

# The study of soil erosion under a systemic conception

## O estudo da erosão dos solos sob uma concepção sistêmica

Inocencio de Oliveira Borges Neto<sup>\*</sup>, Leonardo José Cordeiro Santos<sup>\*</sup>, Dirce Maria Antunes Suertegaray<sup>\*\*</sup>, Rafael Albuquerque Xavier<sup>\*\*\*</sup>

<sup>\*</sup> Departamento de Geografia, Universidade Federal do Paraná, e-mails: iobngpb@gmail.com; santos.ufpr@gmail.com

<sup>\*\*</sup> Departamento de Geografia, Universidade Federal do Rio Grande do Sul, e-mail: dircesuerte@gmail.com

<sup>\*\*\*</sup> Departamento de Geografia, Universidade Estadual da Paraíba, e-mail: xavierra@uol.com.br

<http://dx.doi.org/10.5380/raega.v57i0.92445>

### Abstract

This article aimed to understand how erosion processes can be analyzed from a systemic point of view. Soil erosion is considered here a naturally occurring phenomenon, which can be (and usually is) influenced by human activities, constituting one of the main environmental problems of the planet, in addition to being the main modeling agent of the terrestrial surface. The consequences of the accelerated action of erosion processes are numerous, such as: reduction of natural fertility and productive capacity of soils; silting and pollution of water bodies; impoverishment of rural communities; rural exodus; among many others. Understanding the dynamics of this phenomenon becomes fundamental because a comprehension of a spatio-temporal scope, coupled with the knowledge of the possible problems that may occur with its accelerated performance, provides support for the development of sustainable management. Given that soils are the 'foundation' of the fauna, flora, and mainly of human subsistence, it is a valuable resource. The analytical procedures of this manuscript followed the construction of a system based on a case study, exemplifying how the systemic approach can be developed in the studies of erosive processes. By analyzing soil erosion from a systemic approach, it was possible to observe how the different flows of matter and energy occurred between the variables, explain the importance of understanding erosion processes in an integrated way, and avoid fragmented and reductionist interpretations.

### Keywords:

Systemic Approach, Erosive Processes, Semiarid.

### Resumo

O presente artigo objetivou compreender como os processos erosivos podem ser analisados, sob uma visão sistêmica. Sendo assim, aqui considera-se a erosão dos solos um fenômeno de ocorrência natural, que pode (e geralmente é) ser influenciado pelas atividades antrópicas, se configurando como um dos principais problemas ambientais do planeta, além de ser o principal agente modelador da superfície terrestre. As consequências da atuação acelerada dos processos erosivos são inúmeras, como por exemplo: redução da fertilidade natural e capacidade produtiva dos solos; assoreamento e poluição dos corpos hídricos; empobrecimento das comunidades rurais, êxodo

rural, entre muitos outros. Entender a dinâmica deste fenômeno, se torna fundamental, pois, a compreensão da sua abrangência espaço-temporal associada com o conhecimento dos possíveis problemas que podem vir a ocorrer com sua atuação acelerada, fornece subsídios para a elaboração de gestões sustentáveis, deste recurso tão valioso, haja vista que, os solos são o 'alicerce' da fauna, flora, e principalmente da subsistência humana. Os procedimentos analíticos deste manuscrito, estão fundamentados na construção de um sistema baseado em um estudo de caso, exemplificando como a abordagem sistêmica pode ser desenvolvida nos estudos dos processos erosivos. Ao analisar a erosão dos solos sob uma abordagem sistêmica, foi possível observar como os diversos fluxos de matéria e energia ocorriam entre as variáveis, explicitando a importância de compreender os processos erosivos de forma integrada, evitando interpretações fragmentadas e reducionistas.

**Palavras-chave:**

Abordagem Sistêmica, Processos Erosivos, Semiárido.

---

## I. INTRODUCTION

Erosive processes are natural mechanisms that occur on the Earth's surface, driven by a complex combination of factors, where human beings, through their activities, have significantly contributed to altering the intensity and dispersion of their occurrences (GUERRA et al., 2017; MARTÍNEZ-MENA et al., 2020; XAVIER et al., 2016).

Brady and Weil (2013) state that the use of land by humans associated with other activities, during the second half of the twentieth century, degraded about 5 billion hectares (43% of the globe). The Food and Agriculture Organization of the United Nations (FAO) estimates that by 2050 around 1.5 million km<sup>2</sup> will be lost, if there is no concern in terms of actions that enable sustainable land use (FAO, 2019).

There are several problems arising from the accelerated action of erosive processes, such as: CO<sub>2</sub> emission into the atmosphere (LAL, 2018; OLSON et al., 2016); loss of nutrients essential to the development of fauna and flora such as carbon and nitrogen (CHARTIER; ROSTAGNUM; VIDELA, 2013; WOLKA et al., 2021); pollution and siltation of rivers and reservoirs (BAKKER et al., 2005); decrease in the infiltration capacity and water retention of soils (SANTOS et al., 2016); destruction of natural habitats (PRINCE et al., 2018); acceleration of the desertification process (MIRZABAEV et al., 2019; UNCCD, 2017) and more.

The consequences arising from the intense action of erosive processes can be irreparable for the soil, for the waters, for the environment and consequently for society itself. For example, civilizations such as the Mesopotamian and Egyptian (in the Middle East) and Maya (in Mesoamerica) declined with erosive dynamics being one of the main contributing factors (DOTTERWEICH, 2013; HILLEL, 1991; MONTGOMERY, 2007; VANWALLEGHEM, 2017).

---

Other examples such as the impoverishment of local/rural communities (PRINCE et al., 2018), the abandonment of land followed by rural exodus (SHRESTHA; SURIYAPRASIT; PRACHANSRI, 2014), and in addition to their economic, social, cultural, productive and environmental effects (SANTOS et al., 2016), erosive processes directly interfere in the resilience of the environment and in the daily life of societies (BLAIKE, 1985; FAO, 2019).

According to Loureiro et al., (2022), Parsons (2019) and Poesen (2018), most of the studies that address the dynamics of erosive processes are based on methodologies/techniques such as modeling with geoprocessing (BORRELLI et al., 2017; 2020); in laboratory, by means of radionuclides such as cesium-137 (CORRÊA; AZAMBUJA, 2020); and analog, as is the case of monitoring and/or experiments carried out in the field (GUERRA, 2005; MORGAN, 2005).

This wide diversity of methodologies/techniques for the analysis of erosive processes is important and valid, but according to Parsons (2019), they need to take into account all of the connections between variables that control the dynamics. Under a systemic bias, this means that it is necessary to understand how the exchanges of matter and energy occur through their (inter)relations.

Therefore, it is essential for the planning and management of spaces, mainly rural, to understand the spatio-temporal scope of erosive processes and the problems arising from their effects as intensified by human activities. Following this perspective, it can be understood that the environment should be analyzed as a set of interconnected elements, which perform exchanges of matter and energy (i.e., systemic approach)<sup>1</sup>.

To emphasize the importance of this analytical proposition, Thornes and Brunsden (1977 apud FALCÃO, 2020) stated that the use of a systemic approach in process studies is appropriate and will be increasingly important in establishing a response to these processes.

Falcão (2020), Huggett (2007) and Marques Neto and Oliveira (2022) also reinforced that the study of processes from the systemic approach allows the researcher to take into account the connections and complexity of the elements that compose, energize and govern the erosive processes, because a fragmented

---

<sup>1</sup> A detailed description of the history of this theoretical-conceptual-methodological proposal was not provided as the objective of this study was to construct a system based on a case study on erosive processes, evidencing the main exchanges of matter and energy that occurred between the variables of the chosen study, and by understanding that there is already a vast bibliography that describes the origins, the paths preferably traveled and the main types of systems. Examples: Bertalanffy (2014), Chorley (1962), Chorley and Kennedy (1971), Christofolletti (1979, 1980, 1999), Gregory (1992), Haigh (1985), Huggett (2007), Limberger (2006), Marques Neto (2008), Marques Neto and Oliveira (2022), Scheidegger (1992), Silva and Leite, (2020), Strahler (1980), Vale (2012), Vicente and Perez Filho (2003).

analysis of the phenomenon mentioned above tends to generate numerous problems in the construction of information due to its reductionist aspect.

Thus, the present study aimed to demonstrate how erosive processes can be analyzed under a systemic conception.

## II. MATERIALS AND METHODS

This article resulted from an analysis of erosive processes using the theoretical-methodological assumptions of the systemic approach. To this end, a systemic scheme was constructed from a case study (BORGES NETO, 2021) to correlate interactions of the main variables with each other and with the surrounding environment, when exchanging matter and energy in the erosive dynamics of soils. Thus, the methodological procedures were divided into the following stages:

- 1st Stage: It consisted of the literature search and, subsequently, of a theoretical framework relevant to the systemic approach. All searches were performed on digital platforms (*Google Scholar* and CAPES Periodicals Portal) and in university libraries;
- 2nd Stage: Based on the reading of the references selected in the previous stage, a literature review was produced;
- 3rd Stage: By associating the study of Borges Neto (2021) with the review of the second stage, the systemic model was didactically constructed.

With this, the results were divided into two parts: the first - "*The systemic approach in the study of erosive processes*" - is a review of the literature that explains the importance of this theoretical-methodological proposition for the studies of erosive processes; and the second - "*The analysis of erosive processes from a systemic perspective*" - demonstrates how the main variables (soils and uses) behave amid the dynamics of input and output of matter and energy in the system.

## III. RESULTS AND DISCUSSION

### The systemic approach in the study of erosive processes

The systemic approach is an integrative and dynamic view of the elements that make up the whole, constituting a unity; with this, the phenomena that manifest themselves in space can interact, converging to the maintenance or alteration of systems (OTTO; MORAIS, 2019).

Gregory (1992) considered the systemic approach as a unifying methodology for geography and effective to be used in work focusing on soils and their processes. The aforementioned author also stated that in the

---

branches of physical geography, the systemic approach was employed as part of an essential basis for the study of watersheds, river channels, etc., and has been implemented as a basic instrument for the analysis of other geomorphological fields.

Chorley (1962) drew attention to the importance of the systemic approach in the studies of erosive processes, and according to him, erosion is an important sculpting agent of landscapes, especially of relief. It can be understood as a process that occurs in an open system because it requires constant supplementation and removal of material and energy for its existence. Given this reality, it is fundamental to understand the dynamics of input and output of matter and energy (FALCÃO, 2020; LISBOA et al., 2020).

When employing a systemic approach (such as open systems) in the analysis of erosive dynamics, it is necessary to understand soils as a product arising from a complex interaction between other variables, such as: geological basis, topography, climate, vegetation cover, geographical position, and weather, among other factors (GUERRA; MENDONÇA, 2004; MORGAN, 2005; SCHAETZL; ANDERSON, 2005). Soils are constantly adjusting to various forms of fluctuating mass and energy flows, thermodynamic gradients, and other exogenous environmental conditions (GERRARD, 1992; SCHAETZL; ANDERSON, 2005).

According to Guerra and Mendonça (2004), within a system, materials can be transported from one location to another, or have their physical properties altered by chemical reactions. Therefore, some elements are more important than others in controlling soil formation (SCHAETZL; ANDERSON, 2005) and their respective modeling agents - mainly erosion (FAO, 2019; GUERRA, 1994; GUERRA et al., 2017; MORGAN, 2005).

However, in order to facilitate an understanding of erosive dynamics through a systemic approach, this study was guided by an analysis using water erosion as an example. This type of erosion, according to Mafra (2007), consists essentially of a sequence of transfers of matter and energy, caused by an imbalance of the water-soil-vegetation cover system, resulting in a progressive loss of soil.

Still, Mafra (2007) explained that when the energy of precipitation is applied to the surface of the terrain, from a limit of shear resistance, the exchanges of matter begin by processes of destabilization of the aggregates of the soil, for movement and transport of the particles to the lower areas of the relief.

Consequently, through the joint action of these processes of matter and energy, which are the erosive processes of a water nature, the most superficial layers of the soil – usually the most fertile (BORRELLI et al., 2017; FAO, 2019; MIRZABAEV et al., 2019) – are removed, reducing the thickness of the soil profiles (MAFRA, 2007).

---

In water erosion, the most important input of matter (water) is conditioned by the characteristics of rainfall and the intrinsic properties of the soil, since it is these interactions that define the forms of water circulation (e.g., runoff and infiltration), and its ability to alter systems.

FAO (2019), Guerra (1991; 1994), Morgan (2005) and Vanwalleghem (2017) showed in their respective works that the most important soil properties for the studies of erosive processes are the stability of aggregates and the organic matter content of the soil, since these properties are essential for the control of erosive dynamics.

For example, soils with good aggregation and organic matter content basically present high permeability and protection against the impact of raindrops, thereby reducing the rates of surface runoff. Therefore, these favor the storage of water inside the soil itself, interfering in the temporal distribution and in the relations between surface and subsurface flow, the main routes of circulation of matter (GUERRA, 1994; MORGAN, 2005; ZAVOIANU, 1985 *apud* FALCÃO, 2020).

Another vital variable for the systemic understanding of erosive processes is vegetation cover. There are many studies related to soil erosion which highlight the role of vegetation cover in the control of erosive processes, given that areas that still hold fragments of their native vegetation tend to erode less (BORRELLI et al., 2020) than lands with exposed soil or with monocultures (XAVIER et al., 2016).

This fact mentioned above is directly related to the capacity of the native vegetation cover and of various tree strata to reduce the direct impact of raindrops and runoff on the soil, thus favoring the infiltration and retention of water within the soil, unlike the areas of exposed soil and/or monocultures which, in the vast majority of research focusing on soil erosion, hold the highest levels of eroded material.

Another element to be highlighted is the transport capacity and selectivity of the eroded material. Falcão (2020) stated that the sediment load is the effective or current transport rate, and it can be both higher and lower than the transport capacity. This is in addition, of course, to its selectivity when referring to surface erosive processes, since according to Chartier, Rostagno and Videla (2013); Lal (2018); Olson et al. (2016); Martínez-Mena et al. (2020); and Wolka et al. (2021); such processes tend to selectively remove nutrients such as carbon and nitrogen, and the finer and lighter particles (e.g., clays) that are more vulnerable than the larger particles.

Falcão (2020) understood that these interpretations have a systemic conception, because when the sediment load extrapolates the transport capacity, its deposition occurs at a rate proportional to the difference between the transport capacity and that load. Thus deposition decreases the sediment load, accumulating on

the lower surfaces of the relief and, in turn, these areas of accumulation will typically have higher levels of nutrients and soil particles.

### **The analysis of erosive processes from a systemic perspective**

An interesting example of systemic construction, having as its main concern the erosion of soils, can be viewed when analyzing the study of Borges Neto (2021), who, when studying the hydro-erosive dynamics in the semiarid zone, more specifically in the Cariri of Paraíba (Figure 1) identified some relations of exchange of matter and energy (Figure2).

Before talking about the systemic scheme proposed here, it is important to highlight the main characteristics of the case study used as a reference, as well as its area (BORGES NETO, 2021). In this region, the geological base is predominantly crystalline (CPRM, 2002; 2020). The relief varies from flat to gently undulating in the interior of the Borborema Plateau (CORRÊA et al., 2010). The Cariri of Paraíba is one of the driest regions of Brazil, where the semiarid domain presents an average annual rainfall of 350 mm, with potential evapotranspiration of four times greater than the precipitation and average temperature of 27 °C (KAYANO; ANDREOLI, 2009). The vegetation cover – Caatinga – has great endemic biodiversity (APG, 2016): Shrubs, trees that are 3 to 9 m tall that lose their leaves seasonally, and cactus and grasses adapted to semiarid conditions partially cover the soil (SANTOS et al., 2012).

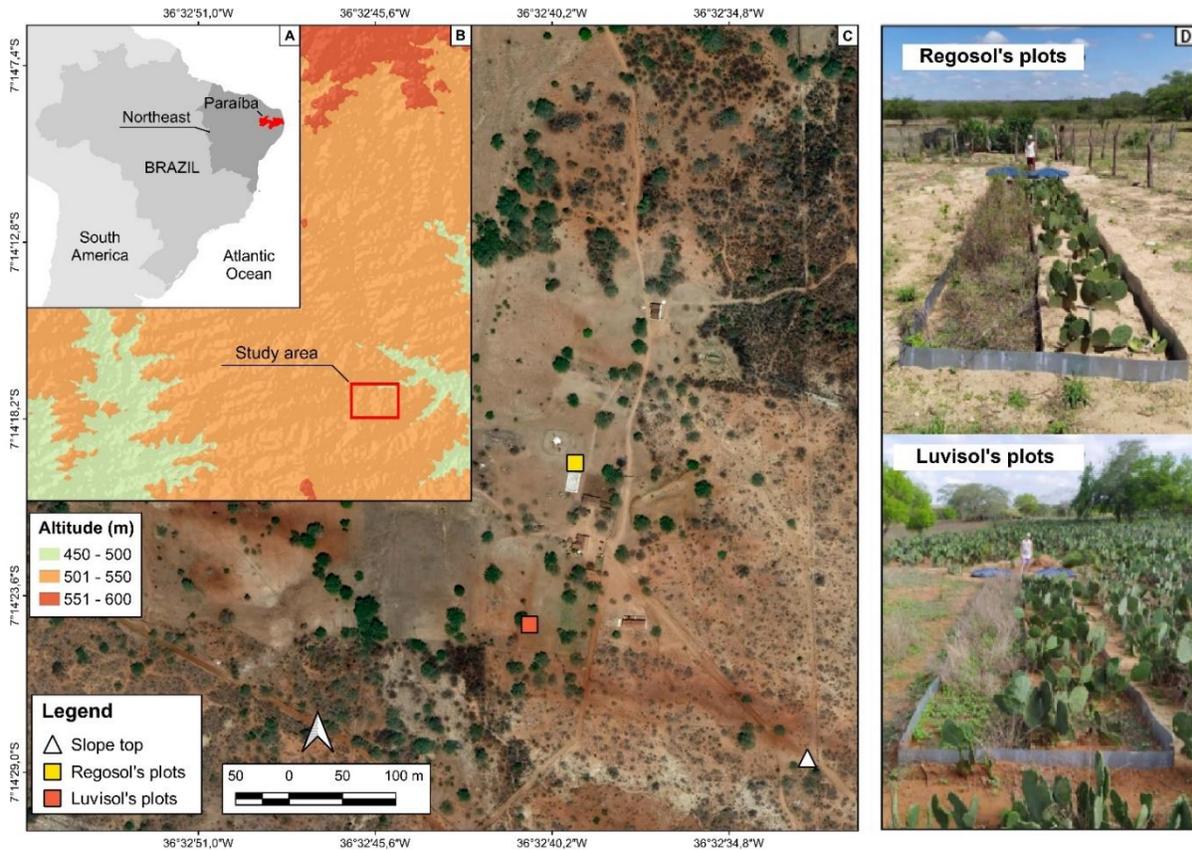


Figure 1 – Location of the study area (A), distribution of plots according to altitude (B), location of plots on the slope (C) and visualization of plots (D). Source: Google Earth (2023), IBGE (2020) and JAXA (2020). Self elaboration, 2023.

Historically, the occupation of Cariri of Paraiba began on the banks of rivers in the sixteenth century (RIETVELD, 2009). In the seventeenth century, the Portuguese crown allowed the colonization and practice of cattle ranching and agricultural cultivation of corn, beans and cotton (SOUZA; SOUZA, 2016). Parallel to the decline of cotton farming from the 1980s, there was an expansion of livestock, especially goats, and urbanization. Currently, the density of goats exceeds the population density in several municipalities (ALMEIDA, 2012). The cultivation of cactus palm accompanied the expansion of livestock as food for cattle due to its resistance to drought (ARAÚJO et al., 2019).

The objective of this case study was to verify the behavior of two classes of soils and in different uses against laminar erosion. The study was carried out in the two most represented soil classes of the region – the Regosols and Luvisols, representing, respectively, 29.14% and 64.68% of the extension of the Cariri of Paraiba – in relief conditions with a gentle slope – about 5° – with similar intensities and amounts of precipitation, in addition to standardization of the management of the uses. The cactus palm crop was chosen for being resistant and serving as fodder for the animals in periods of drought, and the fallow system was chosen to represent an

area in the process of rest. Attention was also drawn to the use, in this study, of hydro-erosive or experimental plots, according to Guerra (2005), for laminar erosion monitoring.

In the organized scheme (Figure 2), precipitation constitutes the independent variable, as the one that initiates the dynamics of the system (input) by providing matter and energy. From a generalist perspective, it is known that when rainwater reaches close to the earth's surface, part of it is intercepted by vegetation cover or by the different uses of the land, which in turn minimize the speed and impact of raindrops on soils. In this way, infiltration rates increase, runoff rates decrease, and consequently there is a reduction in erosive rates.

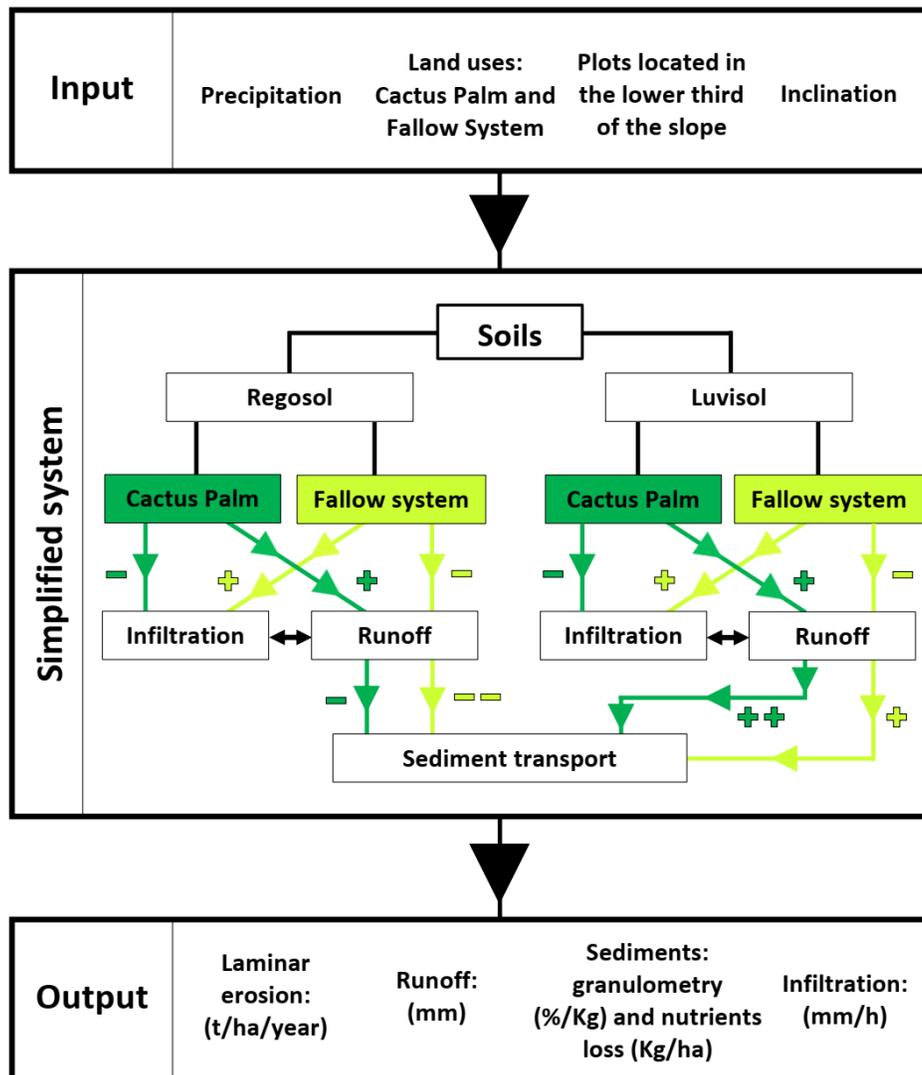


Figure 2 –Simplified example of systemic construction for the study of laminar erosion. Legend: "--" very low; "-" low; "+" high; "++" too high; "t" tonnes; "ha" hectare; "mm" millimeter; "%" percentage; "Kg" kilos; "h" hour. Data source: Borges Neto (2021). Self elaboration, 2022.

The opposite occurs when there is no vegetation cover, whether natural or from the different land uses. In this case, rainwater comes into direct contact with the soil (splash effect), which disaggregates and disperses its particles, favoring the reduction of infiltration rates, so an increase in runoff and erosion is observed.

However, when taking into account the data found/generated by Borges Neto (2021)<sup>2</sup>, it is observed that the different processes and variables, when compared, revealed quite different results. Thus, when describing the scheme of Figure 2, we have the following:

- Input: The beginning of the systemic dynamics occurs with the receipt of matter and energy from the precipitation variables; types of use – palm and fallow; topographic position – lower third of the slope; and, inclination;
- Simplified system: In the "soils" system where the relationships between the variables and processes took place, evidencing the main flows (of matter and energy) and their respective responses.

The results showed that, regardless of the type of soil, the use of cactus palm generated more runoff (+ = high) and less infiltration (- = low), while in the fallow system, the opposite was observed; that is, more infiltration (+ = high) and less runoff (- = low).

Secondly, it was verified that the flow rates of the uses on the Luvisol had the highest values, mainly in relation to the use of the cactus palm (++ = too high), favoring, in theory, the greater capacity of material transport. In Regosol the flow rates were lower, highlighting the use of fallow (-- = very low), with the lowest transport capacity of the entire system.

- Output: The output reflects the products from the various exchanges of matter and energy within the system. It was found that the Regosol, even with the lowest runoff rates (-- = Fallow System and - = Cactus Palm crop), had the highest erosion values. This may be linked to the fact that Regosol is very incipient – pedogenetically less developed than Luvisol – with a sandy loam texture, poor structuring, and reduced capacity to maintain carbon (C) in its interior, making the formation of more stable aggregates unfeasible and directly influencing the selectivity of sediments in the face of erosive dynamics. Therefore, the eroded sediments of this soil obtained a granulometry predominantly of coarse and fine sand, in addition to the highest levels of carbon (C) and nitrogen (N). Alternatively, Luvisol, because it has higher levels of clay in its formation and has a strong structure and greater stability of the aggregates, allows a greater resistance to changes in use/coverage imposed by anthropic activities. The

---

<sup>2</sup> To visualize the data in detail, it is suggested to also consult Borges Neto et al. (2023).

granulometry of the sediments from the erosion of this soil are characterized by the fine fraction (clay and silt), in addition to the lower contents of C and N. However, even eroding less, the Luvisol had the highest values of flow (++ = Cactus Palm crop and + = Fallow System); this may be related to the nature of the clays that make up this soil, expansive clays (of type 2:1), as these clays expand when wet (less infiltration and more runoff) and retract when dry (more infiltration and less runoff). The cactus palm crop in Regosol obtained the highest erosion rates, while in Luvisol they had the highest rates of runoff. When one analyzes the data collected from the fallow system, its ability to mitigate runoff and erosion rates is evident. It is noteworthy that the cultivation of cactus palm is a very important and representative activity for the Brazilian semiarid region, because it is directly linked to livestock, serving as fodder during the long periods of drought in the region, and consequently to the survival of families, but that if managed improperly tends to degrade the soils intensely (ARAÚJO et al., 2019).

These, among many other considerations, were only possible by analyzing the erosive processes from a systemic point of view. Even though the systemic scheme (Figure 2), based on the study by Borges Neto (2021), is generalized and simplified, in a certain way it represents the interactions of the main elements that generated and controlled the dynamics of laminar erosion, showing that the study of erosive processes is easier to understand in a systemic logic, since the fragmented analysis tends not to contribute to the totalizing understanding of the phenomenon.

Given all that has been presented, it is known that there are many systemic interactions that trigger and govern erosive processes. The interpretations described above are just a few examples of several when systemically analyzing the erosive dynamics of soils. To this end, Guerra (1991) warned that whatever the extent, the systemic framework needs to allow the linking of the theoretical, conceptual and methodological contributions, being open to empirical testing, as they are done in the mixed models of measurement and analysis.

#### **IV. CONCLUSIONS**

The exercise of systemic construction presented here (Figure 2) aids in visualizing the interaction between various processes and variables, through the exchange of matter and energy, and enables the creation of a theoretical-conceptual-methodological robustness that allows it to expand its area of activity, thereby becoming increasingly important in environmental debates, decision-making and enforcement actions aimed at the most diverse restorative actions and/or for more sustainable coexistence with the environment.

---

In this specific study, the systemic approach was emphasized which proposes (holistic) reflection of a construction of totality from the objectives of the study, such as the research on erosive processes used here (BORGES NETO, 2021). This allows a broader understanding; however, it does not express the complexity of reality. All knowledge about reality is something unattainable, under any methodological approach.

Given all that has been reported, it is emphasized that the systemic approach aggregated in the studies of erosive processes, in addition to seeking the interpretation of complexity, which clarifies the organization of a spatial system – according to the interactions that are processed between the formative attributes and that gives them a dynamic and non-linear character – has vast potential in research that aims to evaluate the morphodynamic instability of the environment.

## V. REFERENCES

- ALMEIDA, N. V. Ordenamento territorial geoambiental da bacia Hidrográfica do rio Taperoá/semiárido paraibano. Tese (Doutorado em Geografia) – Universidade Federal Fluminense, 2012, 238 p.
- APG. The Angiosperm Phylogeny Group. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants. *Botanical Journal of the Linnean Society*, v. 181, n. 1, p. 1-20, 2016.
- ARAÚJO, J. S.; PEREIRA, D. D.; LIRA, E. C.; FÉLIX, E. S.; SOUZA, J. T. A; LIMA, W. B. Palma forrageira: plantio e manejo. Campina Grande: INSA, 2019, 60 p.
- BAKKER, M. M.; GOVERS, G.; KOSMAS, C.; VANACKER, V.; VAN OOST, K.; ROUNSEVELL, M. Soil erosion as a driver of land-use change. *Agriculture, Ecosystems & Environment*, Amsterdam, v. 105, n. 3, p. 467-481, 2005.
- BERTALANFFY, L. Teoria Geral dos Sistemas: fundamentos, desenvolvimento e aplicações. Tradução de Francisco M. Guimarães. 8ª ed. Petrópolis-RJ: Vozes, 2014, 360 p.
- BLAIKIE, P. The political economy of soil erosion in developing countries. Nova York, Longman Group Limited, 1985, 200 p.
- BORGES NETO, I. O. Processos hidro-erosivos em distintas classes de solo sob diferentes tipos de uso em zona semiárida. Dissertação de Mestrado apresentada ao Programa de Pós-Graduação em Geografia da Universidade Federal da Paraíba, João Pessoa, 2021, 141 p.
- BORGES NETO, I. O.; XAVIER, R. A.; SOUZA, B. I.; SANTOS, L. J. C.; SOARES, D. A.; SOUZA, J. J. L. L. Preliminary experimental data on surface runoff and soil loss in the Caatinga. *Earth Surface Processes and Landforms*, Accepted Author Manuscript, p. 1-12, 2023.
- BORRELLI, P.; ROBINSON, D. A.; PANAGOS, P.; LUGATO, E.; YANG, J. E.; ALEWELL, C.; WUEPPER, D.; MONTANARELLA, L.; BALLABIO, C. Land use and climate change impacts on global soil erosion by water (2015-2070). *Proceedings of the National Academy of Sciences*, v. 117, n. 36, p. 21994-22001, 2020.
- BORRELLI, P.; ROBINSON, D. A.; FLEISCHER, L. R.; LUGATO, E.; BALLABIO, C.; ALEWELL, C.; MEUSBURGER, K.; MODUGNO, S.; SCHÜTT, B.; FERRO, V.; BAGARELLO, V.; OOST, K. V.; MONTANARELLA, L.; PANAGOS, P. An assessment of the global impact of 21<sup>st</sup> century land use change on soil erosion. *Nature Communications*, v. 8, p. 13, 2017.

- BRADY, N. C.; WEIL, R. R. Elementos da natureza e propriedades dos solos. Tradução técnica; Igo Fernando Lepsch. 3ª Ed. Porto Alegre: Bookman, 2013, 686 p.
- CHARTIER, M. P.; ROSTAGNO, C; M.; VIDELA, L. S. Selective erosion of clay, organic carbon and total nitrogen in grazed semiarid rangelands of northeastern Patagonia, Argentina. *Journal of Arid Environments*, v. 88, p. 43-49, 2013.
- CHORLEY, R. J. Geomorphology and general systems theory. In: U.S. Geol. Survey prof. paper, v. 500-B, p. 1-10, 1962.
- CHORLEY, R. J.; KENNEDY, B. A. *Physical Geography: a systems approach*. Londres: Prentice Hall Inc. Co., 1971, 370 p.
- CHRISTOFOLETTI, A. *Análise de Sistemas em Geografia*. São Paulo: Hucitec-Edusp, 1979, 106 p.
- CHRISTOFOLETTI, A. *Geomorfologia*. 2ª Ed. São Paulo: Edgard Blücher, 1980, 189 p.
- CHRISTOFOLETTI, A. *Modelagem de sistemas ambientais*. 1ª Ed. São Paulo: Edgard Blücher, 1999, 256 p.
- CORRÊA, A. C. B.; AZAMBUJA, R. N. Dinâmica superficial numa bacia de drenagem semiárida mediante o uso do céσιο-137: estudo de caso da Bacia do Riacho Salgado-PE. *Geosp – Espaço e Tempo (On-line)*, v. 24, n. 2, p. 381-406, 2020.
- CORRÊA, A. C. B.; TAVARES, B. A. C.; MONTEIRO, K. A.; CAVALCANTI, L. C. S.; LIRA, D. R. Megageomorfologia e morfoestrutura do planalto da Borborema. *Revista do Instituto Geológico, São Paulo*, 31 (1/2), p. 35-52, 2010.
- CPRM. Companhia de Pesquisa de Recursos Minerais – Serviço Geológico do Brasil. Carta Geológica – Folha: SB.24-Z-D-III BOQUEIRÃO. Escala: 1:100.000, 2002.
- CPRM. Companhia de Pesquisa de Recursos Minerais – Serviço Geológico do Brasil. Carta Geológica-Geofísica – Folha: SB.24-Z-D-II JUAZEIRINHO. Escala: 1:100.000, 2018.
- DOTTERWEICH, M. The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation - A global synopsis. *Geomorphology*, v. 201, n. 1, p. 1-34, 2013.
- FALCÃO, C. L. C. A Teoria Geral dos Sistemas e o entendimento dos processos erosivos em uma bacia hidrografia. *Revista Equador (UFPI)*, v. 9, n. 4, p. 21-39, 2020.
- FAO. *Soil erosion: the greatest challenge to sustainable soil management*. Rome, 2019, 89 p.
- GERRARD, J. *Soil Geomorphology – An Integration of Pedology and Geomorphology*. Londres, Chapman and Hall, 1992, 269 p.
- GOOGLE EARTH. Google Earth Pro online. Disponível em: <<https://www.google.com.br/earth/>>. Acessado em março de 2023.
- GREGORY, K. J. *A natureza da Geografia Física*. Bertand: São Paulo, 1992, 367 p.
- GUERRA, A. J. T. Experimentos e monitoramentos em erosão dos solos. *Revista do Departamento de Geografia*, v. 16, p. 32-37, 2005.
- GUERRA, A. J. T.; FULLEN, M. A.; JORGE, M. C. O.; BEZERRA, J. F. R.; SHOKR, M. S. Slope Processes, Mass Movement and Soil Erosion: A Review. *Pedosphere*, v. 27, p. 27-41, 2017.
- GUERRA, A. J. T. Processos Erosivos nas Encostas. In: *Geomorfologia – Uma Atualização de Bases e Conceitos*.
-

(Orgs) GUERRA, A. J. T.; CUNHA, S. B. Rio de Janeiro: Bertrand Brasil, 1994. 4, p. 149-209.

GUERRA, A. J. T. Soil characteristics and erosion, with particular reference to organic matter content. Tese de doutorado. Department of Geography King's College. London, 1991.

GUERRA, A. J. T.; MENDONÇA, J. K. S. Erosão dos solos e a questão ambiental. In: Reflexões sobre a Geografia Física no Brasil. (Orgs.) VITTE, A. C.; GUERRA, A. J. T. Rio de Janeiro: Bertrand Brasil, 2004, p. 225-256.

HAIGH, M. J. Geography and General System Theory, Philosophical Homologies and Current Practice. Geoforum, v. 16 n. 2, p. 191-203, 1985.

HILLEL, D. Out of the Earth: Civilization and the Life of the Soil. New York: The Free Press, 1991, 352 p.

HUGGETT, R. J. A history of the systems approach in geomorphology. Géomorphologie: relief, processus, environnement. v. 13, n. 2, p. 145-158, 2007.

IBGE. Instituto Brasileiro de Geografia e Estatística. Geociências > Organização do território > Malhas territoriais > Malha Municipal, 2020. Disponível em: <<https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html?edicao=30138>>. Acessado em agosto de 2021.

JAXA. Japan Aerospace Exploration Agency. ALOS Global Digital Surface Model - ALOS World 3D-30 m (AW3D30). 2020. Disponível em: <<https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm>>. Acessado em novembro de 2021.

KAYANO, M. T.; ANDREOLI, R. V. Clima da região Nordeste do Brasil. In: I. F. de A. Cavalcanti; N. J. Derreira; M. G. A. J. da Silva; M. A. F. da S. Dias (Eds.); Tempo e Clima no Brasil São Paulo: Oficina de Textos, 2009, p. 213-234.

LAL, R. Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. Wiley One Library, Global Change Biology, v. 24. n. 8, p. 3285-3301, 2018.

LIMBERGER, L. Abordagem sistêmica e complexidade na geografia. Geografia. v. 15, n. 2, p. 95-109, jul./dez. 2006.

LISBOA, G. S.; SOUSA, P. R.; BEZERRA, J. F. R.; PEREIRA, R. C. C.; SILVA, Q. D. A epistemologia da Geografia e a abordagem sistêmica nos estudos dos processos erosivos. Revista Percurso – NEMO, Maringá, v. 12, n. 2, p. 5-21, 2020.

LOUREIRO, H. A. S.; GUERRA, A. J. T.; BEZERRA, J. F. R.; PEREIRA, L. S.; GARRITANO, F. N. 19. Monitoramento da Erosão Hídrica no Brasil: Dos Métodos Manuais aos Digitais. In: Revisões de Literatura da Geomorfologia Brasileira. (Orgs.) CARVALHO JÚNIOR, O. A.; GOMES, M. C. V.; GUIMARÃES, R. F.; GOMES, R. A. T. 1ª Ed. Editora ICH-UnB. União da Geomorfologia Brasileira, 2022, 19, p. 530-563.

MAFRA, N. M. C. Erosão e planificação de uso do solo. In: GUERRA, A. J. T.; SILVA, A. S.; BOTELHO, R. G. M. Erosão e Conservação dos Solos: Conceitos, temas e aplicações. 3ª Ed. Rio de Janeiro: Bertand Brasil, 2007, p. 301-322.

MARQUES NETO, R. A abordagem sistêmica e os estudos geomorfológicos: algumas interpretações e possibilidades de aplicação. Geografia. Universidade Estadual de Londrina, Departamento de Geociências. v. 17, n. 2, jul./dez. p. 67-87, 2008.

MARQUES NETO, R.; OLIVEIRA, T. A. A Geomorfologia nos Estudos Integrados da Paisagem: Enfoque Evolutivo e Dinâmico na Interpretação dos Sistemas Geomorfológicos In: Revisões de Literatura da Geomorfologia Brasileira. (Orgs.) CARVALHO JÚNIOR, O. A.; GOMES, M. C. V.; GUIMARÃES, R. F.; GOMES, R. A. T. 1ª Ed. Editora ICH-UnB. União da Geomorfologia Brasileira, 2022, 29, p. 817-848.

MARTÍNEZ-MENA, M.; CARRILLO-LÓPEZA, E.; BOIX-FAYOS, C.; ALMAGRO, M.; GRACÍA FRANCO, N.; DÍAZ-PEREIRA, E.; MONTOYA, I.; VENEA, J. Long-term effectiveness of sustainable land management practices to control runoff, soil erosion, and nutrient loss and the role of rainfall intensity in Mediterranean rainfed agroecosystems. *Catena*, v. 187, Stoten: 104352, p. 13, 2020.

MIRZABAEV, A.; WU, J.; EVANS, J.; GARCÍA-OLIVA, F.; HUSSEIN, I. A. G.; IQBAL, M. H.; KIMUTAI, J.; KNOWLES, T.; MEZA, F.; NEDJRAOUI, D.; TENA, F.; TÜRKEŞ, M.; VÁZQUEZ, J.; WELTZ, M. Chapter 3: Desertification. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. (Eds.) SHUKLA, P. R.; SKEA, J.; CALVO BUENDIA, E.; MASSON-DELMOTTE, V.; PÖRTNER, H. O.; ROBERTS, D. C.; ZHAI, P.; SLADE, R.; CONNORS, S.; VAN DIEMEN, R.; FERRAT, M.; HAUGHEY, E.; LUZ, S.; NEOGI, S.; PATHAK, M.; PETZOLD, J.; PORTUGAL PEREIRA, J.; VYAS, P.; HUNTLEY, E.; KISSICK, K.; BELKACEMI, M.; MALLEY, J. IPCC, 2019, 3, p. 249-343.

MONTGOMERY, D. R. *Dirt: The Erosion of Civilizations*. Berkeley, CA: University of California Press, 2007, 296 p.

MORGAN, R. P. C. *Soil erosion and conservation*. Blackwell Publishing Ltd, 3ª Ed. 2005, 320 p.

OLSON, K. R.; AL-KAISI, M.; LAL, R.; CIHACEK, L. Impact of soil erosion on soil organic carbon stocks. *Journal of Soil and Water Conservation*, v. 71, n. 3, p. 61A-67A, 2016.

OTTO, C. S.; MORAIS, E. M. B. Reflexões sobre a análise sistêmica na geografia tendo o tema água como referência. Edição Especial - III Colóquio de Pesquisadores em Geografia Física Ensino de Geografia. *ParaOnde!?*, Porto Alegre, v. 12, n. 2, p. 271-280, 2019.

PARSONS, A. J. How reliable are our methods for estimating soil erosion by water?. *Science of the Total Environment*, v. 676, p. 215-221, 2019.

POESEN, J. Soil erosion in the Anthropocene: Research needs. *Earth Surface Processes and Landforms*, v. 43, p. 64-84, 2018.

PRINCE, S.; VON MALTITZ, G.; ZHANG, F.; BYRNE, K.; DRISCOLL, C.; ESHEL, G.; KUST, G.; MARTÍNEZ-GARZA C.; METZGER, J. P.; MIDGLEY, G.; MORENO-MATEOS, D.; SGHAIER, M.; THWIN, S. Chapter 4: Status and trends of land degradation and restoration and associated changes in biodiversity and ecosystem functions. In: *IPBES: Assessment Report on Land Degradation and Restoration*. (Eds.) MONTANARELLA, L.; SCHOLLES, R.; BRAINICH, A. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, 2018, 4, p. 221-338.

RIETVELD, Pe. J. J. *O Verde do Juazeiro: história da paróquia de São José Juazeirinho*. João Pessoa: Imprell Gráfica e Editora, 2009, 360 p.

SANTOS, J. C. N.; ANDRADE, E. M.; GUERREIRO, M. J. S.; MEDEIROS, P. H. A.; PALÁCIO, H. A. Q.; ARAÚJO NETO, J. R. Effect of dry spells and soil cracking on runoff generation in a semiarid micro watershed under land use change. *Journal of Hydrology, Amsterdam*, v. 541, n. 4, p. 1057-1066, 2016.

SANTOS, R. M.; OLIVEIRA-FILHO, A. T.; EISENLOHR, P. V.; QUEIROZ, L. P.; CARDOSO, D. B.; RODAL, M. J. Identity and relationships of the Arboreal Caatinga among other floristic units of seasonally dry tropical forests (SDTFs) of north-eastern and Central Brazil. *Ecology and Evolution*, v. 2, n. 2, p. 409-428, 2012.

SCHAETZL, R.; ANDERSON, S. *Soils Genesis and Geomorphology*. Cambridge University Press, 2005, 817 p.

SCHEIDEGGER, A. E. Limitations of the system approach in geomorphology. *Geomorphology*, v. 5, p. 213-217, 1992.

- SHRESTHA, D. P.; SURIYAPRASIT, M.; PRACHANSRI, S. Assessing soil erosion in inaccessible mountainous areas in the tropics: The use of land cover and topographic parameters in a case study in Thailand. *Catena*, v. 121, p. 40-52, 2014.
- SILVA, D. M.; LEITE, E. F. Abordagem sistêmica e os estudos da paisagem. *Revista Pantaneira*, v. 18, Edição especial IV Workshop do PPGEO/CPAQ/UFMS e 3ª Mostra de pesquisa dos cursos de pós-graduação e graduação em geografia, "Olhares e lugares geográficos do ensino, saúde, ambiente e sociedade na pandemia", UFMS, Aquidauana-MS, p. 14-29, 2020.
- SOUZA, B. I.; SOUZA, R. S. Processo de ocupação dos Cariris Velhos – PB e efeitos na cobertura vegetal: contribuição à Biogeografia Cultural do semiárido. *Caderno de Geografia*, v. 26, número especial 2, p. 229-258, 2016.
- STRAHLER, A. N. *Systems Theory in Physical Geography*. *Physical Geography*, v. 1, n. 1, p. 1-27, 1980.
- UNCCD. *Global Land Outlook. First*. UNCCD, Bonn, Germany, 2017, 336 p.
- VALE, C. C. *Teoria Geral do Sistema: histórico e correlações com a geografia e com o estudo da paisagem*. Entre-Lugar, Dourados-MS, ano 3, n. 6, p. 85-108, 2012.
- VANWALLEGHEM, T. *Soil Erosion and Conservation*. John Wiley & Sons, p. 1-10, 2017.
- VICENTE, L. E.; PEREZ FILHO, A. Abordagem sistêmica e Geografia. *Geografia. Rio Claro*, v. 28, n. 3. p. 323-344, 2003.
- WOLKA, K.; BIAZIN, B.; MARTINSEN, V.; MULDER J. Soil and water conservation management on hill slopes in southwest Ethiopia. I. Effects of soil bunds on surface runoff, erosion and loss of nutrients. *Science of the Total Environment*, v. 757, Stoten: 142877, p. 41, 2021.
- XAVIER, R. A.; SANTOS, I. M.; DAMASCENO, J.; DORNELLAS, P. C.; BORGES NETO, I. O. Processos erosivos superficiais no município de Juazeirinho, Região Semiárida da Paraíba. *Revista do REGNE*, v. 2, Número Especial: III Simpósio de Geografia Física do Nordeste – Caicó-RN, p. 113-122, 2016.
-