Journal of
Geography & Natural Disasters

Shit et al., J Geogr Nat Disast 2014, 4:1
DOI: 10.4172/2167-0587.1000116

Research Article Open Access

# Vegetation Influence on Runoff and Sediment Yield in the Lateritic Region: An Experimental Study

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## Abstract

The lateritic badland topography (Western part of West Bengal, India) is prone to severe erosion, caused by heavy rainfall events of short duration and high intensities. Five catchments were instrumented in order to study the rainfall–runoff process and soil management impact on runoff and/or sediment yield. In the five micro catchments (Rangamati, Medinipur), characterized by a homogeneity of surface geology, a data set of about 43 rainfall–runoff events covering the January 2012 to Sept, 2012 period was generated by field monitoring. Multiple regression analysis is done to define the role of rainfall volume vis-à-vis vegetation cover on sediment yield. The physical and chemical properties of soil were estimated at the initial and final stage of the gully development in the lower gully basin area. Temporal assessment of soil erosion indicated that increase of rainfall volume protracted the whole process of sediment production, and vegetation on the slope delayed that process. Results indicated that the highest spatial coverage of vegetation (73.5%) yield very low amount of soil [basin-I experimental site (*Adjusted* $R^2$ = 0.56)] whereas, the lowest spatial coverage (5.9%) leads to severe soil loss [(basin-IV experimental site (*Adjusted* $R^2$ = 0.33)]. Results illustrated that at the initial stage, the percent of sand was maximum in the upper catchment of each gully basin and the concentration of silt and clay is less. Gradually as vegetation starts trapping the sediment, composition of soil changes registering higher percentage of finer particles. Again, the nutrients detached from the upper catchment were arrested by check dams that induced nutrients supply and water storage, which in turn, increased the growth of vegetation. This result proved the significance of vegetation cover to curb soil erosion and it may help the planners and managers to take proper decision for the conservation of soil.

**Keywords:** Rainfall volume; Vegetation cover; Sediment yield; Gully erosion; Check dam

## Introduction

The overland flow and sediment yield reduce with the growing of plant cover, and this correlation is employed to sanctify the upshot of vegetation in extensive land degradation dilemma worldwide [1]. The growth of the plantations and natural vegetation in many landscapes is limited by the insufficient availability of water and nutrients [2]. At long time scales, the vegetation cover and related litter fall played a central role in relation to amend of hydrological characteristics and soil erodibility, and sediment load in the landscape scenario [3,4]. Field studies have become increasingly significant in a series of overlapping disciplines mostly covering hydrology, ecology and geomorphology [5].

Erosion on the lateritic upland area is proscribed essentially by the connections between raindrop processes and surface runoff processes [6,7]. The splash will be governing erosion process before runoff initiates. The particles are extricated by the collision of rainfall and dislodged by ricocheting water droplets [8]. Moreover, the force of rainfall incoming at the ground surface is the most decisive factor in controlling raindrop detachment rates. Consequently, raindrops interrupted by the shrub and herbaceous grassland naturally will provide ascend to less splash compare to fall openly on the soil surface [9,10]. However, detachment of particles through raindrop is still to be a serious problem to control the soil erosion rates. Once the adequate flow has accrued, flow entrainment may arise and concentrations of flow in rills became the leading pathways for water and sediment.

Field experimental study was conducted in five different small gully catchments to understand the role of vegetation characteristics and runoff in relation to sediment volume in lateritic upland environment of Paschim Medinipur, West Bengal (India).

## Material and Methods

### Outline of study sites

Rangamati badland topography area is located at the left bank of the Cossi (Kansai) river about the 1 km away from Medinipur town (Figure 1). A tropical, monsoonal climate prevails in this region with mean annual temperature of around 28.4°C, and the average summer (May) and winter (December) temperatures of 40.9°C and 7.5°C respectively. The annual rainfall in this region is 1850 mm. There are important topographic variations within the lateritic upland rill-gully landforms [11]. The average slope of this area is between 20° and 40°. The gully basin is covered with of primary and secondary succession of vegetation (*Cyperus rotundus; Rosmarinus officinales; Stipa tenacissima; Hedyotis corymbosa; Lantana camara; Euphoria purpuria; Eragrostis cynosuroides; Evolvulus nummularia; Saccharum munja; Panicum maxima; Andropogon aciculate* etc.). Five small gully catchment areas were selected for monitoring (Table 1).

### Experimental design

Five small gully catchment areas were monitored from January to September 2012. In December 2011, five partial flume collectors were

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**Received** December 05, 2013; **Accepted** January 03, 2014; **Published** January 08, 2014

**Citation:** Shit PK, Bhunia GS, Maiti R (2014) Vegetation Influence on Runoff and Sediment Yield in the Lateritic Region: An Experimental Study. J Geogr Nat Disast 4: 116. doi:10.4172/2167-0587.1000116

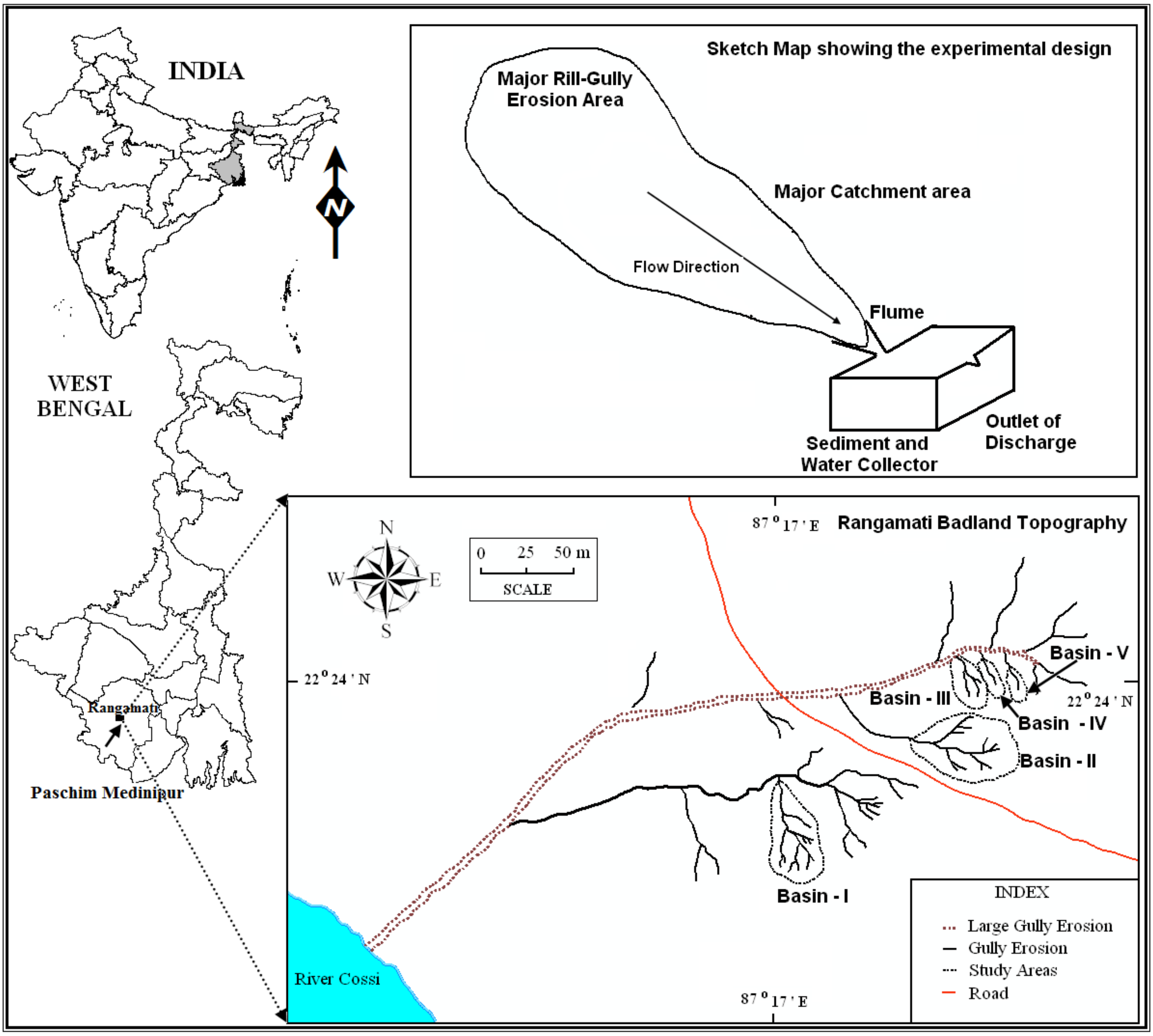


**Figure 1:** Location of the study area and experimental design.

| Experimental Micro watershed (Rangamati badland area) | Area (m²) | Length of the main gully (m) | Watershed width (m) | Average slope degree) | SD of slope (degree) |
|---|---|---|---|---|---|
| Basin-I | 198 | 24.5 | 12.7 | 25 | 14.536 |
| Basin -II | 516 | 35.4 | 25.0 | 30 | 16.876 |
| Basin -III | 246 | 32.0 | 20.0 | 27 | 13.405 |
| Basin -IV | 212 | 18.8 | 16.2 | 34 | 18.352 |
| Basin -V | 168 | 17.9 | 13.0 | 42 | 18.555 |

**Table 1:** Physiographic characteristics of five small gully basin areas.

constructed for measurement of sediment and runoff volumes at mouth of the gully basins (Figure 2). Runoff volumes are influenced primarily by the total amount of rainfall. However, runoff rates resulting from a given rainfall, including peak rate or discharge, are influenced primarily by the rainfall distribution as well as variability of the rainfall rate or intensity over a period of time. A rainfall may be evenly distributed over a time period or can vary widely within that same period. These different types of rain events can produce extremely different runoff volumes and peak discharges. Water level is recorded through the scale in the gully catchment area. Sediment yield and runoff was measured at the outlet of each gullied catchment area after each runoff producing rainfall events (43 recorded rainfall events) by galvanized metal sheets. During the monitoring period the soil loss were collected and measured after each rainfall event. The climatic data were taken from a

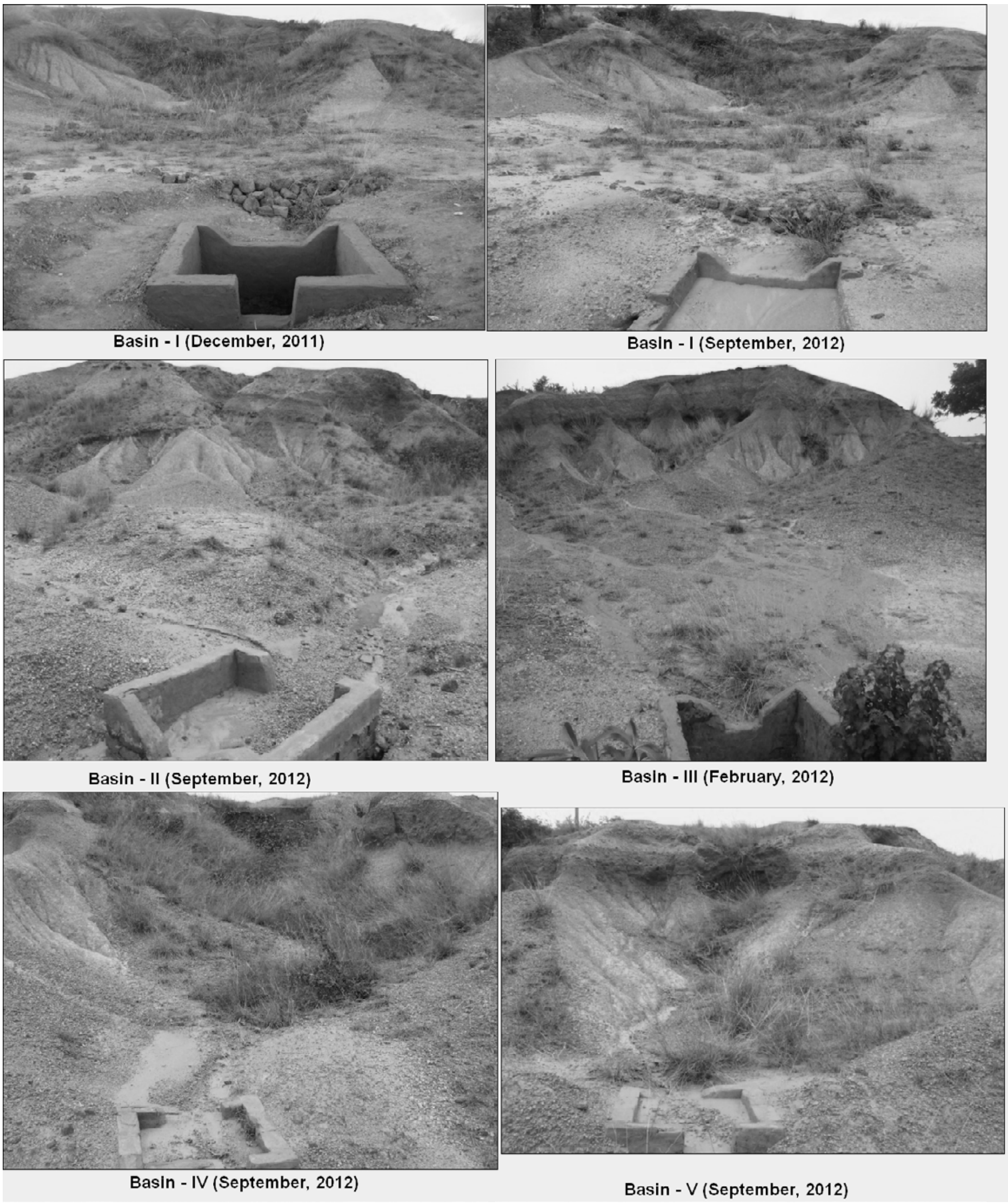


**Figure 2:** Different sizes of small gully catchment at Rangamati badland topography, Medinipur, West Bengal.

Medinipur meteorological station and self-recording raingague in the field during the study period and shown in Figure 3.

### Selected surface features and soil characteristics

Soil properties i.e. bulk density (BD), soil texture, soil pH, Calcium (Ca++), Nitrogen (Na++), Cation-exchange capacity (CEC), potassium (K+), Soil organic matter (SOM), Silica and EC are measured before and after the monitoring period. The samples were collected from depth 0-10 cm of soil profiles in lower section of the gully catchment. Above mentioned physical and chemical properties were determined using the routine methods (Sarkar, 2005). All soil properties are measured in Geo-chemical Lab, GSI, Eastern Region, Kolkata. The physical and chemical properties of each catchment are given in Table 2.

Before experiments, the primary and secondary succession of vegetation grasses were transplanted in the experimental catchment area and the coverage degree is calculated by the grass area occupied the surface area during experiment. The percentage of soil covered by grass species was recorded at the beginning of monitoring period. The whole area of each gully catchment area has been divided into 12 $cm^2$ grid cell. This percentage was determined by counting the number of grid intersections which intercepted vegetation [12-14].

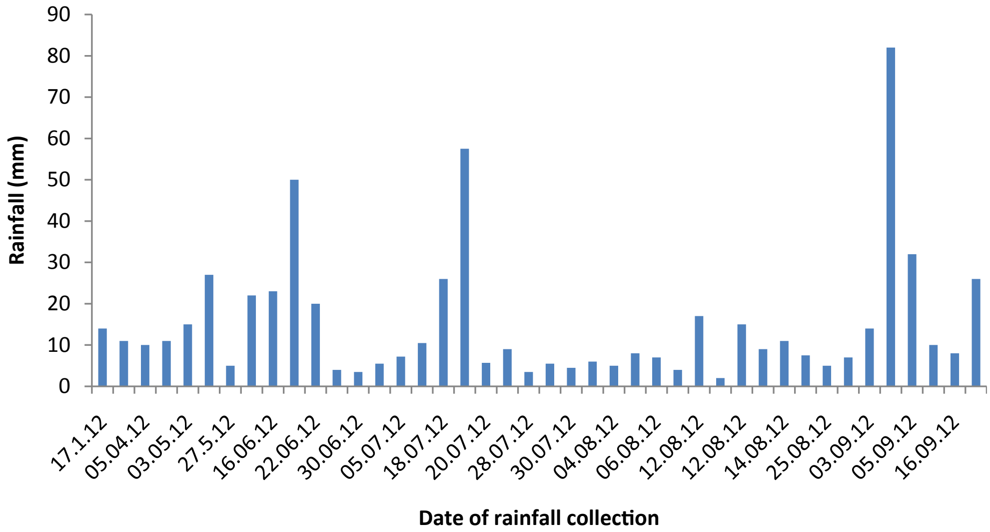


**Figure 3:** Rainfall characteristics of the experimental site during the study period.

| Small gully basin | Monitoring period | Grain size (%) | | | pH | BD (cm³) | Exchangeable cations (C mol $^{(+)}$ kg$^{-1}$) | | | | | V (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | sand | silt | clay | | | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Na^{++}$ | CEC | |
| Basin-I | Jan, 2012 | 54.64 | 16.3 | 29 | 5.8 | 1.2-1.4 | 0.1 | 1.02 | 0.11 | 0.07 | 6.42 | 8.0 |
| | Sept, 2012 | 36.2 | 31.42 | 32.38 | 4.6 | 1.3-1.4 | 0.7 | 0.93 | 0.10 | 0.75 | 3.85 | 43.0 |
| Basin-II | Jan, 2012 | 56.4 | 18.1 | 25.5 | 5.4 | 1.1-1.2 | 0.22 | 0.56 | 0.19 | 0.10 | 4.32 | 5.0 |
| | Sept, 2012 | 40.5 | 28 | 31.5 | 4.9 | 1.3-1.5 | 0.45 | 0.72 | 0.08 | 0.66 | 2.83 | 18.0 |
| Basin-III | Jan, 2012 | 50.4 | 20.5 | 30.1 | 5 | 1.0-1.1 | 0.06 | 0.84 | 0.10 | 0.47 | 1.85 | 10.0 |
| | Sept, 2012 | 47.7 | 33.3 | 20 | 4.2 | 1.1-1.3 | 0.38 | 0.62 | 0.47 | 0.77 | 2.7 | 25.0 |
| Basin-IV | Jan, 2012 | 48.6 | 25.3 | 27.1 | 6.4 | 1.4-1.5 | 0.74 | 0.42 | 0.31 | 0.79 | 3.12 | 34.0 |
| | Sept, 2012 | 42.2 | 33.2 | 24.6 | 5.9 | 1.4-1.6 | 0.59 | 0.44 | 0.42 | 0.76 | 2.15 | 78.0 |
| Basin-V | Jan, 2012 | 51.8 | 27 | 21.1 | 6.1 | 1.3-1.4 | 0.97 | 0.75 | 0.61 | 0.84 | 3.67 | 7.0 |
| | Sept, 2012 | 35.2 | 30.4 | 34.4 | 5.3 | 1.4-1.5 | 0.89 | 0.81 | 0.82 | 0.76 | 3.55 | 33.0 |

BD – Bulk density, Ca- Calcium, Mg – Magnesium, K – Potassium, Na – Sodium, CEC – cataion exchange capacity, V - Vegetation

**Table 2:** Changing the soil properties influenced by vegetation growth at lower section of the gully basin during monitoring period.

## Statistical analysis

Descriptive statistics were calculated for each variable of the experimental sites. Univariate analysis was used to determination relationships between both volume and rainfall volumes and vegetation cover. Importance of vegetation cover and rainfall volume for sediment volume was specified by multivariate regression in SPSS.

# Results and Discussions

## Ground surface variables

Five experimental sites were selected to conduct the study. In each site sediment volume, rainfall and vegetation characteristics were analyzed. Rainfall of the study area is recorded during the period from 17$^{th}$ January 2012 to 18$^{th}$ September 2012. A bar graph is plotted to illustrate the rainfall distribution in the study area (Figure 3). A total of 625.90 mm rainfall was recorded during the study period, with the highest and lowest event on 04th September 2012 and 11th August 2012, respectively (*e.g* less than ± 2mm). However, the distribution of rainfall is not uniformed in the study area. A total of ± 625.90 mm rainfall was recorded during the study period.

The highest and lowest total volumes of rainfall were recorded in the basins IV and V, respectively (Table 3). The vegetation cover reached more than 60% in the basin IV, while only less than 7% in basin II. The lowest and highest sediment inflows were correspondingly measured in the most vegetated basin IV and poorly vegetated basin II, respectively. There was also a relatively strong negative correlation between sediment yield and vegetation cover. The results illustrated that the sediment yield decreases as the vegetation coverage increases in the small gully basin area which corresponded to the results of the earlier study [5].

## Soil physico-chemical analysis

The physical and chemical properties of soil are estimated at the initial and final stage of the gully development in the lower gully basin area. However, this analysis is performed to understand the role of vegetation coverage in the nutrient contents movement of soil through

| Field data collection Site | Parameters | Mean | Standard Error | Median | Standard Deviation | Kurtosis | Skewness |
|---|---|---|---|---|---|---|---|
| Basin - I | Sediment volume(mm3) | 330814.3 | 5618.41 | 167400.00 | 36411.43 | 3.97 | 2.00 |
| | Volume of rainfall(mm3) | 2608.96 | 428.29 | 16631.70 | 2775.64 | 8.12 | 2.67 |
| | % of Vegetation | 23.02 | 1.50 | 22.50 | 9.72 | -1.04 | 0.21 |
| Basin - II | Sediment volume(mm3) | 634800.00 | 10022.42 | 423200.00 | 64952.72 | 8.06 | 2.44 |
| | Volume of rainfall(mm3) | 67990.6 | 1116.14 | 43342.8 | 7233.44 | 8.12 | 2.67 |
| | % of Vegetation | 6.98 | 0.83 | 5.50 | 5.40 | -0.87 | 0.67 |
| Basin- III | Sediment volume(mm3) | 350142.9 | 5047.41 | 213750.00 | 32710.93 | 2.29 | 1.44 |
| | Volume of rainfall(mm3) | 324..42 | 532.12 | 20663.5 | 3448.51 | 8.12 | 2.67 |
| | % of Vegetation | 14.14 | 1.17 | 15.50 | 7.59 | -1.22 | -0.32 |
| Basin - IV | Sediment volume(mm3) | 214313.3 | 4496.71 | 75640.00 | 29142.02 | 4.99 | 2.27 |
| | Volume of rainfall(mm3) | 27933.0 | 458.55 | 17806.8 | 2971.76 | 8.12 | 2.67 |
| | % of Vegetation | 60.17 | 1.06 | 59.50 | 6.84 | -1.13 | 0.11 |
| Basin - V | Sediment volume(mm3) | 333042.9 | 6849.24 | 171000.00 | 44388.14 | 7.05 | 2.66 |
| | Volume of rainfall(mm3) | 22136.0 | 363.39 | 14111.3 | 2355.02 | 8.12 | 2.67 |
| | % of Vegetation | 19.14 | 0.95 | 19.00 | 6.18 | -0.52 | 0.12 |

**Table 3:** Descriptive characteristics of the estimated ground variables.

rill and gully erosion. In each site soil texture (i.e., percent of silt, sand and clay), soil pH, Bulk density, Calcium, Magnesium, Potassium, Sodium, Cation exchange capacity and vegetation coverage (%) were estimated (Table 3). The result of the analysis showed that at the initial stage, the percent of sand was maximum in each gully basin area, whereas it is decreased in downwards. It is due to the fact that the large grain size, percent of area covered with vegetation and transportation capacity along the rill and gully. Consequently, this significant difference could be due to the position of the check dam and the use of thorough vegetation cover in the downstream reaches. However, this result is also corroborated with the previous study [15,16]. On the other hand, the concentration of silt and clay percent is lower at the initial stage; however it is increase due to maximum coverage of vegetation of nutrient contents from the upper catchment area of the gully that aids to grow of vegetation. It was found that the pH of the soil was higher during the imitation of gully head erosion; however, it is decreases gradually in each basin area. Conversely, the higher bulk density is recorded due to the rill and gully erosion in the study area.

Transport of nutrient contents has been investigated in the study area to recognize the nutrient contents exchange *via* rill and gully erosion and its effect on sediment volume (Table 3). It is also observed that calcium and sodium increase due to splash erosion in the rill and gully. Subsequently, the concentration of magnesium and potassium is decreased in the lower part of the gully basin areas in comparison to initiation of rill and gully erosion. One of the most important finding is that the percent of vegetation cover has been increased at the lower gully basin areas. It may be due to the concentration of nutrient contents by the rill and gully erosion that may aid to growth of vegetation and to trap seeds. These results suggest that runoff is an important contributor to the loss of organic nutrients of soil in the upper catchment areas.

## Loss of soil nutrients form gully catchment

Removal of vegetation is usually pursued by a period in which the soil has adequate organic matter to preserve its physical-chemical characteristics, facilitating it to recuperate from the damage, according to the perception of soil pliability [17,18]. Rich with organic matters in the soil are more pliant than the soils with less organic content, such as those of which outweigh in the lateritic upland areas. Furthermore, when the surface layer encloses with fresh plant remains, is eroded, the subsurface material is uncovered and the capability of this substance to grasp nutrients becomes decisive [19]. To evaluate the influence of vegetation, in addition to soil nutrient contents such as, calcium, organic matter, potassium, sodium, organic carbon and silica content is also estimated from the mail gully mouth (Table 4). The results of the analysis showed that all these nutrient contents are decreasing and transported towards the downstream areas. Another important factors is that percent of vegetation cover is very less during the initiation of gully erosion. Afterwards, due to rainfall and splash erosion the nutrient contents were transported to the lower catchment areas that may aid to increase the development of plants as well as reduce erosion through surface runoff. Our study is also corroborated with the earlier study conducted by Schlesinger [20].

## Sediment volume vs. vegetation cover and volume of rainfall

Pearson coefficient of correlation test has been drawn to estimate the relationship between the sediment volume and volume of rainfall (Figure 4). The result of our analysis showed a positive and significant relationship between these two variables. However, in basin – I, maximum r value has been delineated from the basin – I (r = 0.62) and the minimum correlation value was delineated from the basin – IV (r=0.33).

Conversely, the association between the sediment volume and percent of vegetation cover has been performed through Pearson coefficient of correlation test. All these sites were showed a negative and significant relationship (Figure 5). The highest correlation value was recorded from the basin – V (r=-0.57) and the lowest correlation value was measured from the basin – II (r=-0.41).

An analysis was performed to understand the role of vegetation cover and volume of rainfall on sediment volume in the study site (Table 5). The results of multivariate regression analysis of five experimental plots showed in Table 5. The maximum $R^2$ value was obtained from the first experimental site (Adjusted $R^2$=0.56, F=27.34; P <0.01), whereas the lowest value was obtained from the fourth experimental site (Adjusted $R^2$=0.33, F=11.11; P <0.01). The diverse canopy height and structure between the grasses and shrubs escort to the growth of dissimilar infiltration characteristics, possibly due to crusting by splash effect [21,22].

| Small gully basin | Monitoring period | % of vegetation cover | Loss of soil Nutrients (kg/ ha) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $Ca^{++}$ | Organic matter | $K^{+}$ | $Na^{++}$ | Organic Carbon | Silica |
| Basin-I | July, 2012 | 24 | 0.006 | 0.260 | 0.002 | 0.015 | 0.152 | 5.421 |
| | Sept, 2012 | 43 | 0.003 | 0.064 | 0.001 | 0.003 | 0.037 | 1.780 |
| Basin-II | July, 2012 | 10 | 0.013 | 0.451 | 0.003 | 0.026 | 0.264 | 17.86 |
| | Sept, 2012 | 18 | 0.007 | 0.245 | 0.001 | 0.016 | 0.142 | 3.865 |
| Basin-III | July, 2012 | 17 | 0.011 | 0.530 | 0.002 | 0.031 | 0.308 | 6.85 |
| | Sept, 2012 | 25 | 0.006 | 0.213 | 0.001 | 0.012 | 0.183 | 4.56 |
| Basin-IV | July, 2012 | 46 | 0.008 | 0.358 | 0.001 | 0.024 | 0.068 | 4.53 |
| | Sept, 2012 | 78 | 0.004 | 0.130 | 0.001 | 0.011 | 0.032 | 2.60 |
| Basin-V | July, 2012 | 21 | 0.009 | 0.430 | 0.003 | 0.013 | 0.019 | 3.98 |
| | Sept, 2012 | 33 | 0.005 | 0.310 | 0.001 | 0.009 | 0.011 | 1.22 |

**Table 4:** Loss of soil nutrient contents from main gully mouth.

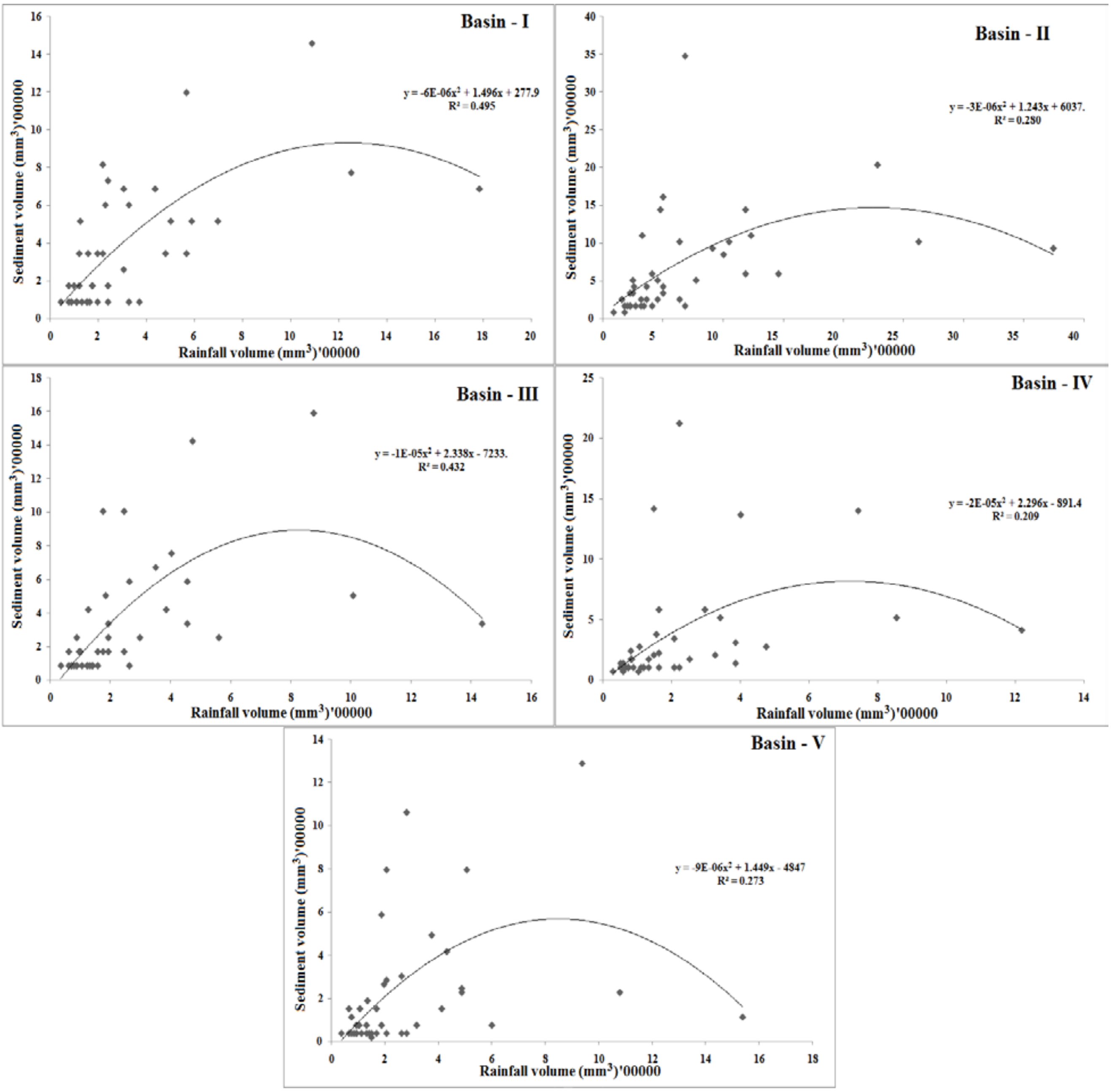


**Figure 4:** Relationship between sediment volume and runoff volume in the gully basin area of five experimental sites.

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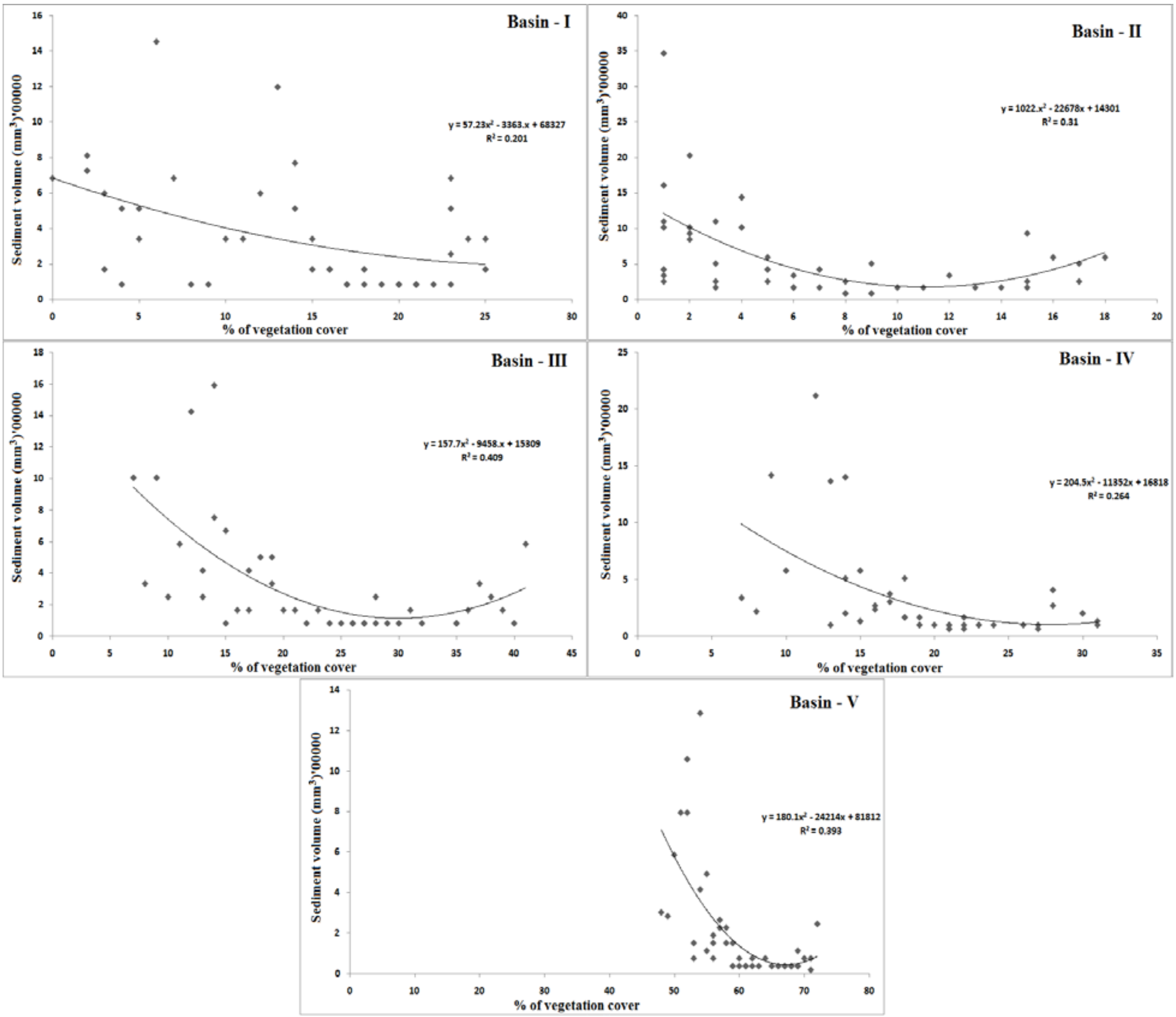


**Figure 5:** Relationship between sediment volume and percentage of vegetation cover in the gully basin area of five experimental sites.

| Site | Variables | β | Standard error | T-stat | P-value | $R^2$ value |
|---|---|---|---|---|---|---|
| Basin – I | Constant | 43424.29 | 7778.42 | 5.58 | <0.0001 | 0.56 |
| | % of vegetation | 0.06 | 0.01 | 6.01 | <0.001 | |
| | Volume of rainfall(mm³) | -19450.5 | 445.36 | -4.37 | <0.001 | |
| Basin – II | Constant | 626.3 | 10950.15 | 5.71 | <0.0001 | 0.49 |
| | % of vegetation | 6.58 | 1.47 | 4.48 | <0.0001 | |
| | Volume of rainfall(mm³) | -20299.0 | 420.53 | -4.76 | <0.0001 | |
| Basin – III | Constant | 162187.89 | 30377.85 | 5.34 | <0.0001 | 0.43 |
| | % of vegetation | 0.04 | 0.01 | 3.13 | <0.003 | |
| | volume of rainfall(mm³) | -2507.39 | 501.65 | -5 | <0.001 | |
| Basin – IV | Constant | 74115.47 | 15149.24 | 4.89 | <0.0001 | 0.33 |
| | % of vegetation | 0.04 | 0.01 | 3.45 | <0.001 | |
| | Volume of rainfall(mm³) | -54017.4 | 1542.23 | -3.5 | <0.001 | |
| Basin – V | Constant | 87024.81 | 18679.47 | 4.66 | <0.0001 | 0.34 |
| | % of vegetation | 0.07 | 0.02 | 3.04 | <0.004 | |
| | volume of rainfall(mm³) | -36503.5 | 915.52 | -3.99 | <0.0002 | |

**Table 5:** Results of multivariate regression analysis.

## Conclusions

The important benefit of field experimental studies as that portrayed here is that they allow to explain the reason of major fluxes of water, sediments and nutrients though the rill and gully erosion. By assimilating the field experimental rainfall-simulation studies at a series of scales with a range of comparatively may be too straightforward estimation techniques, it is feasible to characterize the most significant direct and indirect effect of vegetation on surface processes, jointly with the probable feedbacks of those processes on vegetation intensification. Raindrop falling into skinny water layer cause additional instability and adjoin to the amount of water on the surface of the whole plot. Subsequently the flow velocity of the incoming water during the experiments may differ from that in nature, and is probably lower that may affect the sediment volume. Such management is imperative due to direct hazards such as soil erosion and surface degradation. The conditions of the surface and vegetation coverage are also incessantly variable. The investigational results attained can be seen to be associated very strongly with the previous investigation [5].

However, our results also suggest that vegetation coverage played significant role on the sediment volume in the study area, while rainfall volume showed negative association (Figure 6). In contrast, the percentage of sediment trapped by the vegetation is highest in the lower catchment of gully basin area and is lowest in the upper catchment area. Consequently, the growth of vegetation coverage is also very important factor in the lower catchment areas by increasing the soil nutrient contents through sediment trapping by check dam construction. Vegetation coverage is effective in filtering sediment from surface runoff [22]. This also substantiates the good recital, in terms of retention of fine sediments through vegetation coverage in the lower catchment areas.

Runoff is an elementary practice in land degradation, and also causing huge loss of soil in the gully catchments. Earlier authors have discussed the runoff activities in the context of afforestation or vegetation re-establishment, it is generally concluded that runoff rates and peak flows are reduced [23-25]. Subsequently, human hindrance, such as livestock grazing or modify in the land-use pattern, may irrevocably smash up the recovering vegetation in the upland areas [26]. From these experiments, it is apparent that for a thriving soil and water conservation policy is imperative in order to combat runoff by vegetation restoration. The resulting higher infiltration remuneration plant growth and biomass fabrication and can also guide to groundwater recharge, thus refilling deeper-lying water resources [27,28].

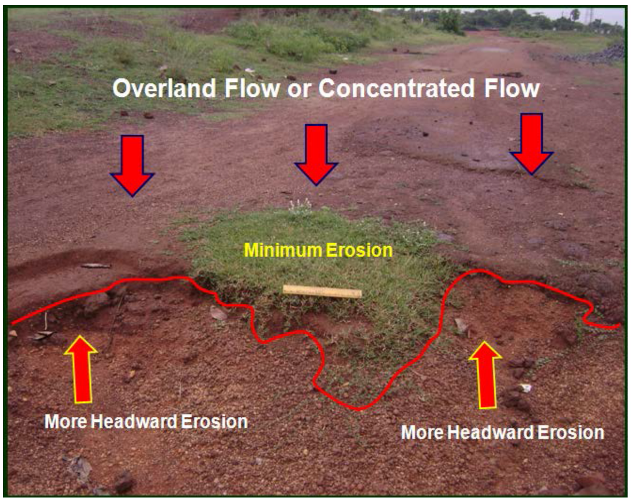


**Figure 6:** Shows the vegetal cover to protect the headward erosion during concentrated flow.

Nevertheless, the inapt subtraction of plant cover and the livestock grazing of the barren/upland areas where rill and gully erosion is endanger for land conservation, raising an urgent need to implement appropriate land management which has a large-scale perspective but acts at the local level. Erosion can be alleviated through a progression of evaluation at regional scales to put broad targets, for growth and restoration of the plant cover, and the introduction of conservation measures within the areas at greatest risk.

### References

1. Valentin C, Poesen J, Li Y (2005) Gully Erosion: Impacts, Factors and Control. Catena, 63: 132-153.
2. Li WQ, Xiao-Jing L, Khan MA, Gul B (2008) Relationship between Soil Characteristics and Halophytic Vegetation in Coastal Region of North China. Pak J Bot 40:1081–1090.
3. Neary DG, Ice GG, Jackson CR (2009) Linkages between Forest Soils and Water Quality and Quantity. Forest Ecology and Management 258: 2269-2281.
4. Shit PK, Maiti R (2012) Rill Hydraulics - An Experimental Study on Gully Basin in Lateritic Upland of Paschim Medinipur, West Bengal. Journal of Geography and Geology 4: 1-11.
5. Wainwright J, Parsons AJ, Abrahams AD (2000) Plot-Scale Studies of Vegetation, Overland Flow and Erosion Interactions: Case Studies from Arizona and New Mexico. Hydrol Process 14: 2921-2943.
6. Webb BW (2000) Erosion and Sedimentation. Hydrology IAHS Publ No 171, 1987.
7. Grellier S, Kemp J, Janeau, J.-L, Florsch N, Ward D, Barot S (2012) The Indirect Impact of Encroaching Trees on Gully Extension: A 64 Year Study in a Sub-Humid Grassland of South Africa. Catena. 98:110-119.
8. Podwojewski P, Janeau JL, Grellier S, Valentin C, Lorentz S, Chaplot V (2011) Influence of Vegetal Soil Cover on Water Runoff and Soil Detachment in a Sub-Humid South African Degraded Rangeland. Earth Surface Processes and Landforms 36:911–922.
9. Cohen S, Svoray T, Laronne JB, Alexandrov Y (2008) Fuzzy-Based Dynamic Soil Erosion Model (Fudsem): Modelling Approach and Preliminary Evaluation. Journal of Hydrology, 356, 185– 198.
10. Gyssels G, Poesen J, Bochet, E, Li Y (2005) Impact of Plant Roots on The Resistance of Soils to Erosion By Water: A Review. Progress in Physical Geography 29: 189-217.
11. Shit PK, Bhunia GS, Maiti R (2012) Effect of Vegetation Cover on Sediment Yield: An Empirical Study Through Plots Experiment. Journal of Environment and Earth Science 2: 32-40.
12. Sarkar D (2005) Physical and Chemical Methods in Soil Analysis. New Age International, Nagpur.
13. Zuazo VHD, Martinez JRF, Pleguezuelo CRR, Raya AM, Rodriguez BC (2006) Soil-Erosion and Runoff Prevention by Plant Covers in a Mountainous Area (Se Spain): Implications for Sustainable Agriculture. Environmentalist 26: 309–319.
14. Zuazo VHD Pleguezuelo CRR (2008) Soil-Erosion and Runoff Prevention by Plant Covers- A Review. Agronomy for Sustainable Development 28: 65-86.
15. Bochet E, Garcia-Fayos P (2004) Factors Controlling Vegetation Establishment and Water Erosion on Motorway Slopes in Valencia, Spain. Restoration Ecology 12: 166-174.
16. Shit PK, Bhunia GS, Maiti R (2013) Assessing the Performance of Check Dams to Control Rill-Gully Erosion: Small Catchment Scale Study. International Journal of Current Research 5: 899-906.
17. Castillo VM, Martínez-Mena M, Albaladejo J (1997) Runoff and Soil Loss Response to Vegetation Removal in a Semiarid Environment. Soil Sci Soc Am J 61: 1116–1121.
18. Durán ZVH, Francia MJR, Rodríguez PCR, Martínez RA, Cárceles RB (2006)

Soil Erosion and Runoff Prevention by Plant Covers in a Mountainous Area (SE Spain): Implications for Sustainable Agriculture. The Environmentalist 26: 309–319.

19. Gregorich EG, Greer KJ, Anderson DW, Liang BC (1998) Carbon Distribution and Losses: Erosion and Depositional Effects. Soil Till Res 47: 291–302.

20. Schlesinger WH, Abrahams AD, Parsons AJ, Wainwright J (1999) Nutrient Losses in Runoff from Grassland and Shrubland Habitats in Southern New Mexico: Rainfall Simulation Experiments. Biogeochemistry 45: 21-34.

21. Eldridge DJ, Freudenberger D (2005) Ecosystem Wicks: Woodland Trees Enhance Water Infiltration in a Fragmented Agricultural Landscape in Eastern Australia. Austral Ecology, 30: 336–347.

22. Van Dijk PM, Kwaad FJPM, Klapwijk M (1996) Retention of Water and Sediment by Grass Strips. Hydrological Processes 10: 1069-1080.

23. Zhou GY, Morris JD, Yan JH, Yu ZY, Peng SL (2002) Hydrological Impacts of Reafforestation With Eucalypts and Indigenous Species: A Case Study in Southern China. Forest Ecol Manag 167: 209–222.

24. Zhang B, Yang Y, Zepp H (2004) Effect of Vegetation Restoration on Soil and Water Erosion and Nutrient Losses of a Severely Eroded Clayey Plinthudult in Southeastern China. Catena 57: 77– 90.

25. Marqués MJ, Jiménez L, Pérez RR, García OS, Bienes R (2005) Reducing Water Erosion in a Gypsic Soil by Combined Use of Organic Amendment and Shrub Revegetation. Land Degrad Dev 16: 339–350.

26. Liu C (1992) The Effectiveness of Check Dams in Controlling Upstream Channel Stability in Northeastern Taiwan. Erosion Debris Flow and Environment in Mountains Regions. IAHS Pub Lic No. 209, 1992.

27. Bouwer H (2002) Artificial Recharge of Groundwater: Hydrogeology and Engineering. Hydrogeology Journal, 10:121–142.

28. Freeborn J (2011) Urban Water Quality Management Residential Stormwater: Put it in its Place (Decreasing Runoff and Increasing Stormwater Infiltration). Publication 426-046. Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, 2011.