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Runoff, Suspended Sediment and Erosion Rate in the Priyadarshini Watershed

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Abstract

The Priyadarshini watershed has 36 ha area contributing runoff. The study has been carried out to measure the rainfall, runoff and soil loss from the watershed. Runoff is the main carrier of eroded material to the outlet of the watershed and the portion of eroded material, which is moved along with the runoff with the suspension, is called suspended sediment. The runoff and suspended sediment are measured at outlet. Total rainfall recorded during the period of monsoon i.e. from June to September was 2919.3 mm and produced runoff 698.71 mm. The magnitude of runoff produced was 115.89 mm, 182.85 mm, 265.91 mm and 134.06 mm in June, July, August, and September, respectively. It is concluded that, during the study period rainfall was less than its average annual rainfall. Integrated station was calibrated for silt parameters. The result showed that there was no significant difference between measured silt and reading shown by integrated station at 5 per cent level of significance. Average sediment concentrations were 21.9 gm/l, 19.3 gm/l, 19.37 gm/l and 17.7 gm/l in the month of June, July August and September, respectively. This magnitude of runoff carried a silt of 2.88 t/ha in month of June, 4 t/ha in July, and 7.47 t/ha in month of August and 3.4 t/ha in the month of September. The observed runoff was 23.93 per cent of the total rainfall during the year 2008. Average soil loss measured by sampling method was found to be 4.3 t/ha and by Integrated station, 4.35 t/ha there was difference of 0.05 t/ha. The total runoff measured was 2934.25 m^3 and 2911.37 m^3 was monitored by integrated station. There was difference of 22.88 m^3 of runoff. Similarly total soil loss measured by integrated station was 148 tons during the observation period.

Keywords: Runoff, suspended sediment, erosion

Introduction

The high amounts of intense rainfall with their high erosivity, the high erodibility of the soil of the tract coupled with moderate to very steep slopes make these hilly regions prone to severe erosion especially when the natural cover is tampered. This is especially true in case of conversion of forest lands having deeper root system into the agricultural lands which have relatively shallow root system and this amounts to temporarily with the soil-water-plant relationship causing havoc in the form of production of larger amounts of runoff, higher peak discharges, flooding of bottom (low lands) lands, reduced ground water discharge, lowering of water table, reduced low flows in streams during summer, choking up of stream beds and water ways, pollution of surface water affecting aquatic life and posing health problem, loss of fertility, siltation of multipurpose reservoirs affecting power and agricultural production, etc. It also results in landslides affecting rail and road transport and communication systems. As a result, all round economy is drastically affected [12].

Nearly 50% of the land area of India suffers from varying degrees of degradation. The most important causes of land degradation are soil erosion, water logging, salinity, alkalinity and over-exploitation of land by the growing population. An estimated 5000 million tons of topsoil is being eroded every year and approximately 1600 million tonnes of this is being permanently lost. Today's degradation problems are not just due to natural causes, much of them are due to man's own selfish motives. Rapid urbanization and industrialization have accelerated the pace of degradation and it is necessary to take urgent corrective measures before the lands are irreversibly damaged.

Out of total geographical area of India, 175 Mha (66 per cent of land) is suffering from deleterious effect of soil erosion and land degradation [10]. Active erosion caused by water and wind alone accounts 150 Mha of land, which amounts to a soil loss over 5000 million tons annually. In addition, 25 Mha have been degraded due to ravines and gullies, shifting cultivation, salinity/ alkalinity, water logging etc. In India, the soil erosion is taking place at the rate of 16.35 tons per ha per annum [11].

The sheet erosion is one of the serious constraints in red soil, occupying an area of more than 70 million hector where the soil depth varies from 20-100 cm and rainfall intensity is very high. The soil loss in this area is in excess of 10 t/ha/y. the lateritic soil occurring in areas of rolling or undulating topography with steep slopes suffer from severe rill erosion because they are in the region of fairly high rainfall. Owing to high intensity rain storms, these soils are losing annually about 40 t/ha in the absence of soil conservation measures [1].

Konkan region of Maharashtra is broadly divided into two agro climatic zone, i.e. South and North Konkan coastal zone, based on soil type, geographical situation and cropping pattern. It is situated along a costal belt of Arabian Sea with length 720 km and width 35-50 km. It is spread over between 15˚ 6'N and 20˚ 22'N latitude and 72˚ 39'E and 73˚ 48'E longitude, covering total geographical area of 3.079 Mha.

Konkan region of Maharashtra state constitutes 10 per cent of geographical area. It is characterized with high intensity rainfall, receives 46 per cent of rainfall of the Maharashtra state. This region is geographically categorized under highly undulating with general slope ranging from 7 per cent to 35 per cent and average rainfall from 3500 to 4000 mm annually. The most reliable month of rainfall is July with the highest normality as 96.77 per cent [8]. The rainfall and slope causing irreparable damage in the form of very severe soil erosion, ranging from 10 to 33 tons per ha per year [7].

Reference [2] estimated the soil loss quantitatively of the Rakti river basin of the Darjeeling Himalaya. Both the potential and predicted or actual soil erosion has been estimated using the equation RKLS and RKLSCP respectively. The result showed that very high and high erosivity zones (> 1000 tons per hr per year and 500-1000 tons per hr per year of actual soil loss had not been confined within the exceptionally high and very high potential soil loss zones. The average soil loss resulted from the actual or predicted soil erosion over this area was greater than 1000 tons per hr per year or greater than 60 mm per year.

Reference [3] estimated runoff and sediment yield from Giri River. They were computed mean monthly and mean annual values for available period of records by measuring the daily runoff and suspended sediment data along the calibrated segments of the river. The mean annual runoff in the river over twelve years was 1039.5 x 10^6 m^3. About 75 per cent of the runoff occurred from June to September. Both annual and monthly runoff values showed a great degree of variation. The mean runoff efficiency for the catchment was 23.22 per cent. The annual suspended sediment load in the river was 2488.2 x 10^3 tons. The annual sedimentation rate of the catchment was 95.7 x 10^3 tons per 100 km^2.

Sediment yield measurement from small watersheds is of vital importance for solution of many water resources problems including the planning and design of soil and water conservation works. Measurement of catchment's runoff is essentially required for almost all types of water resources management and planning studies such as determination of minimum amount of water available for agricultural, industrial and municipal uses, planning and design of irrigation projects and estimation of future dependable water supply for power generation etc.

Suspended sediment is supposed as an indicator for soil erosion occurred in the upland watershed [5] and can be used for watershed priority.

Information on the sediment yield at the outlet of a stream can provide the rates of erosion and soil loss in the watershed. Keeping these in view, the study was undertaken with the objective to measure the runoff and soil loss from Priyadarshini watershed.

Methodology

The traditional methods of measuring runoff and soil loss were quite cumbersome and time consuming. Watershed development planning needs timely and correct information regarding runoff and soil loss for generation of action plan. The information collected by traditional method while reaching to the experts' hand becomes biased due to errors in collection of data and loses its timely value even if it may be correct.

The Integrated Rainfall-Runoff-Soil loss station gave time-to-time readings of water level and silt, which was useful in measuring runoff and soil loss. The study was carried out at the Priyadarshini Watershed, Dapoli District Ratnagiri, Maharashtra state, India located at 17.10 N latitude, 73.260 E longitudes and 250 m above mean sea level during the year 2008-2009. The area falls under warm and humid climate with average annual rainfall of 3500 mm. The distribution of rain concentrated during the monsoon months from June to October. Priyadarshini Watershed has 38.72 ha area. The watershed was fern shaped. The general feature of Priyadarshini Watershed was depicted in Fig. 1.

Area contributing runoff was 36 ha. The location at which all surface runoff from the watershed came together as outflow from the watershed in the stream was called measuring point, since the stream outflow was measured at this point. Therefore Integrated Rainfall-runoff-Soil loss Station was installed at this point also depicted in the Fig.1.

Establishment of Integrated Rainfall-Runoff-Soil loss Station

The Integrated Rainfall-Runoff-Soil loss Station was established at outlet of Priyadarshini Watershed to measure the rainfall, runoff and soil loss from the watershed. The Integrated Rainfall-Runoff-Soil loss station is shown in Fig1. It consists of following parts and the functions of parts are as follows:

Water Level Float Switch

When water level reached up to certain level, the float moved up through 3-5 cm and switched ON the total system into live condition from its sleeping mode.

Water Level Sensor

The water level sensor was worked on the principle of float attached with rotary transducer, to produce the signal; a special string of definite length decided by the range of measurement was wound over the wheel. A float was attached at one end of the string and counter weight at the other end. In this condition the float could move freely up and down as per water level. The sensor head was to be fixed over the gauging weir such that the float could move freely. The sensor produced electrical signals in relation to the water level and recorded by data logger.

Silt Sensor

The silt sensor, which was kept much below the water surface, senses the silt content in the water only when it was fully submerged. The corresponding signals were transmitted through the cable to the data logger. The silt sensor should be always fully submerged condition.

Rainfall Sensor

The collector of the rainfall sensor was 200 mm diameter and it worked on the principle of tipping bucket. Each tipping was counted in the counter. For achieving high precision, each tipping was made for 0.3 mm rain. The tips were sensed magnetically using magnet and reed switch. The rainfall sensor was always in live condition.

Data Logger

The main function of data logger was to activate the system on receiving the commands from the float switch and wakes up signal from the memory module and activates the total system. The signals received from all the sensors were processed for indication in their respective units. The water level was indicated in the LCD display in 'mm', silt in 'gm per liter' and rainfall in 'mm'.

Installation

Integrated Rainfall-Runoff-Soil loss Station was installed at outlet of Priyadarshini Watershed. The rainfall sensor was located in an open space free from obstructions on a level ground. The separate data logger was provided for rainfall sensor.

The data logger was kept in a separate chamber made up of GI sheet. The mesh fencing was provided for protection of chamber. The silt sensor was fixed on the upstream side of the headwall of RCC drop structure at 30 cm above the bottom with the help of clamp. The water level sensor was kept in the PVC pipe of 110 mm diameter. Float and counter weight was kept inside the PVC pipe. Holes were provided at the lower portion on PVC pipe. As water enters from these holes inside the PVC pipe, which acts as a stilling well, float moved up and down as per the water level. The signal passed on to the data logger through cable. Water level float switch was fixed with the help of clamp on the head wall, of RCC drop structure. Water level float switch, water level sensor and silt sensor were connected with individual cable to the data logger.

Determination of Runoff

The rate of flow was measured by using rectangular weir (RCC drop structure) with end contractions at both ends.

$$Q = 0.0184(L - 0.2H) \times H^{3/2}$$

Where,

Q= Discharge, lit/sec

L= Length of the crest, cm

H= Head over the crest, cm

In this formula, H was measured by water level sensor. In water level sensor, a float was attached at one end of the string and it could move up and down as per the water level. The sensor produces electrical signals in relation to the water level and recorded by data logger. The water level sensor reading was recorded and simultaneously the stage was measured manually at a fixed point throughout the observation period.

Grab Sample

The simplest way of taking a sample of suspended sediment was to dip a container into the stream preferably at a point where it was well mixed, such as downstream from the weir. The sediment contained in a measured volume of water was filtered, dried and weighed. This gave a measure of concentration of sediment and when combined with the rate of flow gives the rate of sediment discharge [4].

Calibration

Runoff and soil loss were measured in the rainy season from June to September 2008.

The Integrated Rainfall-Runoff-Soil loss Station was calibrated for runoff and soil loss parameters in the laboratory.

Calibration Procedure

The silt sensor was placed in a water container having capacity 18 litres. Then soil sample of 75 micron, 150 micron and 300 micron of known quantity was added in the water, respectively. The soil sample was mixed in the water with the help of stirrer. Then the reading on the monitor was recorded in gm/lit and compared with actual silt content in the water container.

Laboratory Analysis

Suspended Sediment Concentration

Results of laboratory analysis were reported in gm/l. A unit important for sediment studies. The amount of soil loss from watershed under different practices, a unit of kg/ha was more practical. To convert concentration from gm/l to kg/ha required following inputs:

1. Concentration of sediment (gm/l).
2. Total volume of the water from which the sample was taken (l) and
3. Area of the catchments producing the concentration being measured.

1. Convert the volume of runoff into litre V (l) = V (m^3) $\times$ 1000

2. Convert the concentration (gm/lit) to total mass (kg) by using the conversion factor 1 kg = 1000 gm

$$Mass(kg) = \frac{Concentration(gm/l) \times V(l)}{1 \times 10^3}$$

3. Convert the mass in 'kg' to mass per unit area (kg/ha) using the conversion factor 1 ha = 10^4 m^2

4. Soil loss from watershed (kg/ha) =
$$\left[\frac{Mass(kg)}{Area(m^2)/10^4} \right]$$

Estimation of Soil Loss

Evaporation and filtration were the two methods used for determining suspended sediment concentration.

The filtration method was faster, if the quantity of sediment in the sample was small and relatively coarse grained. In addition if the quantity of sediment was small, the evaporation method required correction if the dissolved solids concentration was high. The evaporation method was usually best for high concentration of sediment [6].

Evaporation Method

The suspended load was estimated by evaporation method. Weight of empty container was taken. A sample of 1 lit was taken in a container and put it in the oven for evaporation. After complete removal of water, weight of the container was taken. The difference between first reading and last reading was given the weight of suspended sediment.

Filtration Method

In this method, water samples were collected at stream outlet in one-liter container. Water samples were filter immediately after collection from pre-weighed filter paper. During this process sample should stirred simultaneously otherwise the silt was settled at the bottom. After filtration, the filter paper with wet silt was put in the oven for evaporation and then evaporation method was used for suspended load.

Results and Discussion

The efforts were made to determine runoff and soil loss from Priyadarshini watershed. To test the feasibility and performance, evaluation of integrated station at Priyadarshini watershed, Dapoli, the data of rainfall, runoff and silt were analyzed.

Rainfall

The rainfall record was obtained through a single rain gauge located in the Priyadarshini Watershed during the season of 2008. There was commencement of rains in the first week of June. The total rainfall of 2919.3 mm was received from June to September. All available rainfall events were combined to obtain the total rainfall for the period of 1st June to 30th September 2008. Fig. 2 shows a daily rainfall time series.

As depicted in Fig.2, three major storm events with 107.4 mm, 152.8 mm and 120.8 mm rainfall occurred on 7th, 8th and 12th June respectively. In the month of July, two major storms with 114 mm and 143.8 mm occurred on 27th and 28th July respectively. In the month of August, three major storms with 146.4 mm, 103.2 mm and 132 mm rainfall occurred on 6th, 10th and 12th August, respectively. One major storm event of 102.6 mm rainfall on 12th September was occurred.

The monthly rainfall was shown in Fig.3. The rainfall recorded in the month of June was 943.6 mm, 694.4 mm in July, 685.1 mm in August and 596.2 mm in th month of September.

Runoff

For continuous record of runoff stage (gauge height) during the rainy season, Water Level Sensor was installed on the head wall of RCC drp structure at gauging site. From the readings of stage, stage hydrograph was plotted. Runoff was calculated from the stage hydrograph as shown in Fig. 4.

As shown in Fig. 5 rainfall started in the first week of June, but runoff started from third week of June. When the runoff started due to storm some runoff quantity was held in online pond in upper reaches of Priyadarshini Watershed. On the main stream, which was flowing through the watershed, there were 14 loose boulder structures in series. This runoff stored in these structures was called depression storage. Therefore there was no runoff in initial two weeks of June. The depression storage was 1966.56 m^3. Runoff was continuously measured at the Priyadarshini Watershed throughout the year 2008. The runoff was calculated by using contracted weir formula with contraction on both ends.

It was observed that runoff producing intense storm recorded on 27th July (114 mm), 28th July (143.8 mm), 6th August (146.4 mm), 10th August (103.2 mm) and 12th September (102.6 mm) during the observation period. The depths of runoff were 115.89 mm, 182.85 mm, 265.91 mm and 134.06 mm in the month of June, July, August and September, respectively.

Soil loss

Calibration of Integrated Station

The calibration was carried out for the integrated station. t-test was applied to perform analysis. The result for 75 micron particle size indicated that there were no significant difference between measured silt and reading shown by integrated station for silt because tcal = 0.0229 was found to be lower than ttab = 1.96 at 5 per cent level of significance. Also for 150 micron particle size tcal = 0.041 was found to be much lower than ttab = 1.96 at 5 per cent level of significance and for 300 micron tcal = 0.041 was found to be much lower than ttab = 1.96 at 5 per cent level of significance. After calibration it was used for recording observations.

The daily sediment was calculated by analyzing the daily collected suspended sediment samples and with respect to mean daily discharge depicted in Fig. 6.

The suspended sediment concentration was high in the month of June though there was low runoff. On an average there was 19.76 gm/l suspended sediment concentration throughout the season. Highest sediment concentration observed was 34 gm/l on 30th June.

As shown in Fig. 7 shows daily rainfall and suspended sediment concentrations both with continuous measurement of runoff hydrograph at the Priyadarshini Watershed from June to September 2008 monitoring period. As there was no runoff at the beginning of the storm, no soil loss was observed.

1. The total silt measured was 148. 32 tons.
2. The average amount of silt measured was 4.35 t/ha.
3. The silt measured in the month of June, July, August, September were 2.88 t/ha, 4.00 t/ha, 7.47 t/ha, and 3.40 t/ha, respectively

Correlation relations were developed for all the monitored suspended sediment concentration with the runoff. Fig. 8 depicted that the relationship between concentrations of suspended sediment with runoff based on the monitor data during the year 2008. Data for each month were grouped together and the individual correlation equation for each month was developed. As shown in the figure, the correlation of suspended concentration varies from month to month showing high dependency of silt occurrence in water during the rainy season. Sediment concentration with respect to runoff was the highest during the month of August. The sediment concentration gradually reduces in July and September. The correlation equations and corresponding correlation coefficients for the individual month may serve as useful tools in predicting sediment concentration in Priyadarshini watershed and similar watersheds under similar geographic, geological, climatic and land use condition.

As shown in Fig. 9, comparison between measured runoff and runoff monitored by integrated station was observed. The total runoff measured was 2934.25 m^3 and 2911.37 m^3 was monitored by integrated station. There was difference of 22.88 m^3 of runoff in the rainy season. Measured runoff and monitored runoff was nearly same.

Comparison between measured and monitored silt by Integration station was shown in Fig. 10. Average soil loss measured by sampling method was found to be 4.3 t/ha and by Integrated station, 4.35 t/ha. There was difference of 0.05 t/ha.

Summary

The high amount of intense rainfall with their high erosivity, the high erodibility of the soil of the tract coupled with moderate to very steep slope makes hilly regions prone to serve erosion especially when the natural cover is tampered. Keeping in mind, the need of measurement of runoff and soil loss from watershed, the study was undertaken.

The study was carried out to monitor runoff and soil loss at Priyadarshini Watershed, Dapoli. Integrated Rainfall-Runoff-soil loss station was established at the outlet of the watershed to monitor runoff and soil loss from the watershed.

Integrated station was calibrated for silt parameters. The results show that there was no significant difference between measured silt and reading shown by integrated station. Runoff amount did agree well with observed runoff. The performance of integrated station was satisfactory therefore it was used for measurement of runoff and soil loss from Priyadarshini Watershed

The study provides a valuable data based on continuous rainfall, runoff and sediment in Priyadarshini Watershed. These data help to understand the complex physical and chemical processes in the watershed.

The results were compared with observed data using statistical methods. The test result showed close agreement between measured and monitored runoff and soil loss.

1. In the monsoon period i.e. from June to September total rainfall occurred was 2919.3mm contributing 943.6 mm in the month of June followed by 694.4 mm, 685.1 mm and 596.2 mm in the month of July, August and September, respectively.
2. In the month of June runoff depths 115.89 mm, 182.85 mm in July, 265.91 mm in August and 134.06 mm in September were observed.
3. The total runoff depth was 698.71 mm.
4. In the month of June runoff carried 2.88 t/ha of silt, 4 t/ha in month of July, 7.47 t/ha in the month of August and 3.40 t/ha in the month of September.
5. The average soil loss was 4.35 t/ha.
6. When runoff measured was compared with runoff monitored by Integrated station, there was 0.78 per cent variation.
7. There was 0.12 per cent variation when measured soil loss was compared with soil loss monitored by Integrated station.

Conclusions

The research findings of the present study have been concluded as; the performance of Integrated Rainfall-Runoff-Soil loss Station was closer to the measured values and hence it can be used for measurement of runoff and soil loss from the watershed. The present Integrated Rainfall-Runoff-Soil loss Station installed at Priyadarshini Watershed, Dapoli was up to the mark and satisfactory. The suspended sediment concentration was high in the month of June though there was low runoff. There was no significant difference between runoff measured manually and runoff observed by integrated station. There was no significant difference between soil loss measured manually and soil loss observed by Integrated station. During the study period rainfall was less than its average annual rainfall. The observed runoff was 23.93 per cent of the total rainfall during the year 2008.

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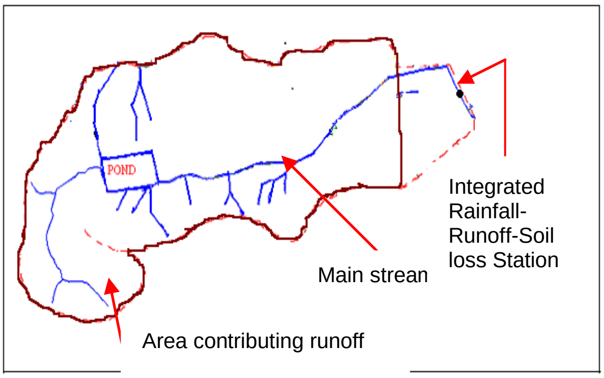

Fig. 1: General Feature of Priyadarshini Watershed

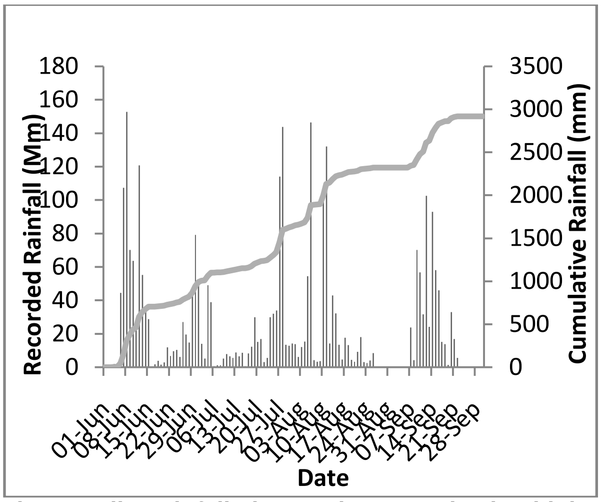

Fig. 2: Daily Rainfall Time Series For Priyadarshini Watershed

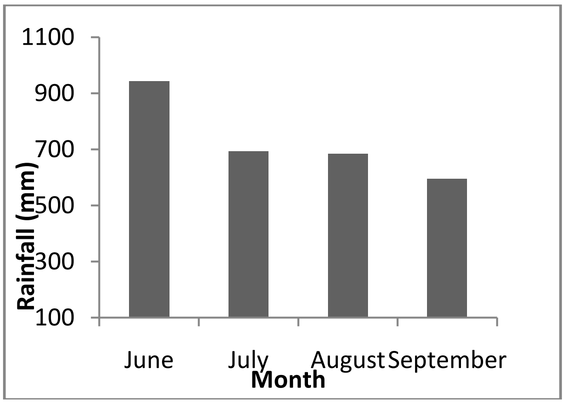

Fig. 3: Monthly Rainfall For Priyadarshini Watershed

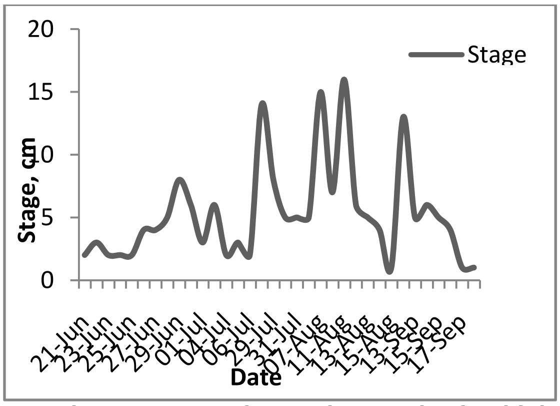

Fig. 4: Stage Hydrograph For Priyadarshini Watershed.

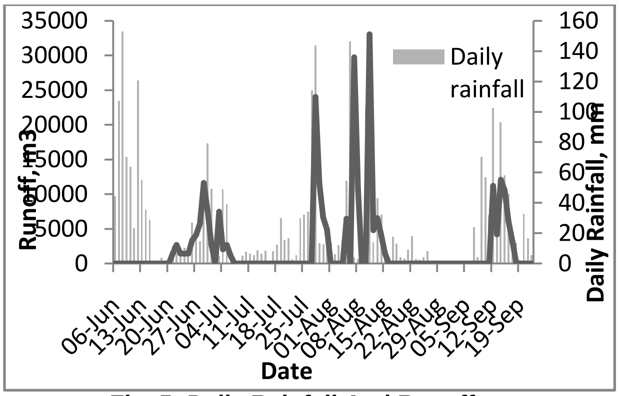

Fig. 5: Daily Rainfall And Runoff

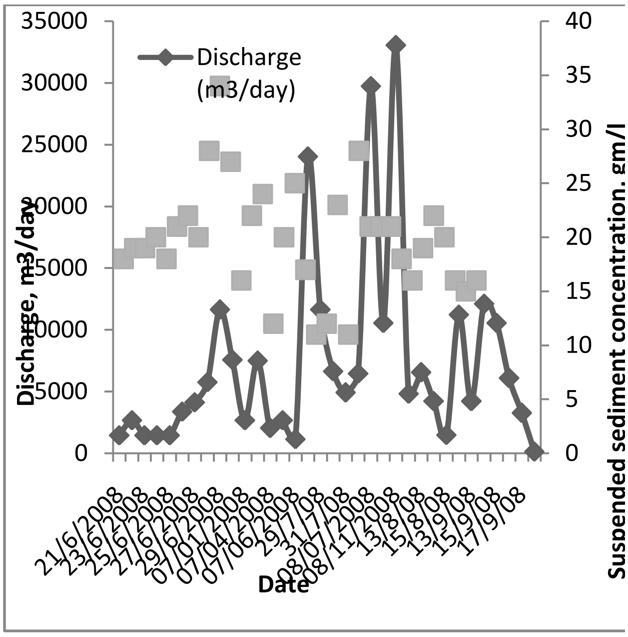

Fig. 6: Hydrograph And Concentration of Suspended Sediment

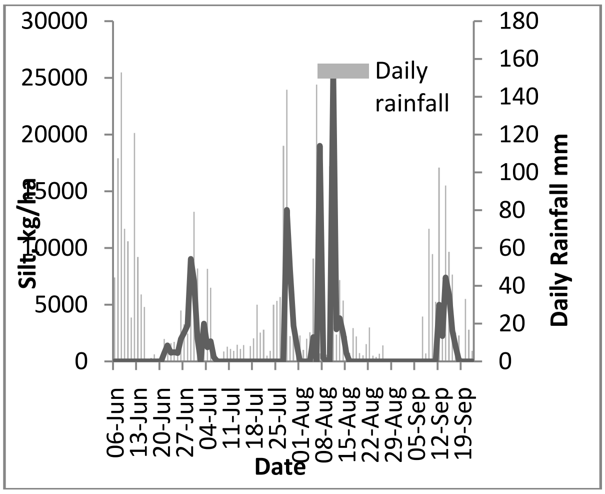

Fig. 7: Daily Rainfall And Silt

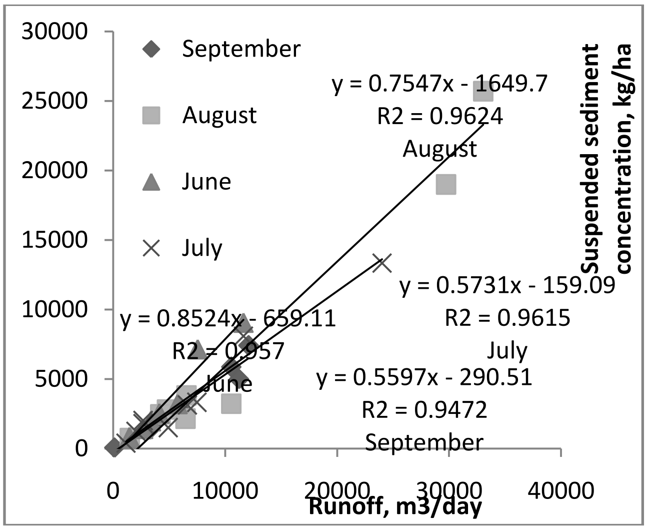

Fig. 8: Comparison of Suspended Sediment Concentration With Runoff

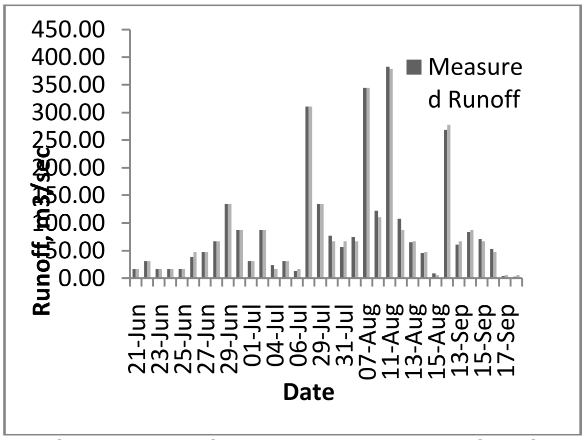

Fig. 9: Comparison Between Measured And Observed Runoff

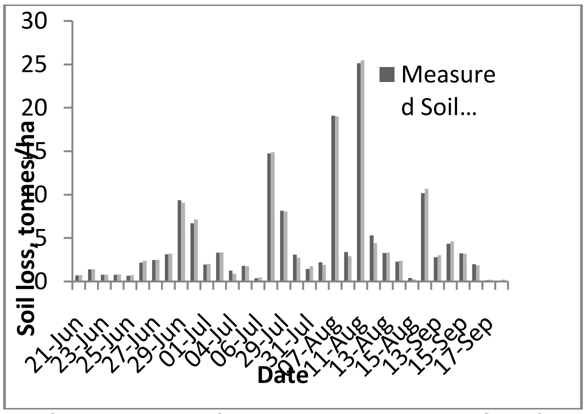

Fig. 10: Comparison Between Measured And Observed Silt