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Erosion and runoff monitoring and modelling in a semiarid region of Brazil

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Abstract Erosion and runoff studies have been carried out in Sume - a semiarid region in Paraiba - since 1982. Several erosion plots of 100 m^2 and four micro-basins were installed in an experimental basin in order to evaluate the effects of land slope and vegetal cover on the surface runoff and sediment yield. Two micro-basins were cleared bare and the other two maintained with native vegetation. The studies show the large protective influence of the natural vegetation against erosion. A physically based event oriented model WESP (Lopes & Lane, 1988) proved satisfactory for modelling the runoff and erosion from the bare micro-basins.

INTRODUCTION

It is well known that normal human activities like agricultural practices, deforestation, urbanization, etc. result in significant changes in the behavior of the hydrologic basins, principally in terms of surface erosion and runoff production. The degree of change resulting from these human interventions depends on several factors but mainly on the prevailing hydrologic regime and the nature of the interventions. In the north-eastern region of Brazil the climate is mostly semiarid to arid and the bulk of the region lies within a drought prone area known as the "polygon of droughts". The principal economic activity of subsistence in the region is agriculture in dry lands. As a consequence, more and more areas covered by native vegetation are being cleared every year and brought under cultivation. The effects of the land clearance over the surface runoff and soil erosion are not known quantitatively. In general, the region faces two conflicting situations: one in which there is a need to maximize surface runoff and store this water in field reservoirs to be used later during the dry period and the other in which the relatively thin soil cover of the region needs to be protected against erosion. The solution to this, evidently, lies in the identification of areas within the watershed where the priority is either runoff or soil conservation. Such identification needs experimentation and collection of field data in order to assess the relative influence of such diverse factors as, land clearance, surface slope and the cultivation practices. Towards this end, an experimental basin was installed in a typically semiarid region of the State of Paraiba near the town of Sume.

THE EXPERIMENTAL BASIN AND INSTALLATIONS

The experimental facilities are located in a private farm land known as "Fazenda Nova" within the Umburana sub-basin (10.7 km^2 area). The sub-basin is a part of the representative basin of Sume (137.4 km^2 area). Brown non Calcic "Vertic" soils predominate in the region with more than 85% of the representative basin being covered by these soils (Cadier *et al.*, 1983). The climate of the region is typically semiarid with irregular rainfall and frequent droughts. The mean annual precipitation is 590 mm with a coefficient of variation of about 0.5. The soil cover is relatively thin and is underlain by the bed rock.

The field installations consist of four micro-basins and several erosion plots of 100 m^2 with all of them designed to permit the measurement of total surface runoff and erosion losses from the area. The micro-basins were selected in such a way that they could represent, among them, different vegetal covers and slopes. Two of them are maintained with the natural undisturbed vegetation consisting of small sized trees and medium height bush of 1 to 2 m. The other two micro-basins had the original surface vegetation completely cleared and are continuously maintained with the bare soil surface. The main physical features of the four micro-basins are shown in Table 1.

Table 1 Physical features of the micro-basins.

Basin no.	Area (ha)	Perimeter (m)	Mean slope (%)	Vegetal cover
1	0.62	398	7.0	Natural bush & small trees
2	1.07	466	6.1	Natural bush & small trees
3	0.52	302	7.1	All vegetation cleared
4	0.48	270	6.8	All vegetation cleared

Each of the four micro-basins is equipped with rectangular sediment and flow collectors of nearly 2300 l capacity and terminating with a 90° triangular weir designed for a maximum discharge of 270 $l\ s^{-1}$. Water level recorders installed in the collectors permit continuous recording of the water levels. As long as no overflow through the weir occurs, the entire surface runoff and the eroded sediments accumulate in the collectors. Whenever the weir overflows, a continuous sampling of the water-sediment mixture is made possible by means of three sampling points located at intervals of 10 cm starting from the crest level of weir. The sampling points are connected to auxiliary containers in which samples are accumulated continuously during the overflow period.

Nine erosion plots of 22.1 m by 4.5 m (100 m^2 area) have been installed in the experimental basin with different surface conditions and natural slope. Five plots were operative in 1982, two more were installed in 1983 and the last two were added in 1986. Table 2 shows the slope and the surface condition of each of the nine plots.

The runoff and the eroded sediments are collected in a 1000 l capacity covered tank provided with an inner calibrated bucket to hold the runoff and erosion from very low precipitation events. The tank is provided with nine uniformly spaced overflow pipes and the central pipe is connected to a second 1000 l capacity tank. The other eight outlets freely spill out the excess from the first tank. In the event of overflow from the

Table 2 General features of the erosion plots.

Plot no.	Year	Slope (%)	Surface cover
1	1982	3.8	bare soil clear of vegetation
2	1982	3.9	mulching with the removal of natural vegetation growth
3	1982	7.2	as above
4	1982	7.0	bare soil clear of vegetation
5	1982	9.3	natural bush & small trees
6	1983	4.0	cactus planted along the slope
7	1983	4.0	cactus planted in contour
8	1986	4.0	ploughed bare and loose soil
9	1986	4.0	renewed natural bush

first tank, the total runoff volume is determined by adding 9 times the volume accumulated in the second tank to the full volume of the first.

MEASUREMENTS AND DATA COLLECTION

All the data collected from the micro-basins and the erosion plots were for the natural precipitation events. In the region of Sume the bulk of the precipitation occurs between January and May with the period of February to April being the most rainy trimester. A weather station centrally located in the experimental basin provided the basic climatic data. In addition, several recording and non recording rain gauges were installed close to the micro-basins and the plots. For each rainfall event the response of the micro-basins and the erosion plots were sought in terms of the total runoff and sediment yield.

In the case of erosion plots the total runoff volume was determined by direct measurement. The average sediment concentration of the runoff was established by sampling at various stages by the siphoning of the accumulated sediment-water mixture. For the micro-basins however, the total runoff volumes for each event were obtained from the hydrographs that were prepared from the water level record and the calibration curves of the sediment collectors and the overflow weir. The sediment production was obtained by adding the amount of sediments retained in the collectors (estimated by sampling at various stages) to the quantity of sediments discharged in suspension through the weir. The latter was obtained by associating the concentration sampled from the flow accumulated in the auxiliary containers with the overflow volume. Details of the sampling procedures and measurements can be found elsewhere (Galvao, 1990).

ANALYSIS OF DATA

More than 200 events of precipitation with runoff were registered between 1982 and 1989. Though the number of events seem to be large enough for a detailed analysis, the events producing very small runoff are far too numerous than events with significant runoff and erosion loss. Further, the range is not uniformly covered by the observations and hence establishment of quantitative relationships through correlation analysis seem to be premature. The trend and the comparative aspects, however, seem to be quite well established and appropriate for the testing and verification of suitable models.

The large protective influence of the native vegetation could be evaluated by comparing the data obtained from micro-basins 1 and 2 (with undisturbed native vegetation) with those obtained from micro-basins 3 and 4 (cleared bare). Similarly, for erosion plots, a comparison of data from plots 1 and 4 (cleared bare) with data from plot 5 (undisturbed native vegetation) would indicate the influence of the vegetal cover on erosion and runoff.

In the case of the micro-basins 1 and 2, only events of more than 30 mm precipitation produced any significant runoff. Even such large precipitations of the order of 90 mm produced less than 9% runoff. The erosion caused by even the largest of the events was very small highlighting the almost complete protection against erosion provided by the native vegetation. For micro-basins 3 and 4 both surface runoff and erosion losses were large. All events that produced any surface runoff also generated erosion loss. However, the sediment production expressed in kg ha^{-1} didn't show any clear trend when related to the corresponding runoff. Any trend was detectable only when the soil loss was related to the erosivity index $E\ I_{30}$, where E (t ha^{-1}) is the kinetic energy of the rain drops and I_{30} (cm h^{-1}) is the maximum 30 min intensity of the precipitation (Wischmeier & Smith, 1958). In general, the natural vegetation showed the effect of reducing by 90% or more both runoff and soil loss for events of 50 mm of rain or less, when compared with bare soil surface.

A comparison of data from different plots showed the relative effects of surface cover and slope. The plots 2 and 3 with a mulch cover, presented runoff volumes of about 50% of what was observed in bare plots (1 and 4). The reduction of erosion due to mulching was of the order of 60%. Considering the bare plots, the effect of slope seems interesting. In terms of runoff, the slopes of 3.8% (plot 1) and 7% (plot 4), presented similar values, but, in terms of erosion the larger slope resulted in significantly higher soil losses. Similarly, contour planting (plot 7) showed about 50% reduction in erosion losses compared with planting along the slope (plot 6). The corresponding reduction in runoff was only about 20%.

RUNOFF AND EROSION MODELLING

While the comparative evaluation of different factors that affect runoff and soil loss are helpful in the planning process, quantitative predictive estimates are necessary for the proper management of river basins. Conceptual models generally provide satisfactory results of surface runoff and for the four micro-basins of Sume excellent results were obtained considering individual events (Srinivasan & Galvao, 1991). The erosion and transport processes, however, are quite complex and are controlled by several, often interdependent, factors (Foster, 1982). The current perspectives seem to indicate that process based fundamental models can provide a firm basis for predictive or simulation needs. This approach, however, is constrained by the complexity of an open system with component processes and state variables that may change rapidly in space and time. This calls for simplified representations to model the erosion and transport processes (Lopes & Lane, 1988).

In order to establish a simulation model for the erosion losses from the micro-basins cleared bare a process based event oriented model was considered. The model WESP (Watershed Erosion Simulation Program) developed by Lopes (1987) was chosen for application as this model was specially developed for small watersheds. The model uses Green & Ampt infiltration equation to compute the rainfall excess rates for an unsteady rain. The kinematic wave approximations are used for the one dimensional unsteady overland flow. The net sediment transport rate for overland flow is estimated by considering erosion by impact, erosion by shear force and deposition processes simultaneously. The concentrated flow in the channels is also considered as one

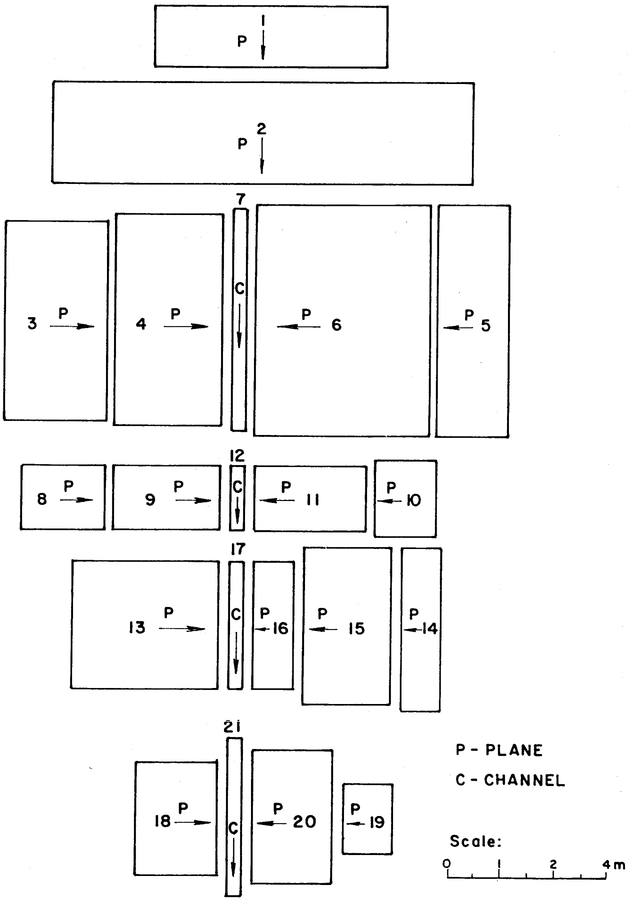

Fig. 1 Representation of micro-basin 4 with planes and channels along with the sequence of flow processing for WESP.

dimensional and unsteady with kinematic wave approximations. The sediment transport rate in any channel reach is established by considering the inflow rate at the upstream end, erosion and deposition rates within the reach and the lateral inflow of sediments in the reach (Lopes & Lane, 1988).

The model treats all the basin processes as either on a plane or in a channel. Thus, the basin is represented in a simplified form as being composed of only planes and channels. The governing equations are numerically solved in the same sequence as the flow would occur, i.e., from the water divide to the outlet. Additional details about the functioning of WESP are found in Lopes (1987), and Lopes & Lane (1988).

Application of WESP

Figure 1 shows the representation of micro-basin 4 in the form of planes and channels. The physical characteristics of planes and channels, the values of relevant parameters have been presented in detail by Galvao (1990). The calibration of the model was carried out with reference to four key parameters, the rest being either known or adopted based on values recommended in the literature. The four parameters are: the capillary potential (N_s) of the soil (mm), the erodibility parameter of impact (K_I) for planes (kg s m^{-4}), the erodibility parameter for shear (K_R) on planes (kg m $N^{-1.5}$ s^{-1}) and the erodibility parameter (a) for channels (kg m $N^{-1.5}$ s^{-1}). Thirteen events occurring between February 1987 and July 1988 were chosen for the calibration of the model on event by event basis. The data from plot 4 were used to obtain the mean optimum values of the parameters K_I and K_R that were used in the micro-basin 4 as pre-fixed. Being left with only two parameters (N_s and a) to optimize, N_s was calibrated for each event to adjust the runoff volume, and then "a" was optimized to adjust the sediment yield. The final output of WESP are the runoff hydrograph and the sedimentgraph.

RESULTS

As one would expect, the parameters N_s and K_R depend on the soil moisture and surface conditions and hence varied from event to event. The parameters K_I and a were relatively stable. While the model is capable of producing the exact runoff volume and erosion loss by optimizing the parameters N_s and K_R for each event, it is necessary to adopt some representative values for the purposes of simulation. These values would be better represented if they are associated with some antecedent moisture conditions. For the 13 events used in the calibration of the model no clear criteria could be established. Thus either the average or most frequent values were adopted and 21 events were simulated. It was found that runoff volumes were better simulated than erosion losses. In 60% of the cases the calculated runoff volumes could be considered satisfactory where as in the case of erosion 45% could be considered satisfactory. The situation should turn out to be even more promising if distributed parameter values are used in the basin.

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