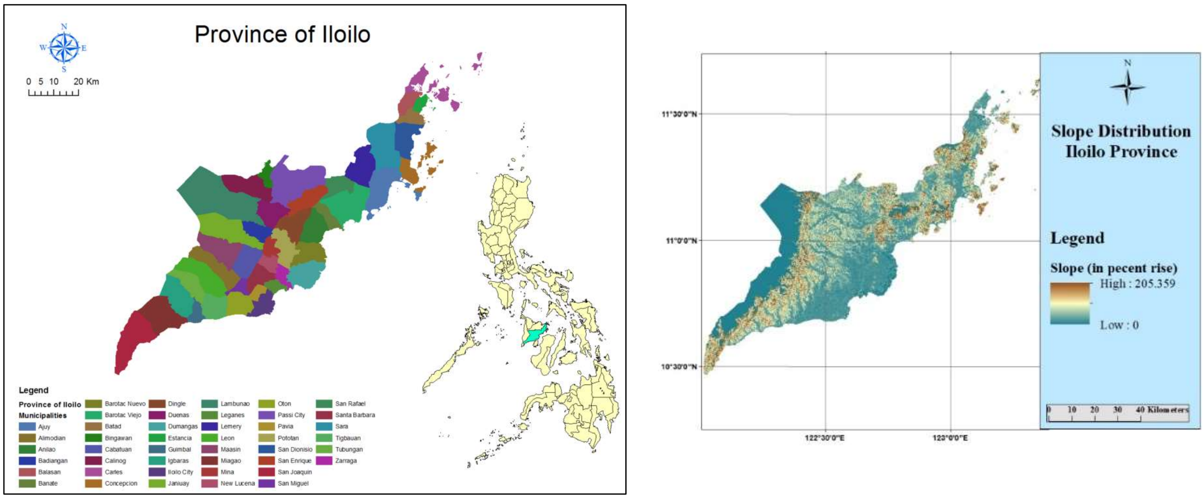
The field experiment was conducted on the hillslope of Ajuy (Fig. 2) in the northeastern part of Iloilo in the Philippines. Ajuy is an agricultural town that produces various crops such as corn, coconut, sugarcane, fruit trees, bananas, coffee, bamboo, root crops, and other minor crops.

Badiangan is a barangay in Ajuy with an estimated elevation of 201.7 meters (661.7 feet) above mean sea level. The barangay's topography is predominantly sloping, making it susceptible to land degradation.

Experimental Materials

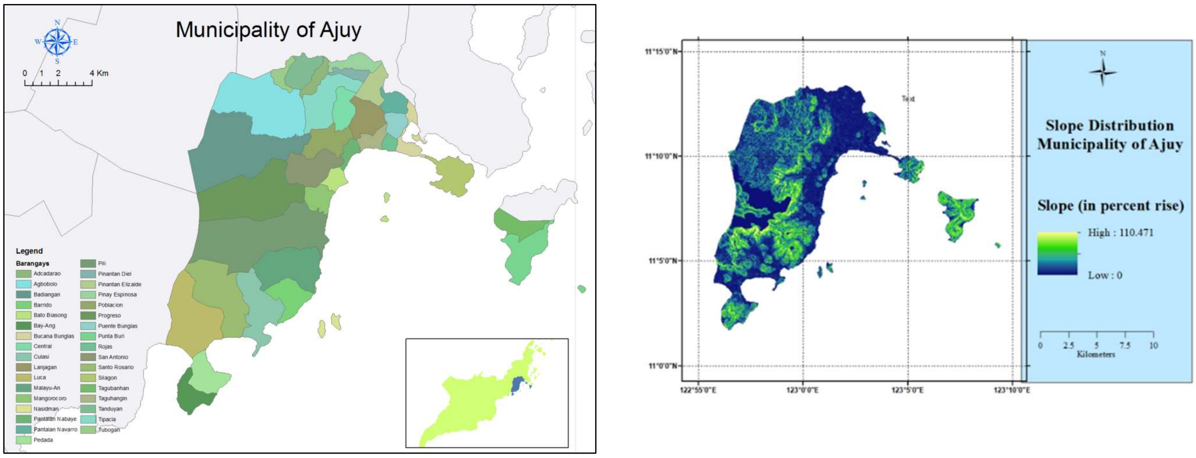
All experiments were carried out from January 2020 until January 2021. The experimental set-ups were placed at slopes of 0%, 5.94% (3.40), 10.17% (5.820), 24.57% (14.01) and 48.92% (27.70). These locations were selected based on the slope variability of the chosen hillslope.

The instrument used is a modified splash collector, which is made up of a soil tray and lateral splash collectors. The splash source was exposed to the natural rain. The soil trays contain soils with more than 50% or more of coarse fractions passing the number 8 sieve and less than 5% passing the number 200 sieve. Therefore, all soils are considered clean sands. More than 50% of soil particles are of sizes between 0.425 mm to 2.00 mm. Therefore, sandy soils are considered medium coarse sands. Based on the grain size distribution curves for all soil samples, it was found that uniformity coefficients (Cu) for all soils are less than 6. Therefore, all



(a) (b)

Fig. 1: Map of the Province of Iloilo and its slope distribution.



(a) (b)

Fig. 2: Map of the Municipality of Ajuy and its slope distribution.

soil samples in trays 1 to 5 are Poorly Graded Medium Coarse Sand (SP). Samples of the soil particles detached from and thrown outside of the splash source were collected by the splash collectors.

The splashed soil retrieval was done in an irregular schedule due to some difficulty in doing it on steep slopes at times when the soil is still wet because it is slippery. The soil inside the tray was cleaned from stone fragments and roots. The retrieved soil samples are oven-dried and weighed to get the amount of soil splashed after the event.

Rainfall Measurement

Rainfall intensity was measured using a tipping bucket HOBO Rain Gauge with a Data Logger, that is, the Data Logging Rain Gauge is a battery-powered rainfall data collection and recording system that includes a HOBO® Pendant Event data logger integrated into a tipping-bucket rain gauge. This model automatically records up to 3200 mm of rainfall data that can be used to determine rainfall rates, times, and duration. This data logger operates in an outdoor environment, and in this experiment, the recording was set at a 1-minute time interval.

Wind Energy

Wind energy affects splash erosion by rolling soil particles along the surface through to a strong wind that lifts a large volume of soil particles into displacements, creating splash erosion. Pedersen & Hasholt (1995) first studied the influence of wind speed on rain splash erosion, where they demonstrated that the rise in kinetic energy of raindrops due to prevalent wind direction during an event can be determined, realizing that wind speed enhances the kinetic energy of rainfall intensity (Pedersen & Hasholt 1995). Because of the varying components of the wind direction, it can cause splash erosion at different directional components.

Wind energy can dislodge surface soil particles and transport them to great distances, with a 5-meter maximum displacement. According to Morgan, the most erodible particles are 0.10–0.15 mm in size; particles between 0.05 and 0.5 mm are generally selectively removed by the wind (Morgan 2005). The soil movement depends upon the grain size of the soil. Clay and sandy soil are more likely to erode than medium-textured soils (Krogman 1983). Resistance to wind erosion increases rapidly when primary particles and aggregates larger than 1 mm predominate (Morgan 2005). In this experiment, the wind direction and velocity were not measured, but its effect was minimized because the perimeter of the set-ups was covered with a tarpaulin (0.8 m high) and, at the same time, the surrounding hills shielded them from direct exposure to the prevailing wind. This analysis can indicate that the wind speed can explain outliers between splash erosion and kinetic energy, especially in those events that are not characterized by other rainfall parameters in splash erosion. However, Pedersen et al. highly noted that it is also important to know the slope aspect of the wind to emphasize how much slope aspects influence energy levels (Pedersen & Hasholt 1995).

Model Formulation for Splash Detachment and Transport

As raindrops impact the soil, it detaches particles and transports them. This detachment is taken as soil splashed upslope added to the soil splashed downslope, while net splashed transport is soil splashed downslope less soil splashed upslope (Grosh & Jarrett 1994, Quansah 1981).

$$Q_{\mathrm{det}} = Q_{\mathrm{upward}} + Q_{\mathrm{downward}} \qquad \ldots(1)$$

$$Q_{\mathrm{trans}} = |Q_{\mathrm{downward}} - Q_{\mathrm{upward}}| \qquad \ldots(2)$$

Quansah noted that downslope splash increased significantly with increasing slope angle and suggested that:

$$Q = a(KE)^b S^c \qquad \ldots(3)$$

Where Q is classified into two components – Q_{det} and Q_{trans}. The Q_{det} represents the splash detachment while Q_{trans} describes the net splash transport. S is the percent slope, and a, b, and c are empirically determined constants.

Several researchers demonstrated that the power law is the most suitable mathematical function between rainfall kinetic energy and rainfall intensity. However, Quansah (1981) did not include rainfall intensity in their model which was debunked by other researchers. For example, Shin et al. (2016) described the universal power law for a relationship between rainfall kinetic energy and rainfall intensity. They proposed a new model based on the rainfall power theory under an ideal assumption that raindrop is uniformly distributed in constant rainfall intensity. Incorporating rainfall intensity into their model, the accuracy of the model increased by 20% when compared to Quansah (1981). Moreover, using rainfall intensity to splash erosion model has a small average relative difference (0.32%) against the testing data – proving that rainfall intensity increases the predictive capability of the splash erosion model. Therefore, in this study, rainfall intensity is used as one of its explanatory variables.

Regression Modeling

There are 40 rainfall events gathered and have been considered in the processing. Since the data collected in the experiment consisted of outliers that lie at an abnormal distance from other values in a random sample from a population, multiple options, like the omission of some data from the record, were explored to obtain a higher value for the R-squared.

According to Kinnel (2005), if the soil has no slope, material splashes away from the point of impact randomly in the surrounding area. Still, in the sloping ground, the amount of splashed soil increases as the slope increases (Morgan 2005). Thus, datasets obtained from the slope 0% were discarded.

On a slope receiving rain, the soil particles that are detached by the raindrops may cause more material to travel downward along a hillslope as it travels further than upslope. The downslope transport increased with slope, whereas upslope transport decreased (van Dijk et al. 2003). This downward movement of soil material is caused by the distance of splash along a slope being longer downward than in the upward direction. Splash erosions, therefore, must correspond to this inequality. $Q_{downward} > Q_{upward}$, hence, the discarding values with $Q_{downward} < Q_{upward}$ was also explored.

The amount of rain inducing significant erosion was also studied. Rainfall depth less than 10 mm and maximum rainfall intensities less than 12 mm.h^{-1} ($I_R < 12$) and 25mm.h^{-1} ($I_R < 25$) were discarded to check if there was an improvement in the model to capture the data points. Hudson's study in Zimbabwe emphasized that rainfall intensities less than 25 mm.h^{-1} are not able to yield splash erosion in a significant amount (Hudson 1965). Morgan also used this threshold in his study in Malaysia and values larger than 10 mm.h^{-1} in England (Foot & Morgan 2005, Pedersen & Hasholt 1995).

Model Simulations

The experimental setup of the study has gathered 40 samples from Badiangan, Ajuy, and Iloilo. Not all of them were used because some samples were discarded, as mentioned in the previous section. Microsoft Excel was used in the regression analysis.

The splash erosion results are evaluated using R-squared and Mean Squared Error (MSE). These performance measures are usually used for model comparison, and it is mathematically expressed as:

$$R^2 = 1 - \frac{\Sigma(y_i - \hat{y_i})^2}{\Sigma(y_i - \bar{y})^2} \qquad \ldots(4)$$

where y is the actual splash erosion, while $\hat{y}$ is the predicted splash erosion.

To determine the accuracy made by the regression model, the standard error of estimates (SEE) is used to measure the uncertainty associated with the observed data. It is calculated as:

$$\sigma_{est} = \sqrt{\frac{\Sigma(Y - Y')^2}{N}} \qquad \ldots(5)$$

where σ_{est} is the standard error of the estimate, Y is an observed data, Y′ is a predicted data, and N is the number of data pairs. The smaller the value of the SEE, the better the performance of the regression model.

Data and Processing

The first objective of the study is to relate the amount of the directional splash components to the different rainfall parameters at varying slopes. Linear regression was used in the context of sensitivity analysis to determine which explanatory variables are strong enough to predict splash erosion. Moreover, the impact of uncertainties in the explanatory variables on the response variable, using the statistical p-value of the regression analysis, was also measured.

The splash erosion collected at the upper slope of the source area results from downward and upward directional components were organized in terms of their corresponding slopes, such that *D(g)* and *U(g)* are the amount of sediments in grams (g) from the downward and upward direction, respectively. The rainfall depth is also included and is measured in millimeters (mm). The study also used the maximum rainfall intensity for the different time durations (5, 10, 15, 20, 25, 30, 45, 60 min) and is measured in millimeters per hour (mm.h^{-1}). The instantaneous rainfall intensity is used to calculate the value of the kinetic energy using the equation below recommended by Fornis et al. (2005) as a reference for soil erosion studies. The kinetic energy is in Joules per meter squared (J.m^{-2}.mm^{-1}) and expressed as:

$$KE = 30.8\,(1 - 0.55e^{-0.032I}) \qquad \ldots(6)$$

RESULTS AND DISCUSSION

Sensitivity Analysis for the Directional Splash Components

The statistical significance of the proposed splash erosion model was analyzed to determine the relevant parameters. To assess its significance, normal probability plots and residuals of fitted values were used to determine its probability density function. For the downward splash component, the distribution follows a normal curve. Moreover, using regression analysis, the rainfall intensity is statistically significant with a downward splash component with a p-value of $0.00006767 < \alpha = 0.05$.

Rainfall intensity simulated on an upward splash direction follows a normal distribution. It is also statistically significant to the upward splash component with a p-value of $0.000000539 < \alpha = 0.05$. This significance suggests that the data in the upslope component and rainfall intensity can be used to formulate a splash erosion model.

The relationship of the lateral slope (i.e., right and left) to the rainfall intensity at varying slopes using regression analysis was also evaluated. Results showed that both left and right directional splash components follow normality. This conclusion assumes that a regression model to the lateral directional splash components can also be used. The p-values of the right and left splash components are $1.006\text{x}10^{-5}$ and $8.679\text{x}10^{-8}$, respectively, suggesting the statistical significance of the rainfall intensity to the lateral directional component. Therefore, rainfall intensity, as an explanatory variable, is a vital component in splash erosion. However, there is still a need to analyze the effect of the impact of raindrops on splash erosion, measured as kinetic energy, to analyze its statistical significance. In the next section, the statistical significance of the kinetic energy in terms of the directional splash component (i.e., upward, downward, right, and left) was also analyzed.

Splash erosion is directly caused by the kinetic energy of raindrops, which is a crucial parameter in erosion prediction models. Simple linear regression was applied to delineate the correlation between splash erosion rate and its directional components with kinetic energy. Table 1 shows the statistical significance of kinetic energy in relation to its directional components.

Results showed that only the downward splash component is statistically significant for the splash erosion model. Other directions have p-values greater than the assumed level of significance. This conclusion correlates with the initial assumption that once raindrops reach the soil surface due to their kinetic energy, they primarily infiltrate and flow downslope along the surface. Moreover, rainfall kinetic energy is often estimated based on measured rainfall intensity due to the lack of direct measurement. A correlation test was used to analyze the relationship between these two parameters. It showed a strong, positive linear relationship, indicating a direct correlation between rainfall intensity and kinetic energy. Because of these findings, the proposed model used only rainfall intensity to simulate splash erosion in the downward component, as other directional components showed no significant effect. Rainfall intensity, soil, and other land use factors affect splash erosion caused by raindrop impact and surface runoff. Specifically, splash erosion depends on the erosivity due to the amount and intensity of rainfall, as well as the resistance of the soil surface or the slope degree, influenced by intrinsic soil properties and the topography of the landscape.

Downward vs Upward Splash Erosions

Evaluating the results gathered from the experimental setup, descriptive statistics of the independent variables (i.e., rainfall intensity, kinetic energy, slope) and the response variables (i.e., upward and downward slopes) were presented. Some data were omitted to improve the performance of the models, as the dataset contained

Table 1: Statistical Significance of the Kinetic Energy in terms of its Directional Components.

Direction	Estimate	Standard Error	p-value < 0.05
Downward	-0.0006257	0.9407508	0.00989**
Upward	0.0001291	0.0001377	0.357
Left-lateral	0.0003661	0.0003422	0.294
Right-lateral	0.0003661	0.0003422	0.172

**Significant code: level of significance at 0.05

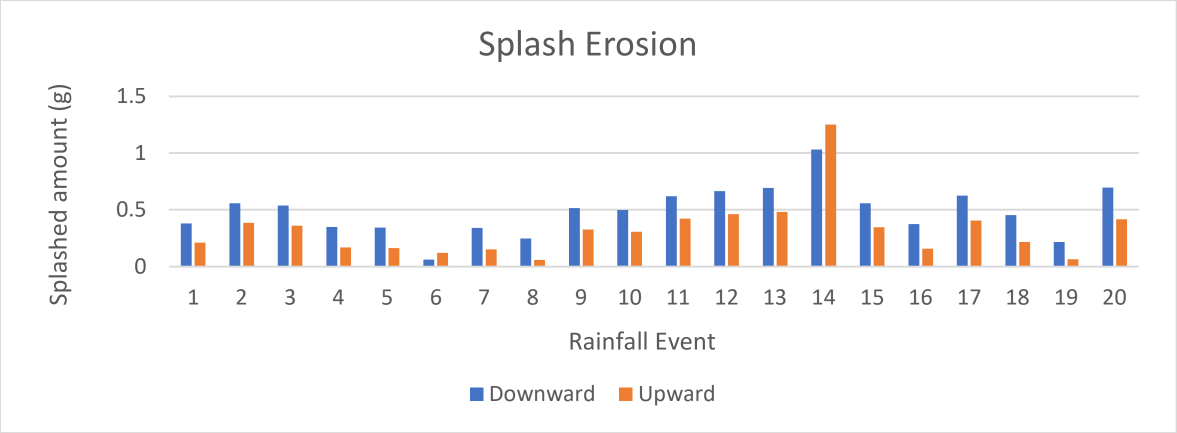


Fig. 3: Downward and upward splash erosions at various rainfall events.

extreme outliers and was compressed from a wide range to a narrower one.

What remains are twenty (20) datasets from the training data for analyzing the statistical setup of downward and upward splash erosion. On a slope receiving rain, soil particles detached by raindrops may cause a net downward movement of soil material along the hillslope. This downward movement occurs because the distance of splash along a slope is longer in the downward direction than in the upward direction. This scenario is validated by the study results, as shown in Fig. 3. Splash erosion in the downward setup is higher than in the upward setup. A positive, linear relationship between the two types of splash erosion was observed, indicating a dependent relationship between the two variables.

Splash Erosions vs Depth

As hypothesized, rainfall depth plays an important role in splash erosion due to its variation at the spatial and temporal scales from its effects of rainfall intensities. Its effect was also studied against the amount of splash erosion, wherein each treatment included eight groups of rainfall duration (i.e., 5, 10, 15, 20, 25, 30, 45, and 60 mins of rainfall intensity). For the sake of the statistical relationship, the analysis was first done on the relationship between splash erosions and the rainfall depth. The results show that splash erosion is associated with rainfall depth, having a positive linear relationship between the depth and splash erosions for both downward and upward directions.

Splash Erosions vs Rainfall Intensity

The results indicated that higher intensities of rainfall lead to a higher splash erosion rate on hillslopes. In this study, the experimental setups were surrounded by a corn canopy. The spatial variation of rainfall kinetic energy became relatively complex under the corn canopy, leading to randomness and non-uniformity in the spatial distribution of the splash erosion rate.

Net Splash Erosion

Evaluation of splash erosion, Q in terms of rainfall intensity I_{RT} as its explanatory variable, such that time T refers to the set $T = \{5, 10, 15, 20, 25, 30, 45, 60\}$. The rainfall intensity and splash erosion rate had a linear relation, using multiple R-squared, R-squared, and adjusted R-squared as the model performance measurement. The splash erosion and the rainfall intensity from different directional components, i.e., downward, upward, left-lateral, and right-lateral, were analyzed. The average rainfall intensity and splash erosion rate increased progressively with higher rainfall intensity, as observed from the experimental setup. Additionally, the significance of each level of rainfall intensity on splash erosion was evaluated using an Analysis of Variance (ANOVA). When classified into four directional components, it was found that downward splash erosion is the most significant, as it has the highest F-score among the directional components.

To validate the effectiveness of the model in terms of its R^2, the sensitivity of the rainfall intensity parameters to splash erosion Q was analyzed from the different directional components using standard error, t-test, and ANOVA. It was found that only I_{RT} with $T = \{10, 15, 20, 25, 30, 45, 60\}$ are sensitive to the splash erosion since the p-value < 0.05 – making their results consistent with the accuracy as described above. Moreover, only the downward component generated a p-value < 0.05.

Splash Erosion vs Rainfall Kinetic Energy

The relationship of the splash erosion in terms of the rainfall kinetic energy through simple linear regression models was analyzed using the same model performance methods, i.e., R-squared, adjusted. R^2, and multiple R^2 such that a higher value suggests the best model performance. In terms of the rainfall kinetic energy, the downward component produced the best regression model with the highest model performance measurement, while the upward directional component generated the poorest model.

Equation Fitting Between Splash Erosion with Rainfall Physical Parameters

The linear fit of the splash erosion Q for both transport and detachment was evaluated against the significant rainfall physical parameters, i.e., rainfall intensity (RI) and kinetic energy (KE). The linear fit used two tests – training and validation test to verify the accuracy of the proposed model in terms of splash amount, Q, for transport and detachment for the different slope gradients. The training set uses 30 datasets from the results of the experimental setup, while the remaining 10 samples were used for the validation set.

There are six (6) cases considered to evaluate the performance of the model using the standard error of estimate (SEE). SEE was used because it represents each data and, therefore the accuracy of the prediction. Table 2 presents the different cases with the models generated and their respective standard error of estimate (SEE).

After analyzing the results of the different cases, Case 1, which considered all datasets, generated the lowest value for the SEE, which is 26.48 and 18.70 for Q_{det} and Q_{trans}, respectively. This can be associated with the number of datasets considered, as the formula for calculating the Standard Error of Estimate (SEE) includes the number of observations in its denominator. Thus, the higher the number of observations, the lower the SEE value. This finding contrasts with previous research on splash erosion in sloping areas and the tendency of rainfall kinetic energy to detach soil particles, as discussed in the methodology. Additionally, it was noted that a 20-minute rainfall duration consistently yielded the lowest SEE values for both detachment and transport. These results are detailed in the appendices.

The models generated for Case 5 were recommended for both the Q_{det} and Q_{trans}. These models omitted datasets, which include the 0% slope, upslope> downslope, rainfall depth < 10 mm, and RI<12 mm.h^{-1}. The recommendation was done after it was used in the datasets of Case 6 and found out that it was able to give values for SEE, which are almost the same as that of Case 5.

Table 2: Summary of the Models Obtained with its Respective Standard Error of Estimate.

Case		Model	Standard Error of the Estimate	Remarks
1	Q_{det}	$Q = 0.00000847(KE^{0.8})(S^{0.1158})({I_{20}}^{1.3419})$	26.48104	All Data Sets were considered.
	Q_{trans}	$Q = 0.0051(KE^{0.2486})(S^{0.700})({I_{20}}^{0.8648})$	18.69784	
2	Q_{det}	$Q = 0.00000847(KE^{0.8})(S^{0.1158})({I_{20}}^{1.3419})$	29.21948	Omit: Slope 0
	Q_{trans}	$Q = 0.0051(KE^{0.2486})(S^{0.700})({I_{20}}^{0.8648})$	20.89959	
3	Q_{det}	$Q = 0.00000693(KE^{0.8})(S^{0.1160})({I_{20}}^{1.4095})$	29.06314	Omit: Slope 0, Upslope> Downslope
	Q_{trans}	$Q = 0.0046(KE^{0.2521})(S^{0.700})({I_{20}}^{0.8836})$	21.34689	
4	Q_{det}	$Q = 0.00000680(KE^{0.8})(S^{0.1161})({I_{20}}^{1.4125})$	33.28780	Omit: Slope 0, Upslope> Downslope , Depth < 10 mm
	Q_{trans}	$Q = 0.00325(KE^{0.2672})(S^{0.700})({I_{20}}^{0.9288})$	25.53425	
5	Q_{det}	$Q = 0.0093(KE^{0.8})$	33.72979	Omit: Slope 0, Upslope> Downslope , Depth < 10 mm, RI<12 mm/hr
	Q_{trans}	$Q = 0.0598(KE^{0.1072})(S^{0.700})({I_{20}}^{0.6999})$	26.00408	
6	Q_{det}	$Q = 0.0139(KE^{0.8})$	32.24859	Omit: Slope 0, Upslope> Downslope , Depth < 10 mm, RI<25 mm/hr
	Q_{trans}	$Q = 0.0474(KE^{0.2819})(S^{0.700})({I_{20}}^{0.3279})$	25.80290	

Table 3: Validating Datasets Used in the Model with its Respective Standard Error of Estimates.

Model	SEE
$Q_{det} = 0.0093(KE^{0.80})$	11.9118
$Q_{trans} = 0.060(KE^{0.107})(S^{0.700})({I_{20}}^{0.700})$	9.3999

Utilizing the validating datasets to assess the accuracy of the models in predicting splash erosion, the Case 5 models consistently yielded low SEE values. This result is comparable to the values obtained when using the validating datasets of Case 6. This is presented in Table 3.

CONCLUSION

In this study, an analysis of the effects of rainfall intensity, kinetic energy, and slope angle on the different directional components of splash erosion in hillslope agriculture was done. Five (5) experimental set-ups were created in the hillslope of Badiangan, Ajuy, and Iloilo, such that its splash source was exposed to the natural rain, with varying degrees of slope. The statistical significance of the directional components was evaluated for the splash erosion, and it was found that the downward component is the most significant among others since the material splash downslope travels further than those in other directional components, resulting in the net downslope migration of the splash materials. Moreover, the downward directional component is directly proportional to the slope gradient since the downward component increases as the slope gradient increases. Because of this, only the samples produced from the downward component were used to investigate the effects of rainfall parameters at variable slope angles. The two models of splash erosion using the rainfall parameters were generated and presented as: $Q_{det} = 0.0093(KE^{0.80})$ and $Q_{trans} = 0.060(KE^{0.107})(S^{0.700})({I_{20}}^{0.700})$.

The statistical significance of splash components was first evaluated for each rainfall parameter using ANOVA and regression models. It shows that kinetic energy and rainfall intensity are the most sensitive parameters, resulting in a model with sufficient SEE. Kinetic energy is significant in the splash erosion model as it has the ability to detach soil particles from the surface. The values of the constants used for kinetic energy in detachment and slope in transport align with the research conducted by Quansah (1981) on sandy soil, which is characteristic of the research site. Additionally, rainfall intensity, particularly with a duration of 20 minutes, generated the best model among the different cases, as it consistently provided the lowest SEE value across all cases.

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REFERENCES

Aissa, H., Mouzai, L. and Bouhadef, M. 2014. The effect of soil surface slope on splash distribution underwater drop impact. Int. J. Agric. Biosyst. Eng., 8(8): 588-591. https://doi.org/10.5281/zenodo.1337411

Bai, X. Y., Wang, S. J. and Xiong, K. N. 2013. Assessing spatial-temporal evolution processes of karst rocky desertification land: Indications for restoration strategies. Land Degrad. Dev., 24(1): 47-56. https://doi.org/10.1002/ldr.1102

Bryan, R. B. 1979. The influence of slope angle on soil entrainment by sheetwash and rain splash. Earth Surf. Process., 4(1): 43-58. https://doi.org/10.1002/esp.3290040105

Dussaillant, A. R. 2011. Estimation of combined splash, interrill, and rill erosion using a hillslope erosion numerical model: An application to dry lands of Chile. J. Soil Water Conserv., 66(2): 142-147. https://doi.org/10.2489/jswc.66.2.142

Fernández-Raga, M., Fraile, R., Keizer, J. J., Varela Teijeiro, M. E., Castro, A., Palencia, C., Calvo, A. I., Koenders, J. and Da Costa Marques, R. L. 2010. The kinetic energy of rain measured with an optical disdrometer: An application to splash erosion. Atmos. Res., 96(2-3): 225-240. https://doi.org/10.1016/j.atmosres.2009.07.013

Foot, K. and Morgan, R. P. C. 2005. The role of leaf inclination, leaf orientation and plant canopy architecture in soil particle detachment by raindrops. Earth Surf. Process. Landforms, 30(12): 1509-1520. https://doi.org/10.1002/esp.1207

Fornis, R. L., Vermeulen, H. R. and Nieuwenhuis, J. D. 2005. Kinetic energy – rainfall intensity relationship for Central Cebu, Philippines for soil erosion studies. J. Hydrol., 300: 20-32. https://doi.org/10.1016/j.jhydrol.2004.04.027

Grosh, J. L. and Jarrett, A. R. 1994. Interrill erosion and runoff on very steep slopes. Trans. ASAE, 37(4): 1127-1133. https://doi.org/10.13031/2013.28186

Hammad, A. H. A., Børresen, T. and Haugen, L. E. 2006. Effects of rain characteristics and terracing on runoff and erosion under the Mediterranean. Soil Tillage Res., 87(1): 39-47. https://doi.org/10.1016/j.still.2005.02.037

Hoyos, N. and Waylen, P. R. 2005. Seasonal and spatial patterns of erosivity in a tropical watershed of the Colombian Andes. J. Hydrol., 314: 177-191. https://doi.org/10.1016/j.jhydrol.2005.03.014

Hudson, N. W. 1965. The Influence of Rainfall on the Mechanics of Soil Erosion: With Particular Reference to Southern Rhodesia. MSc Thesis, University of Cape Town, p. 90.

Jiang, Z., Lian, Y. and Qin, X. 2014. Rocky desertification in Southwest China: Impacts, causes, and restoration. Earth Sci. Rev., 132: 1-12. https://doi.org/10.1016/j.earscirev.2014.01.005

Kinnell, P. I. A. 2005. Raindrop-impact-induced erosion processes and prediction: A review. Hydrol. Process., 19(14): 2815-2844. https://doi.org/10.1002/hyp.5788

Krogman, K. K. 1983. Annotated bibliography on soil erosion by wind applicable to southern Alberta agriculture. Government of Alberta, Alberta, pp. 1-29.

Ma, B., Liu, Y., Liu, X., Ma, F., Wu, F. and Li, Z. 2015. Soil splash detachment and its spatial distribution under corn and soybean cover. Catena, 127: 142-151. https://doi.org/10.1016/j.catena.2014.11.009

Morgan, R. P. C. 2005. Soil erosion and conservation. Third edition. Blackwell Publishing, Oxford, UK

Parsons, A. J., Abrahams, A. D. and Luk, S. H. 1991. Size characteristics of sediment in interrill overland flow on a semiarid hillslope, southern Arizona. Earth Surf. Process. Landforms, 16(2): 143-152. https://doi.org/10.1002/esp.3290160205

Pedersen, H. S. and Hasholt, B. 1995. Influence of wind speed on sage grouse metabolism. Catena, 24: 39-54. https://doi.org/10.1139/z95-088

Quansah, C. 1981. The effect of soil type, slope, rain intensity, and their interactions on splash detachment and transport. Eur. J. Soil Sci., 32(2): 215-224. https://doi.org/10.1111/j.1365-2389.1981.tb01701.x

Renschler, C. S., Mannaerts, C. and Diekkrüger, B. 1999. Evaluating spatial and temporal variability in soil erosion risk: Rainfall erosivity and soil loss ratios in Andalusia, Spain. Catena, 34(3-4): 209-225. https://doi.org/10.1016/S0341-8162(98)00117-9

Shanshan, W., Baoyang, S., Chaodong, L., Zhanbin, L. and Bo, M. 2018. Runoff and soil erosion on slope cropland: A review. J. Resour. Ecol., 9(5): 461-470. https://doi.org/10.5814/j.issn.1674-764x.2018.05.002

Shin, S. S., Park, S. D. and Choi, B. K. 2016. Universal power law for the relationship between rainfall kinetic energy and rainfall intensity. Adv. Meteorol., 1-11. https://doi.org/10.1155/2016/2494681

Syvitski, J.P.M., Kettner, A.J. and Green, P. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science, 6: 376-380. https://doi.org/10.1126/science.1109454

Torri, D. and Poesen, J. 1992. The effect of soil surface slope on raindrop detachment. Catena, 19(6): 561-578. https://doi.org/10.1016/0341-8162(92)90053-E

van Dijk, A. I. J. M., Bruijnzeel, L. A. and Eisma, E. H. 2003. A methodology to study rain splash and wash processes. Hydrol. Process., 167: 153-167. https://doi.org/10.1002/hyp.1154

van Dijk, A. I. J. M., Bruijnzeel, L. A. and Rosewell, C. J. 2002. Rainfall intensity-kinetic energy relationships: A critical literature appraisal. J. Hydrol., 261(1-4): 1-23. https://doi.org/10.1016/S0022-1694(02)00020-3

Vrieling, A., Hoedjes, J. C. B. and van der Velde, M. 2014. Towards large-scale monitoring of soil erosion in Africa: Accounting for the dynamics of rainfall erosivity. Glob. Planet. Change, 115: 33-43. https://doi.org/10.1016/j.gloplacha.2014.01.009

Zuazo, V. H. and Pleguezuelo, C. R. 2008. Soil erosion and runoff prevention by plant covers: A review. Agron. Sustain. Dev., 28(1): 65-86. https://doi.org/10.1051/agro