Effect Of Raindrop Diameters And Slopes On Runoff And Soil Loss In A Hilly Terrain

Florence Akangle Panme, Laxmi Narayan Sethi, Anamika Yadav, Avinash Kumar, Sudipto Sarkar

Abstract: Soil and water are the critical natural resources for the agro-ecosystem which needs to be conserved for the sustainability within the ecosystem. Soil erosion is a naturally occurring geomorphic process over the earth's surface and is a serious environmental problem threatening the natural resources, agriculture, and the environment. A field experiment conducted to investigate the potential effects of different patterns of rainfall and slopes on soil erosion and runoff. Rainfall simulation system was set up to produce different rainfall intensities. The field experiment was carried out considering sites having a slope of 20.04%, 30.80% and 39.83%. Each study site was further divided into six test plots with the help of acrylic sheets, giving a total of 18 test plots for the experiment. The rainfall nozzle of 1 mm size gave the lowest intensity (57 mm/hr) while the nozzle size of 6 mm produced the highest rainfall intensity (132 mm/hr) for same flow rate. The results of the rainfall simulation were analyzed which showed that the average time to runoff proved Plot-1>Plot-2>Plot-3 for the three test plots. The highest runoff volume of 239.70 mL/m^2/min was observed in Plot-3 (Slope=39.83%) under rainfall intensity of 132 mm/hr and lowest volume of 60.31 mL/m^2/min was observed in Plot-1 (Slope=20.80%). The highest average sediment yield of 76.51 gm/m^2/min was observed in Plot- 3 (Slope=39.83%) under rainfall intensity of 132 mm/hr and the lowest average yield of 5.32 gm/m^2/min was observed in Plot-1 (Slope=20.80%).

Index Terms: Raindrop Diameter, Rainfall Simulator, Runoff Simulator and Sediment Yield

1. INTRODUCTION

Each year, globally, soil erosion causes loss of about 75 billion tonnes of soil from the land [11]. Degradation of soil in India is a pervasive problem [1]. The Himalayan ranges, North-Eastern states, and the Western Ghats, together constitute 45% (130 M ha) of the total geographic area. These areas are highly affected by serious soil erosion problems through ravines, gullies, shifting cultivation, cultivated wastelands, water logging, sandy areas and deserts. The North-Eastern states in general and Assam, in particular, have high rainfall, weak geological formation, active seismicity, uncontrolled differentiation and prevalent practices of shifting cultivation. High rainfall in Cachar district of Assam generally concentrated during the months of May to August have been found to contribute strongly to the loss of soil as the district consists of a number of hills which spreads across the district, though, it is mostly made up of plains. Soil erosion is influenced by both the total rainfall amount and the intensity of rainfall but is more dominantly affected by the intensity of rainfall and energy rather than rainfall amount alone. Simulating rainfall gives the prospect of varying the system configuration to simulate different scenarios of rainfall field characteristics that is the duration, intensity and distribution of drop size of rainfall. In the event of heavy precipitation events in the hills of North East India becoming more frequent because of climate change, flood risk in the valley areas and flash flood and landslide risks in the hills are most likely to be augmented [2]. Hence depending on the above criteria, a field experiment was conducted to determine the potential effects of different intensities produced by different drop size of rainfall in relation to slope on soil erosion and runoff in a hilly terrain of Barak Valley, Assam.

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2 MATERIALS AND METHODS

2.1 Experimental Design

The experiment was conducted in a hilly terrain located in Assam University, Silchar (24˚68′ North, 92º45´ East) under the Barak Valley zone located in the southern part of Assam in North East India. The experiment was carried out in three sites having varying slope of 20.04%, 30.80% and 39.83% in a hilly terrain.

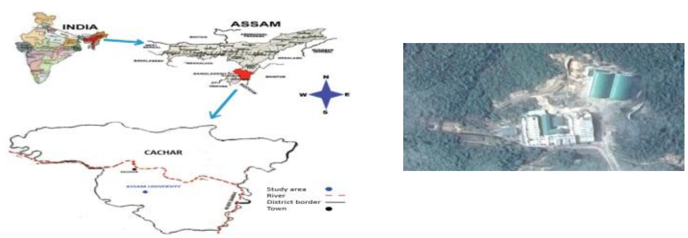
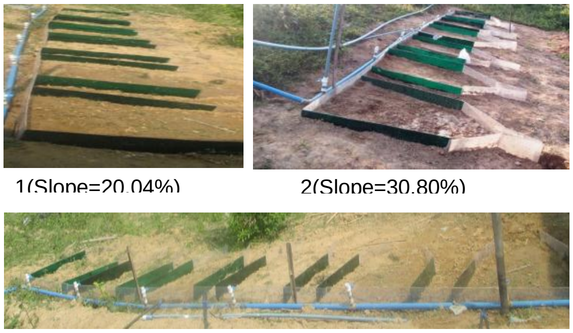


Fig. 1. *Location of the study area*

The experimental test plot covered an area of 6.3 × 1 m2 each. Each test plot was further divided into 6 sub-test plots by an acrylic sheet covering an area of 1 m2 each and in between each sub-test plot, a buffer zone of 0.30 × 1 m2 was provided. The purpose of the experiment was to determine the quantity of soil removed and the runoff generated from barren soil when exposed to different intensities of rainfall. Therefore, during the preparation of test plot, the vegetation or weeds were cleared out using proper tillage implements.Different diameters of raindrops have been shown to produce differential in rainfall intensities [3]. Therefore, rainfall nozzles of hole size with 1 mm, 2 mm, 3 mm, 4 mm, 5 mm and 6 mm were fabricated locally to produce raindrops of different diameters. Each plot was hydrologically isolated from adjacent areas by installing acrylic sheet parallel in the soil, embedded to a depth of 10 cm and extending 10 cm above the soil surface along the frame to prevent water from flowing outside the plot. A reservoir tank having a capacity of 1000 Litre was operated to supply the water for the purpose of experimentation. To record the rainfall intensity, a non-recording rain gauge was used. Other equipment includes the motor and pumping units, valves, pipes, hoses and other pipe fittings needed for the experiment.



PPlot-3(Slope=39.83%)

Fig. 2. *A view of the installed experimental setup*

The simulator consisted of riser pipes (1/2") that support single rainfall nozzle above the plot at a height of 2 m to replicate the velocity and kinetic energy of natural rain [9]. The rainfall simulator covered the whole area of the test plot to distribute the rainfall equally and uniformly. Pipe fittings facilitated the vertical position of the rainfall nozzles. Ball valves were used to control the flow to the desired rate and couplings were used to allow quick change over between the hoses of the required size and also during shifting of the experimental setup from one plot to other. A runoff collector was placed at the lower end of the test plot to collect and concentrate the runoff and sediment into the runoff container.

2.2 Performance Evaluation of Rainfall Nozzle Setup

In order to evaluate the performance of the nozzle, the discharge rate, intensity and coefficient of uniformity of each rainfall nozzles was determined and calibrated. The volumetric method [7] was adapted to determinate the standard flow rate. For the determination of uniformity coefficient of the rainfall, the total quantity of water collected in each beaker was measured for each trial, providing the average intensity and the spatial uniformity on the surface, computed via the uniformity coefficient proposed by Christiansen (1942):

$$CU = [1-(\sum x/mn)]\times 100 \qquad (1)$$

Where, CU = Coefficient of uniformity; n = Number of readings; m = Average catch; x = deviation from meanThe intensity of rainfall is related to the kinetic energy of a rainstorm which is influenced by both, the size of the raindrop and the terminal velocity of the raindrops. Hence, the amount and intensity of rainfall determines the energy of a rainstorm. The kinetic energy (KE) of rainfall was calculated as suggested by Wischmeier & Smith, 1978. Energy of a given mass in motion is always proportional to mass and velocity squared, the rainfall energy is directly related to rain intensity. This relationship is expressed by the equation:

$$KE = 11.897 + 8.73 \, \mathrm{Log}_{10}(I) \qquad (2)$$

Where, KE = Kinetic energy (J m-2mm-1); I = Rainfall intensity (mm/hr). The initial moisture content of the soil was obtained by following the standard gravimetric method or oven drying method. Upon the start of rainfall simulation, the initiation of time to runoff was recorded.

2.3 Runoff and sediment measurement

Runoff and sediment generated from each plot during simulated rainfall were recorded as a function of time. The runoff generated and the sediment samples were collected after every three minutes after the generation of runoff. The total volume (mL) and the pick runoff (mL m-2 min -1) were calculated during the later portion of the simulation when the total runoff volume in each sampling inter-time was steady. A standard method of filtration was adopted to determine the total suspended solids and runoff volume. After each rainfall simulation, 1µ filter papers were used to filter sediments from the collected cumulative runoff. The filtered sediments were dried at 60°C for 24 h and weighed to calculate the sediment concentration. The dried filter papers and soil weight was compared with oven dry weight prior to filtration.

3 RESULT AND DISCUSSIONS

3.1 Time to runoff

The time to runoff was greatest in Plot-1 of 20.80 % slope. It was observed that the combination of antecedent soil water content and rainfall intensity affects the runoff initiation time [6], [7], [8], [10].

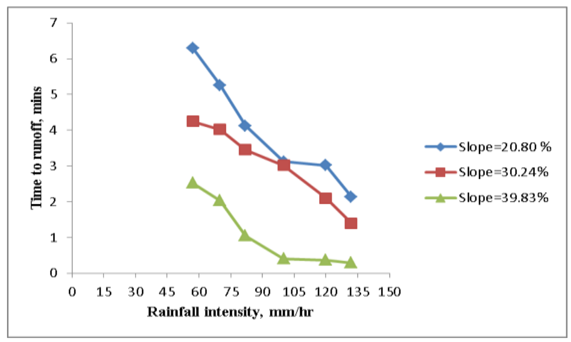


Fig.3. *Variation of time to runoff under different rainfall intensities*

The Time began to flow in Plot-1 was 6.7 min for 57 mm/hr and gradually decreased with the increase in rainfall intensity reducing up to 2.14 min under the heavy rainfall intensity of 132 mm/hr. In case of Plot-2, the time to runoff began after the elapse of 4.25 min for low intensity of 57 mm/hr reducing up to 1.40 min under 132 mm/hr rainfall intensity. The time to runoff in case of Plot-3 was exceedingly reduced from 2.53 min under 57 mm/hr to 29 sec under 132 mm/hr rainfall intensity. This may be due to the increase in runoff. Analysis results show that time began to flow under different rainfall intensity in Plot-1 is 1.4 to 1.5 times greater than that of Plot-2 and 2.4 to 7.3 times that of Plot-3.

3.2 Surface Runoff Response to Different Rainfall Patterns

The amount of rainfall increased gradually with the increase in the rainfall. The average runoff generated in 30 min of simulation is also presented in Fig. 4. The average volume of runoff generated under different intensities shows an increasing trend with the increase in slope. For an intensity of 57 mm/hr, the total runoff generated was highest in Plot-3 (13.6 L), followed by Plot-2 (11 L) and lowest in Plot-1(9.2 L). Similarly, the total runoff generation under the rainfall intensity of 132 mm/hr was highest in Plot-3 (35.5 L), followed by Plot-2 (24 L) and Plot-1 (20.7 L). The total runoff generated in Plot-3 was 1.47 times more of Plot-2 and 1.71 times more of Plot-1.

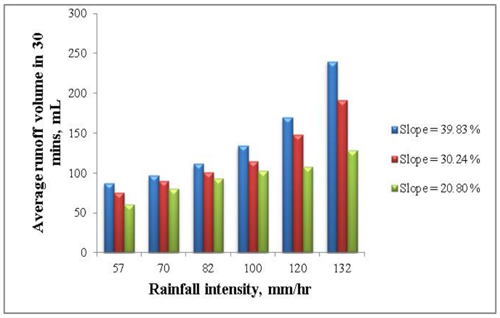


Fig. 4. *Variation of average runoff for different slopes*

3.3 Response of Sediment Yield and Soil Loss to Rainfall Intensity

The greatest peak sediment concentration was detected on Plot-3, where the sediment concentration ranged from 22.73 gm/m^2/min to 100.63 gm/m^2/min. With the increase in rainfall intensity, the runoff amount also increased, thereby, leading to increase in sediment yield. For high intensity of 132 mm/hr, the total sediment yield was highest in Plot-3 (37.74 gm/m^2/min), followed by Plot-2 (25.72 gm/m^2/min) and lowest in Plot-1 (20.62 gm/m^2/min). The sediment generated in Plot-3 was 1.46 times more than Plot-2 and 1.83 times more than Plot-1.

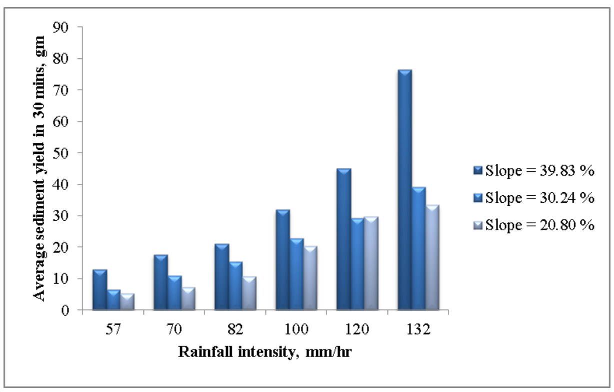


Fig. 5. *Variation of average sediment yield for different slopes*

4 Conclusion

The study on effect of raindrop diameters and slope on soil erosion revealed that the land with higher slopes produced higher rate of runoff and sediment loss, which lead to the increase in soil erosion rate. In the present study, an upward trend of the parametric values of runoff and sediment yield was found to be continuous with the increase of rainfall intensity and slopes (Plot-3>Plot-2>Plot-1). The constructed simulator was an easy to use tool, low- cost, and easy to transport and assemble in the field, thus allowing the necessary experimental replicates to be carried out. The results provided comparative information on the effect of rainfall intensity and slope gradient on runoff and sediment yield in steep barren land of Barak valley, Assam.

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