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Hydrosedimentological monitoring in runoff plots of a degraded tropical area under restoration of the Brazilian Atlantic Forest

Abstract

Rainfall erosion is a concerning process for landowners, government agencies and civil society as it involves soil loss, an indispensable natural resource for the production of food, fibers, and biofuels, as well as a means to support enterprises or even preservation of large conservation areas for sustainability and potential carbon sink. Specific Projects using runoff and soil loss plots have been adopted in different parts of the world, contributing to the understanding of erosion dynamics. This research is the result of extensive fieldwork carried out on a rural property undergoing forest restoration through a Payment for Environmental Service initiative. Four runoff plots with dimensions of 22m x 4m x 0.5m (length x width x depth) connected to sediment catchment tanks were implemented on a convex slope to analyze erosion in four different treatments: planting native seedlings, seedlings with green manure, natural regeneration with selective pruning, and exposed soil. The results of monitoring over approximately one year showed that 80.15% of all accumulated surface runoff occurred in the plot with exposed soil, as well as 99.15% of all soil loss. The treatment that presented the best conservation rates was natural regeneration, since there was no need to dig holes to introduce seedlings, causing less soil disturbance. Thus, it was concluded that land use and changes in land use are one of the main factors controlling erosion and surface runoff in the study area, however, in the long term, variations in soil properties due to vegetation may reflect more strongly this dynamic.

Keywords: runoff plots, soil erosion, hydrossedimentological processes, payment for environmental services, forest restoration

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Introduction

Interactions between the soil surface and the impact of raindrops are considered an initial part of water erosion on a slope. There is a detachment of particles and formation of soil crust resulting from the breakdown of aggregates potentially hindering water infiltration and contributing to runoff.[1] Soil erodibility is closely related to soil physical, chemical and biological properties, which indicates that the composition, size and structure of the soil have a great influence on the resistance to transport of their particles.[2]

Soil erosion in country lands of the state of Rio de Janeiro, Brazil, specifically in farmlands slopes with a history of environmental degradation resulting from different economic cycles that embraced unsustainable practices in the use and management of vegetation cover and soils, has become a source of concern for local population and governments. This issue is critical due to its adverse effects on water supply, electricity production, watercourse contamination, and the loss of land with agricultural potential.[3,4]

Although erosive processes are natural phenomena in the evolution of terrain, their acceleration poses a problem that directly affects the capacity of soils to operate in balance with their rates of pedogenesis. Despite soils being considered renewable resources, the renewal process does not unfold within a human time scale.[5] For this reason, efforts to understand soil loss rates have been developed over more than a century of research and experiments,[6] aiming to quantify the contribution of sediments and runoff from agricultural slopes to watershed areas.

Runoff plots are a common method in soil sciences for determining soil loss and surface runoff in various types of crops[7] and slopes.[8] They usually appear with several names such as “Field plots”, “Experimental field plots” “Erosion control plots”. They are also employed to observe the development and branching of rill erosion[8] and estimate the hydraulic contribution of slopes to watershed drainage. Given the complexity and unpredictability of rainfall, as well as other controlling factors of the water erosion process, they are presented in multiple forms in numerous scientific studies. These variations depend on the researcher’s needs and the phenomenon to be observed. Some of these forms include automated runoff plots,[9] runoff plots with rainfall simulators,[10] and indoor laboratory plots,[2] all equipped with various sediment catchment tanks. Despite the diverse types, they generally follow the classic model established by Wischmeier, consisting of a narrow rectangle at its outlet for convergence and capture of flows.

Faced with this scenario, this research aimed to estimate through an experimental station with runoff plots, soil loss and runoff due to water erosion on a convex slope undergoing forest restoration in the Sacra Familia watershed, part of the middle region of the Paraiba do Sul River Valley, Brazil.

Material and methods

The initial phase of the work involved selecting the installation area for the experimental station within the rural property. Although this area may not represent the location with the highest erosive potential to be monitored, it signifies the region where the Payment for Environmental Services initiative has led to forest restoration practices. Four blocks measuring 25m x 12m were marked in parallel for the construction of four runoff plots, each measuring 22m x 4m x 0.5m. Each plot was built at the center of a block, maintaining a buffer zone of 8 meters between them.

The plots were connected to two sediment catchment tanks, each with a capacity of 1000 liters. The quantification of surface runoff and soil loss was conducted through a linear regression test, involving the gradual emptying of each tank to obtain the equation. Thus, by measuring the height of the collected water layer, the volume of runoff from the sampling area can be determined.

To determine sediment rates, samples of the solution retained in the tanks were collected, dried in the laboratory, and weighed to serve as parameters for the following equation.

$$Rv \times Sm \times (Tv \div Sv)$$

Where:

Rv – Measured runoff volume

Sm – Soil mass

Tv – Total tank volume

Sv – Sample volume

Soil samples were also collected before the start of the operation and at the end of the project. Sampling was carried out at six different points per plot, with two depths each (0-10cm and 10-20cm), both in undisturbed and disturbed conditions Figure 1.

Figure 1 Runoff plots, from left to right: Nature Seedling (P1), Green Manure (P2), Natural Regeneration (P3), and Exposed Soil (P4).

Source: The authors

Study area

The study area is located at coordinates 22°32'39,21" S, 43°46'51,07" W corresponding to a relative sea elevation of approximately 446 meters. The region's climate is defined by the seasonality of dry winters and rainy summers with an average annual rainfall ranging from 1200 to 1400 mm Figure 2.

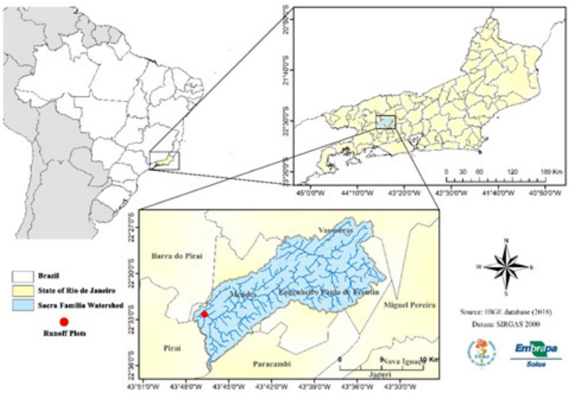

Figure 2 Location of study area.

Source: Manso et al (2023)[11]

The region's topography is distinguished by undulating hills that have withstood the processes of differential denudation, thereby providing energy to hydrological flows on the slopes and influencing erosive processes related to the headwaters and local base levels. Latosols, cambisols, and compacted and dystrophic argisols define the soil composition of the area, products and results of intemperic alteration of granite and gneiss and some metamorphic rocks related to a particular geotectonical offset of this region. Erosive features, such as gullies and ravines, are prevalent on the slopes, shaping the landscape and contributing to the formation of sedimentary packages Figure 3.

Figure 3 Farm where the plots were installed.

Source: The authors.

Results

After one year of monitoring runoff plots, average values related to various soil properties were obtained and compared to those measured before the initiation of the study and the implementation of different treatments, i.e., the degraded pasture that covered the study area. The observations revealed that the change in land use resulted in significant variations in soil structure, nevertheless, these changes do not only reflect the development of the planted vegetation but also the invasive actions of pit excavation and soil disturbance for planting Table 1.

The values represent the average of three points per depth of each plot carried out on the studied slope. The properties were divided into perennial (texture, particle density) and dynamic (organic carbon, soil aggregates stability index, soil density and total porosity) Figure 4.

The monitoring results of runoff indicated that soil exposure to climatic factors led to increased erosion, as higher rates of soil loss were found. The highest concentrations of surface runoff were also observed in the exposed soil plot, possibly due to the absence of vegetative cover and its roots, combined with soil compaction and clogging of surface pores by particles detached through splash erosion, making water infiltration into the soil matrix difficult.

During on-site observed rainfall events, it was noticed that the preferential water path occurred along the edges of the plot, highlighting the influence of the convex-shaped slope, revealing the diffusion of flows. Runoff followed the small concavities of the soil, at times forming small puddles, allowing water accumulation on the surface (direct influence of antecedent moisture and soil compaction). In plots with vegetative cover, observing runoff formation was more challenging, with the notable ability of plants to retain raindrops on their leaves and significantly reduce their kinetic force. Dampening the impact of raindrops directly on the soil favors less breakage of surface soil aggregates and, consequently, greater infiltration. Together with increased porosity, this may explain the low runoff rates found.

Table 1 Average values of soil properties before and after one year of forest restoration

Plots	Depth (cm)	P D (g/cm³)	Organic C (g/kg⁻¹)		ASI (%)		S. Density (g/cm³)		T. Porosity (%)	
			Before	After	Before	After	Before	After	Before	After
1	0 – 10	2,71	12,10	10,85	85,54	58,05	1,62	1,49	40,55	45,45
	10 – 20	2,69	10,08	7,37	83,49	68,88	1,67	1,48	38,09	45,28
2	0 – 10	2,64	13,41	10,80	86,07	62,47	1,62	1,50	38,60	42,92
	10 – 20	2,66	12,51	5,53	85,80	71,76	1,65	1,49	37,99	44,04
3	0 – 10	2,66	11,38	11,07	78,19	67,44	1,61	1,51	39,26	43,29
	10 – 20	2,63	7,87	6,21	77,01	66,24	1,63	1,49	37,93	43,16
4	0 – 10	2,69	9,36	6,75	85,82	74,33	1,67	1,59	37,69	40,59
	10 – 20	2,67	7,29	5,53	83,03	66,79	1,64	1,61	38,43	39,59

Source: The authors.

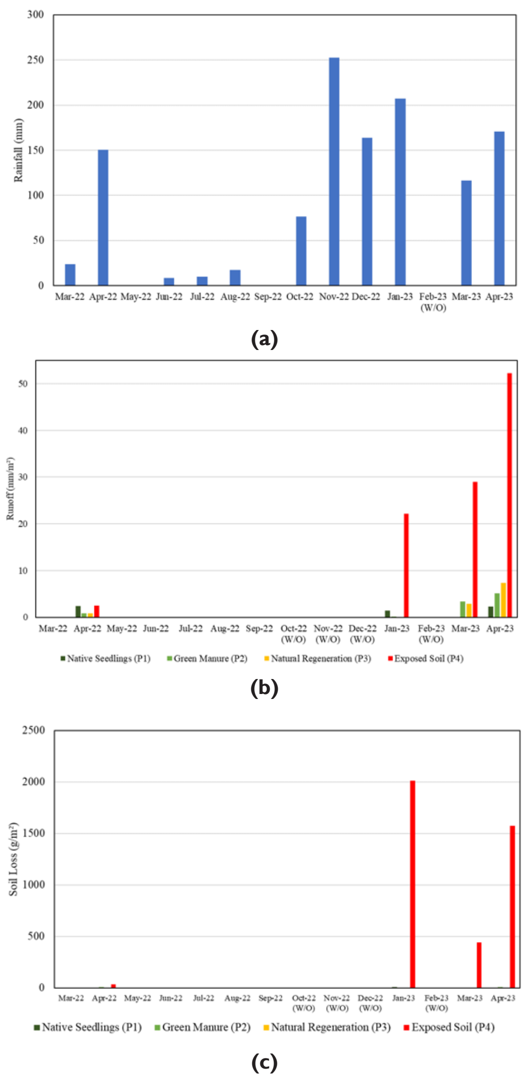

Figure 4 (a) Rainfall distribution, (b) Runoff graph, (c) Soil loss graph. *(W/O) – Without data.

Source: The authors.

Discussion

Studies conducted in runoff plots demand rigorous monitoring by researchers to prevent gaps in data and to better understand of climatic events and possible cyclic correlations that reflect and control weathering effect. In this research, due to difficulties encountered during monitoring, there was a data void in critical months such as November and December, when precipitation totals were high. At the beginning of the project, some measurements were outsourced to the landowner, significantly reducing operational financial costs. However, part of the agreement was breached, resulting in the loss of important measurements.

Regarding soil samplings, the results indicated that dynamic soil properties are highly susceptible to land use change. Although a correlational analysis of erosion to these changes in values was performed, it is noteworthy that the development of seedlings has a positive impact on soil structure, reducing compaction and likely increasing infiltration rates.

Conclusion

In this case study, where the observation of the hydro-sedimentological dynamics of the slope was proposed under different forest restoration techniques, vegetation had a significant influence on total soil loss and runoff generation. Considering the high number of erosive features with exposed soil in the watershed, it can be concluded that degraded pasture in the region and the forest restoration techniques have both the capacity to mitigate the effects of erosive processes. However, in the initial stages, the land use change with some type of pre-existing cover resulting from the adopted techniques may cause some disturbance to the soils, leading to minimal soil loss rates when compared to exposed soil.

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Conflicts of interest

The author declares there is no conflict of interest.

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