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Tests to verify soil erodibility potential in risk areas: a systematic literature review

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Abstract

Through disordered urban growth, areas of slopes with high slopes were occupied, which causes a reduction in vegetation cover, increases the occurrence of soil erosion, and generates slope instability.

Objective: To analyze studies on tests that verify the erodibility potential of soils that are commonly used, through a systematic literature review.

Methodology: The search was carried out in four databases (Scopus, Science Direct, Web of Science, and Google Academic) to search for articles, limited to scientific articles and book chapters in the field of civil engineering in the last 10 years.

Relevance: Given the importance of studying the erodibility of soils in risk areas, a compilation of which tests are used for this purpose can help researchers on the subject choose the most appropriate test for this purpose.

Results: Of the 124 articles selected, 36 were considered for data extraction. There are various tests to check the erodibility potential of a given soil and monitor risk areas, classified as direct methods (Inderbtzen and rain simulator) and indirect methods (drone, Crumb test, pinhole test, and Miniature Compacted Tropical - MCT).

Contributions: All methods proved to be effective for analyzing the erodibility of slopes in risk areas, contributing to the stabilization of the area. Indirect methods require associations between assays to obtain reliable results. Of these methods, the drone brings a technological innovation that is capable of expanding the understanding of risk areas and sediment transport.

Keywords: soil stability, tests, risk area, monitoring

Ensaios para verificação do potencial de erodibilidade do solo em áreas de risco: uma revisão sistemática de literatura

Resumo

Através do crescimento urbano desordenado, áreas de encostas com elevadas declividades foram ocupadas, o que ocasiona redução da cobertura vegetal, aumenta a ocorrência de erosão do solo e gera instabilidade de taludes.

Objetivo: Analisar os estudos sobre ensaios que verificam o potencial de erodibilidade de solos que são comumente utilizados, através de uma revisão sistemática de literatura.

Metodologia: A pesquisa foi realizada em quatro bases de dados (*Scopus, Science direct, Web of Science* e Google acadêmico) para busca de artigos, limitada em artigos científicos e capítulos de livros na área da engenharia civil nos últimos 10 anos.

Relevância: Dada a importância de se estudar sobre erodibilidade de solos de áreas de risco, uma compilação de quais ensaios são utilizados para este fim pode auxiliar os pesquisadores do tema a escolher o ensaio mais adequado para tal finalidade.

Resultados: Dos 124 artigos selecionados, 36 foram considerados para extração de dados. Existem variados ensaios para verificar o potencial de erodibilidade de um solo e monitorar áreas de risco, classificados como: métodos diretos (Inderbtzen e simulador de chuva) e métodos indiretos (drone, Crumb teste, teste de pinhole e Miniatura Compactada Tropical (MCT)).

Contribuições: Todos os métodos mostraram-se eficazes para análise de erodibilidade de taludes em áreas de risco, contribuindo para estabilização da área. Os métodos indiretos necessitam de associações entre ensaios para obtenção de resultados confiáveis. Destes métodos, o drone traz uma inovação tecnólogica que é capaz de ampliar a compreensão sobre áreas de risco e transporte de sedimentos.

Palavras-chave: estabilidade de solos, ensaios, área de risco, monitoramento

Ensayos para verificar el potencial de erosionabilidad del suelo en zonas de riesgo: una revisión sistemática de la literatura

Resumen

A través del crecimiento urbano desordenado, se ocuparon áreas de laderas con altas pendientes, lo que provoca una reducción de la cobertura vegetal, aumenta la ocurrencia de erosión del suelo y genera inestabilidad de laderas.

Objetivo: Analizar estudios sobre ensayos que verifiquen el potencial de erosionabilidad de suelos de uso común, a través de una revisión sistemática de la literatura.

Metodología: La investigación se realizó en cuatro bases de datos (Scopus, Science direct, Web of Science y Google academic) para la búsqueda de artículos, limitándose a artículos científicos y capítulos de libros en el campo de la ingeniería civil en los últimos 10 años.

Relevancia: Dada la importancia de estudiar la erosionabilidad de los suelos en zonas de riesgo, una recopilación de qué ensayos se utilizan para este fin puede ayudar a los investigadores en la materia a elegir el ensayo más adecuado para tal fin.

Resultados: De los 124 artículos seleccionados, 36 fueron considerados para la extracción de datos. Existen varios ensayos para verificar el potencial de erosionabilidad de un suelo y monitorear áreas de riesgo, clasificados en: métodos directos (Inderbtzen y simulador de lluvia) y métodos indirectos (dron, Crumb test, pinhole test y Miniature Compacted Tropical (MCT)).

Contribuciones: Todos los métodos demostraron ser efectivos para analizar la erosionabilidad de taludes en áreas de riesgo, contribuyendo a la estabilización del área. Los métodos indirectos requieren asociaciones entre ensayos para obtener resultados fiables. De estos métodos, el dron trae una innovación tecnológica que es capaz de ampliar la comprensión sobre las áreas de riesgo y el transporte de sedimentos.

Palabras clave: estabilidad del suelo, ensayos, zona de riesgo, seguimiento

Introduction

The rural population migrated to urban centers in search of technology, jobs, and development, leading to disorderly urban growth (Song et al., 2021). This population advance has caused changes in the environment, due to human actions, transforming spaces and natural environments and generating problems to be solved (Liu; Ma, 2020; Santos, Silva & Vital, 2022). The United Nations 2030 Agenda (UN, 2015) mentions that adopting actions to reduce natural disasters is one of the objectives of sustainable development (SDG-11 Sustainable Cities and Communities).

Risk areas are being occupied, increasing the instability of the natural environment, resulting from inadequate excavations and landfills that reduce vegetation cover, and increase the occurrence of disasters and environmental impacts (Carvalhais et al., 2019). Heavy rains in a short space of time, combined with intense occupation, harm the stability of slopes (Melo, 2021). In 2022 and the first months of 2023, Recife, Santa Catarina, and São Paulo were particularly affected by landslides in risk areas due to their geographic location, topography, and population density (Morais & Fernandes, 2023; Parma, 2023; Macedo & Sandre, 2022; Silva & Polivanov, 2022).

In the Metropolitan Region of Recife, in 2022, 128 deaths and more than 9 thousand homeless people were recorded (Globo, 2022).

According to the Recife City Master Plan (Plano Diretor), the city's territorial area is of many slopes, and, currently, around 10,000 risk points have been identified, with the highest incidence on the Casa Amarela and Ibura hills (Recife City Hall, 2023). Xavier et al. (2019) report that most of the hills in the Metropolitan Region of Recife were mostly occupied by low-income populations, due to the real estate market's appropriation of areas most favorable to housing construction. These are precarious occupations that lack infrastructure and can increase the vulnerability of naturally more fragile areas and enhance the occurrence of morphodynamical processes.

Landslides in 2022 occurred in several cities, where the most serious cases were in the neighborhoods of Jardim Monte Verde, Ibura, Vila dos Milagres, Córrego Jenipapo, Sítio dos Pintos. A third of Recife's population lives in areas unsuitable for occupation, such as riverbanks and places with little infrastructure, a legacy of the process of social exclusion arising from the history of Brazil (Santana, 2019). The irregular settlement of the population in areas of river sources and slopes occurs frequently and access to basic urban services, such as sanitation, energy, education, and health, is becoming increasingly difficult (Monteiro et al., 2020). As a result, topography and landscapes are constantly altered by human activities to meet housing needs due to socioeconomic restrictions (Santos, Falcão & Lima, 2020).

As a result, accidents caused by the mass movement of occupied slopes have intensified over the years (Bispo, Melo & Toujaguez, 2019), and contributed to the effects of inadequate human actions.

It is noteworthy that one of the problems generated by urban growth is the decrease in vegetation, which causes erosion and results in soil instability (Moura-Bueno et al., 2018; Roccati et al., 2021). The intensification of these processes is related to rainfall, consolidation of geological materials, topography, inadequate area occupation, and vegetation suppression (Thoma et al., 2022; Nascimento et al., 2020; Basilio et al., 2019).

Climatic conditions also interfere with the erosion process, in addition to being one of the main components of the environmental cycle, as it is responsible for supplying water that supplies groundwater, watercourses, rivers, their tributaries, and, finally, the ocean, (Costa & Rodrigues, 2015).

Soil degradation through erosion contributes to losses in fertility and livelihood productivity also in semi-arid environments and continues to be one of the biggest environmental problems worldwide, threatening developed and developing countries (FAO, 2014). Water erosion in agricultural areas not only removes fertile soil but also degrades water quality, causing siltation in streams, rivers, and reservoirs (Zhu et al., 2013).

In the case of vegetation cover, it acts as soil protection against the action of raindrops through the interception of water by the vegetation structure located above the soil surface, which reduces the speed of the raindrop and partially removes the intensity of the rain and the splash effect, responsible for causing aggregate rupture and sealing the soil surface (Guerra, 2012), in addition to structuring the soil through the dispersion of its roots, which can increase infiltration capacity and reduce the intensity of surface runoff and erosive processes resulting from it. In tropical forests, 4.5% to 24% is intercepted by vegetation, with 1% to 2% of the remainder flowing through their trunks, indicating that 75% to 96% reaches the soil surface (Arcova, Cicco & Rocha, 2003).

In arid and semi-arid regions, soils with little or no vegetation cover are exposed to torrential precipitation events, vulnerable to the occurrence of physical and chemical processes that alter the conditions of the surface layer, such as surface waterproofing and crusting. When the surface is dry, a hard layer is formed (crust). Crusty soils are typical of these dry areas, where soil degradation leads to a decrease in infiltration rates and increasing runoff and erosion rates (Ries & Hirt, 2008).

The soil erosion process affects the landscape, security, and economy, and is considered a global phenomenon (Polovina et al., 2021). Laboratory experiments allow checking the erodibility potential of a soil, directly or indirectly, depending on the parameters to be analyzed. The direct form of investigation is Inderbitzen (Bandeira et al., 2021), however, it is possible to verify indirectly through tests: Crumb test (Masrour et al., 2021); Pinhole Test (Alabdullah et al., 2022); Drones (Padró et al., 2022); MCT (Couto & Gomes, 2020); and rain simulator (Zivanovic et al., 2022).

The Inderbitzen test (direct form) was originally proposed by Anton L. Inderbitzen in 1961 to study surface soil erosion. The most common way to analyze soil erosion is through physical and chemical properties and external conditioning agents. In this sense, the test seeks to simulate field situations to quantify erodibility. The test is carried out in the laboratory and is not yet standardized, however, it has been considered very promising by several researchers (Lafayette, 2006; Gonçalves & Silva, 2019; Oliveira et al., 2021; Bezerra, 2022), as it simulates a flow surface on a specimen, in which soil loss is quantified at pre-determined time intervals, however, it does not simulate the phenomenon of disintegration due to particle splashing, due to the impact of rainwater.

In surface erosion, the erosive power of water and its transport capacity depends on the density and speed of water flow, the thickness of the water depth, and the slope of the slope; Inderbitzen's essay seeks to consider these factors.

The limitation of the original test is that it does not consider the effect of splash erosion. However, for soils with efficient vegetation cover, the impact effect of raindrops is not as relevant, and the aforementioned limitation is not significant. An important precaution is regarding the sample collection depth, which is recommended not to exceed 25 cm for the study of surface runoff.

The crumb test (direct form) is a practical and quick method for identifying soil dispersibility and is standardized by ASTM D6572 (2012) and NBR 13601 (ABNT, 2020a). This test, although considered qualitative in nature, is possible to evaluate the erodibility conditions linked to the maintenance of the initial properties (integrity) of the proposed layer, in the face of water percolation inside and on the surface.

The relationship between the amount of sodium cations and the amount of potassium, calcium, and magnesium cations dissolved in the interstitial water will define the susceptibility of internal erosion occurring through diffusion, as sodium acts to increase the thickness of the water layer. diffuse (involves individual clay particles), reducing the forces of attraction between particles (ABNT, 2020a). It is worth highlighting that, when the test indicates the occurrence of dispersion, it is probably an easily erodible soil, whereas the opposite is not necessarily true, that is, an erodible soil can be classified as non-dispersive.

The pinhole test directly and qualitatively determines the dispersibility of clayey soils by the flow of distilled water through a small axial hole in a specimen molded from an undisturbed sample block, contained in a cylinder. This test was developed as a method of direct measurement of the erodibility of fine-textured soils. The turbidity of the effluent, the flow rate, and the final dimensions of the hole will give the soil dispersibility classification.

As for digital elevation models, they are widely used in the comparative study of large areas to monitor erosion, fires, urban occupation, and planting, among others (Souza, 2018). On the other hand, its results in monitoring small regions are not so common due to the low resolution of satellites and the distance between the study area and the sensors. With the emergence of the Unmanned Aerial Vehicle (UAV) or drone, the resolution of digital models improved and made it possible to analyze smaller regions, but with greater detail.

Despite this, the construction of a time series of models generated with drones intended for monitoring an area is still uncommon. Drones (indirect form) are ideal for capturing smaller areas or emergency situations, as they can be taken more quickly and easily than satellite images. However, the resolution of the images may be lower and the high initial investment for using drones may be a disadvantage. Furthermore, it is important to consider that drones have limitations in relation to the weather, and it is not possible to fly in bad weather situations.

On the other hand, the versatility and competitiveness of drones in the market are advantages to be considered. A wise and cost-effective option is to combine drones with satellite imagery whenever possible. This way, it is possible to obtain high-resolution images of smaller areas and an overview of large areas. Furthermore, the use of drones allows greater flexibility and speed in obtaining images, while satellite images provide broader coverage and an overview of the terrain. Combining these two technologies can be extremely useful for companies that need to monitor large areas but also need precise details in smaller areas.

In the field or laboratory, rain simulators can be used (indirectly) to determine losses of soil, water and nutrients, crust formation, water infiltration, and leaching of compounds or metals in soils. This method has been widely used in the field of agronomy, in studies of soil and water conservation and management.

However, researchers in the field of geotechnics have carried out some experiments, as this procedure brings some advantages: a) reduction in experiment time, when compared to those carried out with natural rain; b) reduction of the cost of the experiment; c) greater control of the experiment conditions – when carried out with natural rainfall, there is great temporal and spatial variability in the distribution of drops within the same rain event; d) possibility of repeating the test under identical conditions – the repetition of various rain events of different intensities and kinetic energy is one of the main advantages of the test. The main disadvantage of field simulators is the difficulty of transportation, operation, control of wind, natural rain, and water supply (Morgan, 2005; Guerra, 1991).

The study of natural and simulated rainfall must be carried out together, as the characteristics of natural rainfall are of great importance when choosing the type of simulator.

In tests using the MCT method, it is possible to portray geotechnical properties and behaviors more adequately, thus revealing an evolution in comparison to conventional systems that are based on particle size, liquidity limit, and plasticity limit tests. Consistency tests use samples in the spatulated state, with no control over the energy expended in handling. Consequently, this procedure interferes with the results of these tests. The list of tests for classification purposes, called Mini-M.C.V. and associated, aims to verify whether or not the soil has laterite technological behavior and, also, the prediction of behavior through the use of properties in a hierarchical manner.

The choice of test must depend on the specific needs of each project. It is important to consider the advantages and disadvantages of each method before deciding. Combining the methods may be an option, as it allows coverage of larger areas and obtaining data in real-time. Furthermore, combining technologies can help overcome the limitations of each method individually, resulting in more informed and effective decision-making.

In this sense, the Systematic Literature Review (SLR) is a systematic scientific method of transparent and reproducible investigation that identifies the existing bibliography for a specific research question, evaluating and extracting data from the manuscripts found (Barbosa & Pio, 2020; Siddaway, Wood & Hedges, 2019). According to Okoli (2019), there are 8 essential steps to carry out an SLR: (1) Identify the objective; (2) Plan the protocol and train the team; (3) Apply practical selection; (4) Search bibliography; (5) Extract the data; (6): Assess quality; (7) Synthesize studies; (8) Write the review.

A tool developed that helps validate RSL quality standards is the Preferred Reporting Program for Systematic Reviews and Meta-Analysis (PRISMA), which describes the systematic review step by step, through a diagram showing the standard process for inclusion and exclusion of articles (Oliveira et al., 2022; Galvão & Ricarte, 2019).

Therefore, this study aims to analyze studies on tests that serve to verify the erodibility potential of a soil or composite that is being most used, through a systematic literature review.

Methodology

In order to obtain the methodological rigor necessary for this type of analysis (Tranfield, Denyer & Smart, 2003), a series of steps were followed. A literature search was carried out between September/2022 and January/2023 to answer the question: which tests are commonly used to investigate the erodibility potential of soil?

The search string was generated with the following keywords and Boolean operators (*OR, AND*): (“erosão” OR “*erosion*” OR “erodibilidade do solo” OR “*soil erodibility*” OR “área de risco” OR “*risk area*”) AND <u>(“MCT” OR “*Miniature, Compacted, Tropical*”)</u>. The underlined keywords in the string were replaced depending on the essay that was searched. For the Inderbitzen test: (“inderbitzen” OR “*test inderbitzen*” OR “ensaio inerbitzen”); for Drone: (“drone” OR “vant” OR “veículo aéreo não tripulado” OR “*unmanned aerial vehicle*”); for the Crumb test: (“crumb teste” OR “*crumb test*”); for the Pinhole test: (“Pinhole” OR “*Pinhole test*”); for rain simulator: (“simulador de chuva” OR “*rain simulator*”). However, it should be noted that the use of synonyms can change the number of articles found.

As a search tool, Google Scholar and the Periodical Portal of the Coordination for the Improvement of Higher Education Personnel (CAPES) were used, in which scientific articles and book chapters were consulted, in databases with a wider range of topics in general, Scopus, Science Direct and Web of Science. In the process of searching for manuscripts, some limitations/filters were applied to the databases as well as inclusion and exclusion criteria, as shown in Table 01.

Table 01

Parameters and limitations defined for the research

PARAMETERS	LIMITATIONS/FILTERS
Keywords from the string	Title; Abstract; or Keywords
Publication Field	Civil Engineering
Language	English; Spanish; or Portuguese
Period of Publication	2013 to 2022 (last 10 years)
Type of articles	Review articles, research articles, and book chapters
Inclusion (I) and Exclusion (E) Criteria	(I.1) provides information on tests used to verify the potential for soil erodibility in a risk area; (I.2) Complete texts; (I.3) Peer-reviewed articles. (E.1) Duplicity; (E.2) Title not consistent with the objective; (E.3) Summary not consistent with the objective; (E.4) No access to the full text.

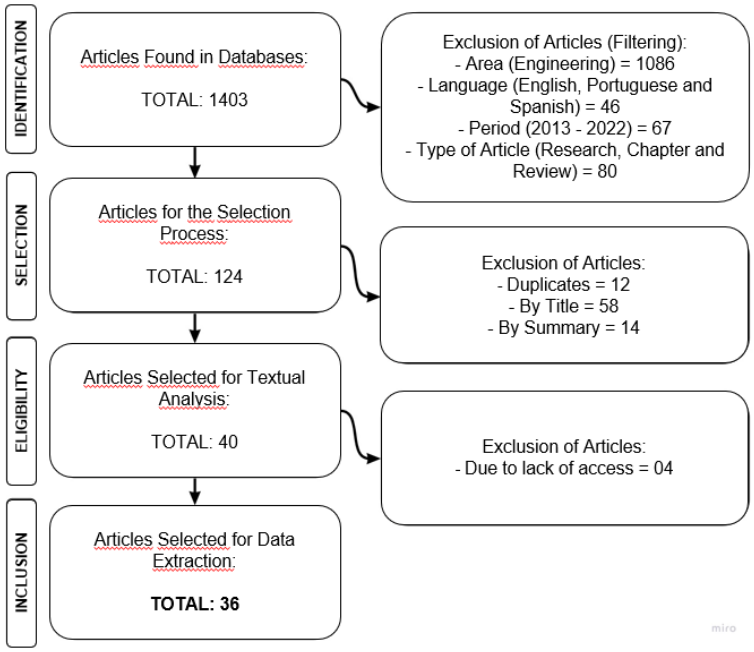
Source: Elaborated by the authors.

Results

The systematic review was carried out between September/2022 and January/2023. A total 1403 articles were found in the four databases and were subsequently subjected to filtering. The PRISMA model flowchart (Figure 01) presents a summary of the results after filtering.

Figure 01

Flowchart of Article Search Results



Source: Elaborated by the authors.

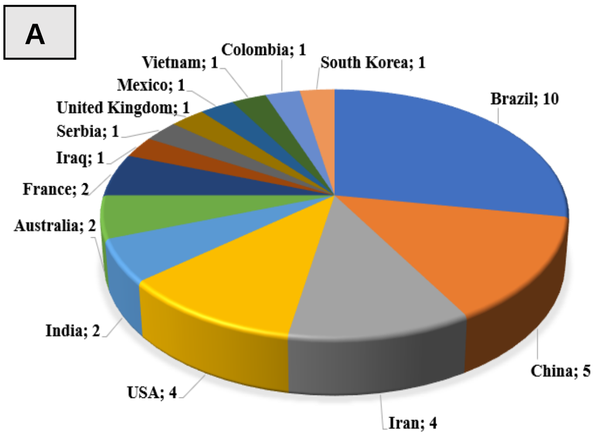
Next, an analysis was carried out to exclude duplicate articles, reading the titles and abstracts. Of the 124 publications selected after filtering, only 40 articles were selected for textual analysis, four of which were not found in full text, totaling 36 articles according to the research objective. This number corresponds to approximately 28.4% of the articles that were selected.

Bibliometric Analysis

Brazil was the country that published the most, in the last ten years, on the topic of this review, appearing in 10 of the 36 studies analyzed, as shown in Figure 02.A. Soon after, come the countries China, with 5 publications; the USA and Iran, with four publications each; India, Australia, and France appear with two studies; the remaining articles are divided into eight countries, showing that the tests found are used in several countries around the world.

Figure 02

Published articles: By countries (A); Assays used (B)



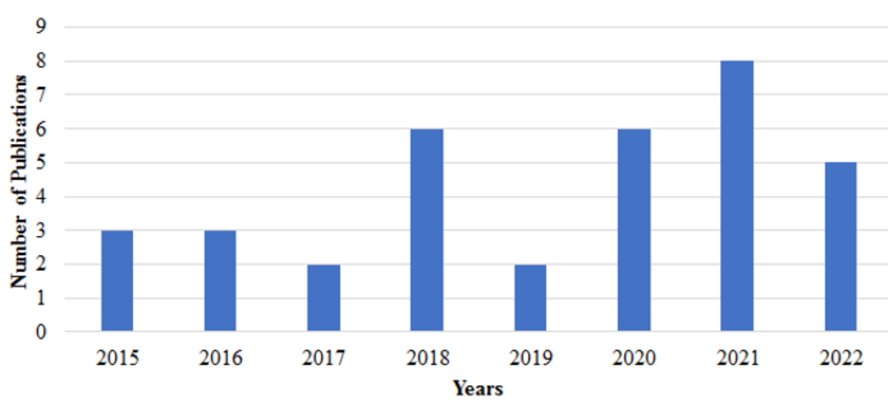
Source: Elaborated by the authors.

Figure 02.B quantifies the number of articles found for each type of test used to study soil erosion. It is observed that the most used test was the drone (12 studies), however, other tests are being commonly used, such as the pinhole test (10 studies); Crumb Test (8 studies); inderbitzen (6 studies); the Rain Simulator and Miniature Compacted Tropical (MCT), with 2 studies each.

In 2021, the largest number of articles published from the studies selected for data extraction occurred, with 8 publications from the 36 studies, as shown in Figure 03.

Figure 03

Number of publications per year

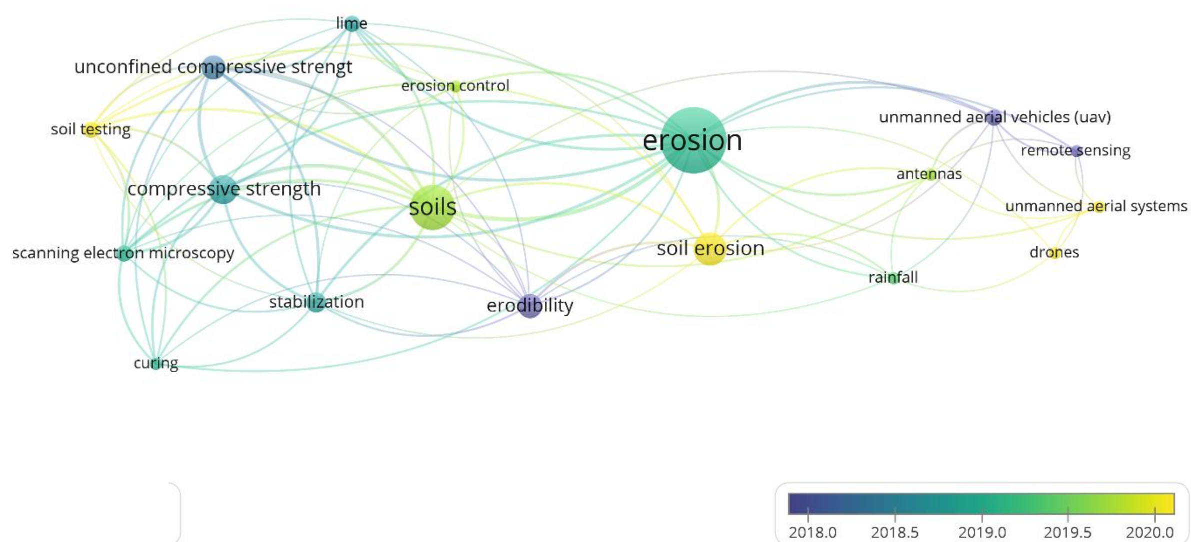


Source: Elaborated by the authors

The keywords mentioned at least three times in all articles are presented in Figure 04, highlighting the keywords: “erosion”, “soil”, “soil erosion”, “erodibility”, “erosion control”, and“ drones” showing that the articles under analysis are in accordance with the proposed objective. The lines correspond to the connection between words in the articles. The colors represent the periods of citation of these words indicated in the caption.

Figure 04

Keywords and Correlations



Source: Elaborated by the authors

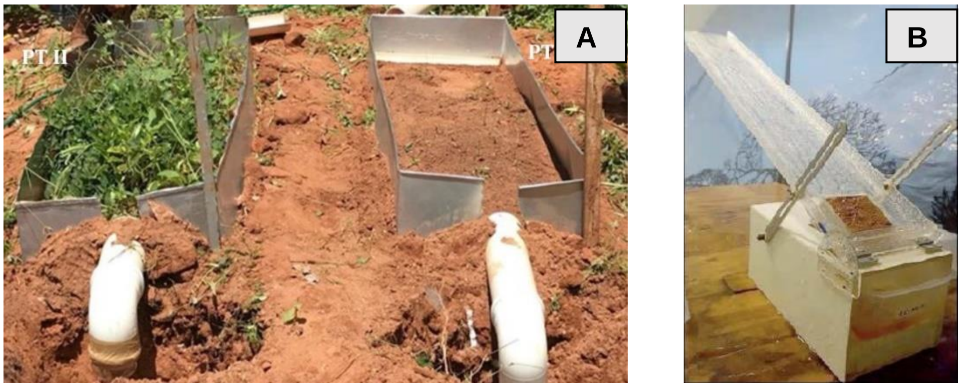
Descriptive Analysis

Inderbitzen

The Inderbitzen test aims to verify the soil's resistance to surface erosion (Figure 05). There are some methodologies for carrying out this test, such as Almeida et al. (2013) which correlates the mass of soil that is not retained in the sieve with the soil particle size curve; Thomas et al. (2020) state that this test makes it possible to evaluate soil erodibility at different slopes (simulating different slopes), varying the intensity and duration of precipitation and surface runoff; and the impact of the raindrop that causes the particle to detach from the soil (Bandeira et al., 2021).

Figure 05

Inderbtizen test: slope (A); different inclinations (B)



Source: Bandeira et al. (2021) (A); Soares et al. (2018) (B)

Nascimento et al. (2019) carried out the underbite test, using the methodology of Almeida et al. (2013), in a sample of pure soil and soil composites stabilized with 1%, 2%, and 4% lime, in four curing times (1, 7, 28 and 56 days). They concluded that treating the soil through the use of lime solution caused a reduction in soil mass loss and that the curing time was not relevant to this loss but was significant in improving structural stability.

In a natural reserve located in the city of Juazeiro do Norte-Ceará-Brazil, Bandeira et al. (2021), using the in-situ inderbitzen test with rain simulation, carried out the test in an area with vegetation cover and another without vegetation. They found that the lack of vegetation cover increases susceptibility to erosion processes, also intensified by human intervention on the site, without planning for rainwater drainage. Concluding that natural and anthropogenic factors are responsible for the erosion of the natural reserve, making non-structural and structural measures necessary to rehabilitate the degraded area.

Thomas et al. (2022) carried out the Inderbitzen test on soil samples with vegetation cover and without vegetation cover at three different slopes (5%, 17.5%, and 35%. The results showed a soil loss ranging from 0.03 to 2 .1 g/cm² and found that the vegetation cover was quite efficient in reducing soil losses due to erosion, and the slope contributed to this loss, corroborating Roccati et al. (2021) and Melo (2021). are important in erosion tests, in agreement with Bandeira et al. (2021).

To evaluate the erodibility of soils on road embankments located in the city of Bom Jardim-RJ, Soares et al. (2018) verified the erodibility indices of soil samples using the Modified Inderbitzen test, considering regional average slopes (11º and 20º) and intense rainfall regime (v = 6.8m/s) in a simulator specially built for this purpose. With the test it was possible to achieve the objective, classifying the samples based on the parameters of Bastos (1999), and concluded that the cut slopes in the region must adopt measures to avoid water erosion.

Using two types of soil (Cambisol and Oxisol) from the city of Senador Canedo-GO, Almeida et al. (2015) analyzed the influence of suction on erodibility, in unformed samples, using the inderbitzen test. They observed that the greatest soil erodibility occurs in dry samples when they suffer saturation due to surface water runoff, however, moistening interferes with the intensity of erodibility. Another point verified is that lower initial suction values were more resistant to surface erodibility.

Fonseca et al. (2016) verified, through the Inderbitzen test, the erodibility of a Cambisol soil, from the Yung stream in the city of Juiz de Fora-MG. They took two soil samples, one from horizon B and another from horizon C. They observed that greater loss of accumulated soil was presented by horizon C, because of the lower clay content and absence of structure, concluding that this horizon has a greater potential for soil erosion, requiring monitoring.

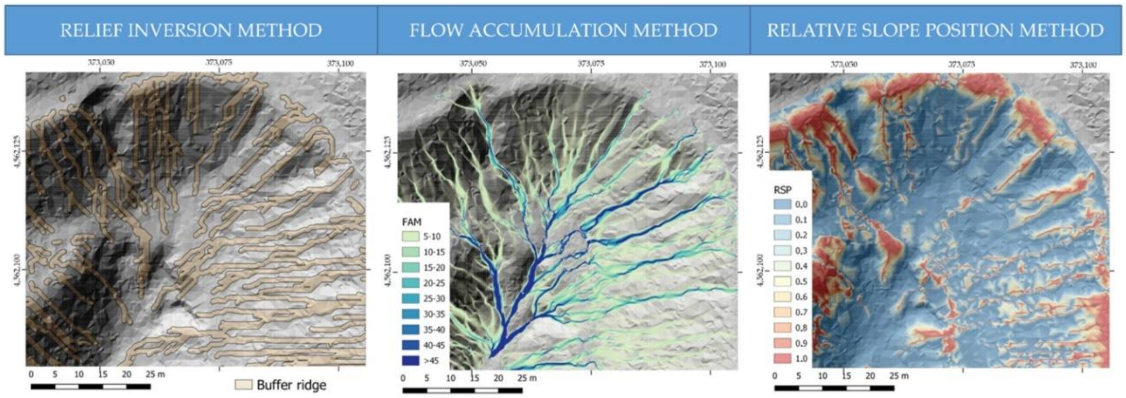
Drone or unmanned aerial vehicle (UAV)

In northern Tanzania, Blake et al. (2020) concluded that high-resolution aerial photography and geospatial analysis were important to understand that erosion on high-slope pasture lands was not only caused by animal husbandry, but the lack of vegetation influenced this process. As a result, some measures were adopted to prevent this erosion, such as planting trees in hydrologically vulnerable points, new pasture management regimes, and commitment to a community land management plan.

Carabassa et al. (2021) presented a practical method to estimate the volume of eroded material in restored areas of an open pit mine located in El Vendrell in Spain, through the use of drone images, photogrammetric techniques, and remote sensing. They found that it is possible to obtain maximum and minimum estimates of the volume of material eroded on slopes, which is relevant for identifying where the main erosion processes occur (Figure 06). They concluded that this method facilitates the quantitative assessment of erosion processes, being viable for restoration programs.

Figure 06

Method to estimate the volume of eroded material



Source: Carabassa et al. (2021)

To verify the influence of rainfall on the development of gullies on a slope located in northeast China, Tang et al. (2022) used an Unmanned Aerial Vehicle (UAV) to collect photogrammetric data with a resolution of 0.08 m, to monitor morphological changes in ephemeral gullies in the heavy rain season. With the drone, it was possible to observe that the volumetric loss of soil from the ravines in a heavy rain event was responsible for around 29 to 45% of the total erosion in the field.

According to Zheng et al. (2020), it is possible to create an elevation model of an area and monitor the erosion of areas using an unmanned aerial vehicle (UAV). With the images, it was possible to verify that erosion in an area located in Yanghe River-China is greater than agricultural expansion, destroying places and cultivable lands and causing losses in agricultural production. Through this, they concluded that appropriate measures are necessary to reduce the advancement of erosion, such as planting native species, which improves the physical and chemical structure of the soil, reduces erodibility, and increases the capacity for water infiltration into the soil.

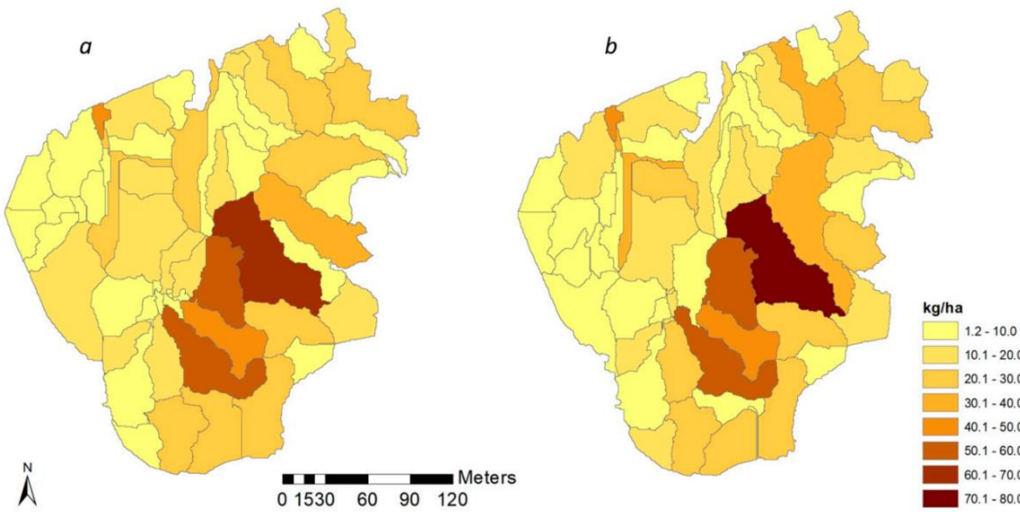
Also, in an area of China, more precisely on the Sancha River, Wang et al. (2016), used the drone to evaluate gully erosion using the 3D photo reconstruction method and satellite images. The results revealed in detail the area of human agricultural use and water erosion, in addition to providing the volume of the ravine. With the images generated, it is possible to carry out an effective assessment of ravine erosion at various spatial scales, and it is important to continue monitoring erosion in this region.

Intending to improve the understanding of the erosion patterns of cliffs located in southeastern Wisconsin, USA, as well as identify the processes that intensify them, Roland et al. (2021) used the drone to observe the erosion rate in the area. The results indicate that the erosion rate, in periods of frost, is 3 to 4 times greater than in hot periods, concluding that the risks of landslides in coastal areas are higher in the colder period, however it is common for these to occur. disasters on steeper slopes all year round.

In another region of the city of Wisconsin-USA, in Waukesha County, Hupy and Wilson (2021), used the images acquired by the drone to make a digital terrain model to estimate the flow of sediment load in the area. To validate this flow using the model made by the drone, a comparison was made with a model generated by the LiDAR (Light Detection and Ranging) system, which is an appropriate model for this type of analysis (Figure 07). They concluded that, in the absence of a model made with data from the LiDAR system, the model made by the drone proved to be efficient.

Figure 07

Comparison of sediment erosion generated: LiDAR System (a); drone (b)



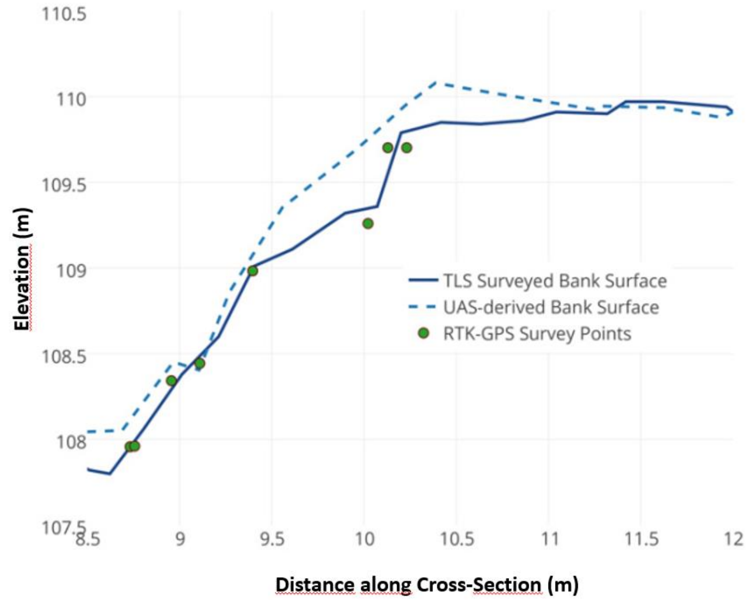
Source: Hupy and Wilson (2021)

Padró et al. (2022) corroborate that remote sensing with drone images is a very useful tool for monitoring restored areas that have suffered erosion processes. They found that slope control and calculation of erosion rates make it possible to monitor active erodible areas and facilitate crucial decision-making for the implementation of stabilization measures in areas of high susceptibility to landslides. And they concluded that remote sensing with drone images is proven to be valid and suitable for monitoring and may apply to other similar scenarios.

Validating the application of topographic data from drones to evaluate and quantify the erosion of coastlines located in Burlington-USA, Hamshaw et al. (2017) compared such data with a terrestrial laser scanner (RIEGL VZ-1000 TLS) and an RTK geodetic GPS (TopCon). They found that even with some limitations (for example obstruction of vegetation), the amount of erosion in some areas was similar to that found by the terrestrial laser scanner, concluding that the drone was efficient in detecting or monitoring areas showing erosion (Figure 08). Yasuhara et al. (2016), when investigating coastlines in Vietnam, corroborate that the drone is a powerful tool for monitoring coastlines that experience erosion.

Figure 08

comparison of the slope profile made by the equipment



Source: Adapted from Hamshaw et al. (2017)

Perez, Zech, and Donald (2015) used drones to inspect construction sites for erosion control practices, concluding that drones are economical, flexible, and have the potential to provide high-quality aerial images and data and can assist in local inspections of practices. environmental control and erosion monitoring (YASUHARA et al., 2016).

Analyzing, through photogrammetric processing carried out by drone, an area before and after the eruption of a volcano located on the west coast of Mexico, Walter et al. (2018), made high-resolution digital terrain models and verified the geomorphological impacts caused by the 500mm rain caused after the eruption. They detected several types of erosion 8 km away from the volcano, with surface runoff and networks of furrows, developing large erosive ravines with a depth of more than 4 m. They concluded that camera monitoring is very useful for studying the relationship between landscape evolution.

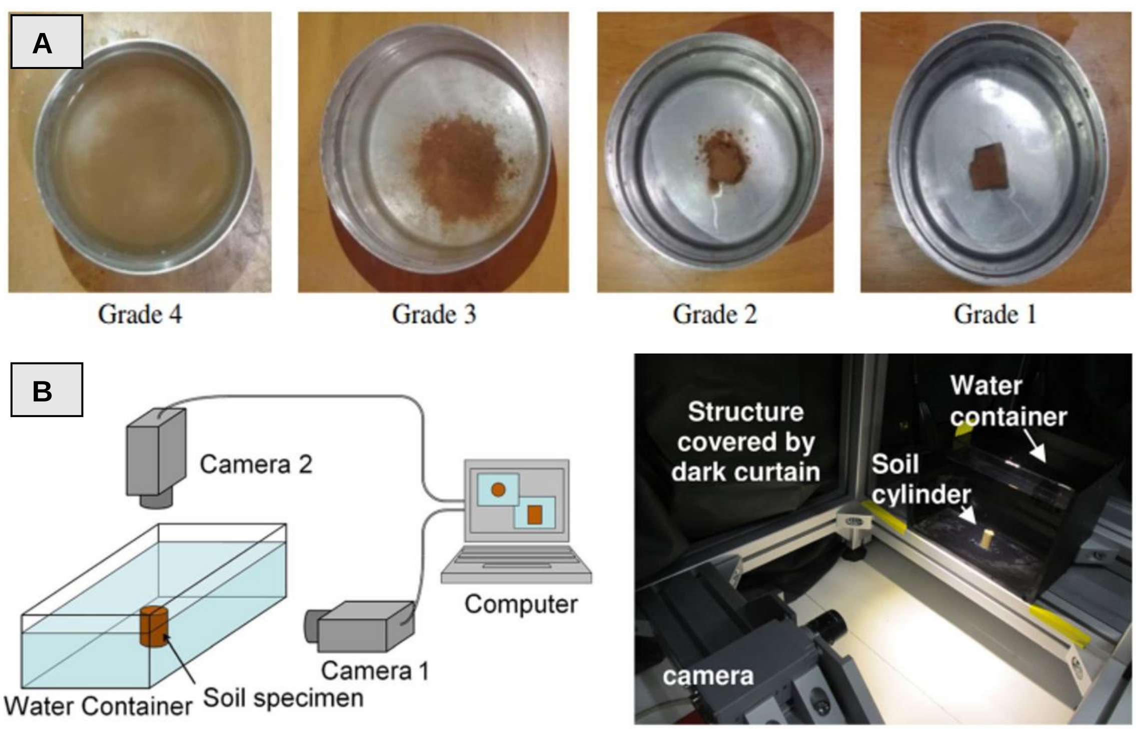
Crumb test

The crumb test is used to qualitatively determine the nature of soil dispersity and is considered the simplest of the tests used to detect dispersive clays (Reddy, Saride & Haldar, 2020; Joga & Varaprasad, 2020). According to Reddy, Saride, and Haldar (2020), the test is carried out by placing a soil sample approximately 15 mm in diameter in a glass or transparent plastic partially filled with diluted 0.001 M sodium hydroxide solution.

The sample is placed in the container and left to rest for at least 1 hour. At the end of the waiting period, the clod and water are observed and the presence of any colloidal clouds in the water is assessed. According to Masrour et al. (2021), the crumb test determines the dispersity potential of the soil based on the quality of the water that permeates through the specimens, which is categorized into 4 grades (Figure 09.A), with Grade 1 referring to non-dispersive samples and Grade 4 being for highly dispersive soils. (ASTM 2013).

Figure 09

Crumb test: conventional (A); automated (B)



Source: Adapted from Masrour et al. (2021) (A); Haghighi et al. (2020) (B)

To investigate the impact of different nano-silica contents on the dispersity potential and mechanical behavior of dispersive soil, authors Masrour et al. (2021) replaced the soil with nano-silica in proportions of 0.4%, 0.6%, 0.8%, 1%, 1.2% and 1.5% in samples with curing times of 7 and 28 days. Applying the crumb test, they concluded that in the proportion of 1%, the samples are classified as non-dispersive, however, for the other proportions (less than or greater than 1%), the samples showed dispersity.

When carrying out the crumb test on a clayey soil from Kuttanad in natural conditions, Reddy, Saride, and Haldar (2020) found that the soil presents degree 3 of dispersity (intermediate dispersive). To reduce the degree of dispersity of the soil, the authors made composites by replacing the soil with bentonite, in proportions of 10% to 60%; however, they did not present satisfactory results, worsen the condition when replacing 50%, making the soil in degree 4 of dispersity.

Joga and Varaprasad (2020) studied the addition of biopolymers, xanthan gum (XG) in the proportions of 0.5%, 1%, 1.5%, and 2% in a dispersive soil from the state of Karnataka-India. They concluded that samples with a 1% addition of XG reduced soil dispersity. Also using xanthan gum (XG), in proportions of 1%, 2%, and 3%, and guar gum (GG) in proportions of 0.5%, 1%, and 2%, Swain et al. (2018) reduced the dispersity of a soil from the city of Rourkela, India, showing the effectiveness of xanthan gum and guar gum in stabilizing the highly dispersive soil.

Haghighi et al. (2020) carried out the crumb test in an automated way (Figure 09.B), attaching a camera to check the behavior of the soil in more detail. While the conventional test is observed with the naked eye, the modified test adopted by the authors verified the degradation and quantified it based on time and/or dimension parameters. The geometric change of the specimens during the swelling phase at the beginning of the test was per infiltration theories and the tendency towards disintegration was consistent with the results of the hole erosion test. However, they concluded that more results are needed to validate the correlation between disintegrating properties and erodibility parameters.

To investigate the erodibility potential of a soil from the city of Lion-France, Elandaloussi et al. (2019) used the crumb test. The authors' objective was to stabilize the soil with the addition of 1% hydrated lime to the natural soil. They observed that the natural soil collapsed immediately when immersed in the water tank, showing that the soil is susceptible to erosion; however, the composite with 1% lime helped to stabilize dispersion, as it remained intact after 1 week of immersion.

Using fly ash to stabilize dispersive soil from the city of Victoria-Australia, Premkumar et al. (2016), through the crumb test and pinhole test, observed that composites (ranging from 3% to 12% fly ash) are effective as they showed a reduction in erosion rates compared to dispersive soil. Fan et al. (2018), in a study carried out in China using the pinhole test and crumb test, corroborate that fly ash had a significant influence on the dispersity of dispersive clay, reducing soil dispersion with increasing fly ash content (0% - 10%) and curing time (0 – 7 days).

Mahmodi, Soloki, and Azimian (2015) verified 17 clayey soil samples from an area that had regions with different erosions, located in the Zahmat-Keshan-Iran plain. Using pinhole and crumb tests, they observed that the majority of samples had high erosion rates, requiring more in-depth studies to propose solutions focused on reducing the erodibility of the area.

Pinhole Test

Another test used to check the dispersity potential of a soil is the pinhole test (Figure 10), which is carried out following the recommendations of standard NBR 14114 (ABNT 1998) on compacted cylindrical specimens (37 mm in diameter and 38 mm tall). Once the curing period has been completed, a hole is made with a 1 mm diameter needle along the entire length of the specimen. Then, the specimen is subjected to constant hydraulic loads over 5-minute time intervals. After each interval, the average flow rate and water turbidity are checked (Filho et al., 2021).

Figure 10

Pinhole Test

Source: Masrour et al. (2021)

To improve a moderately dispersive soil, Filho et al. (2021) made composites by adding glass powder (10% to 30%) and lime carbide (5% to 12%) to the soil and performed the Pinhole test on the specimens with 7 days of curing and which had the lowest weight dry unit (16.5 kN/m³), trying to simulate the worst possible scenario. After the test, all tested specimens could be classified as non-dispersive. It was then concluded that the proposed stabilization method was successful, reducing the dispersity of the natural soil.

Alabdullah et al. (2022), used the pinhole test to measure the dispersity of soil samples from three regions of Baghdad, one in the natural state and the other at optimal humidity. They found that the three soils are registered as highly dispersive soils at natural humidity, and at optimum humidity, soils A and C are between intermediate and highly dispersive, while Soil B is highly dispersive. Concluding that dry density and water content can increase the degree of dispersity.

Intending to investigate the erodibility of different soil types, ranging from clayey to sandy soils, collected from the Nakdong River (South Korea), Dinh et al. (2021) used the pinhole test for this characterization. They observed that grain sizes ranging from 0.2 to 0.6 mm are more susceptible to soil erosion, concluding that particle size distribution and soil uniformity coefficient are significant factors that affect soil erosive characteristics.

Tabarsa et al. (2018), through laboratory tests and field tests, investigated the stabilization of a soil in the Gonbad-Iran canal dam. Stabilization was carried out with nano clay, in proportions ranging from 0.2% to 3.0%, added to the natural soil. The pinhole test was used to verify the dispersity and induced collapse behavior, showing that the use of nano clay improves soil dispersity, concluding that the higher the nano clay fraction, the less erosion occurred.

Using lignosulfonate and polypropylene fiber as stabilizers to improve erosion resistance and mechanical strength of a highly dispersive soil from Estahban city-Iran, Vakili et al. (2018), through the pinhole test, observed that the dispersion potential of the soil decreased considerably due to the stabilization of the lignosulfonate, concluding that the composite with 2% lignosulfonate and 0.35% polypropylene fiber obtained a reduction in the dispersity of the soil. pure soil, making it a non-dispersive material.

Miniature, Compacted, Tropical (MCT)

For soil classification purposes, empirical coefficients obtained in two MCT Methodology tests can be used. The MCT test is regulated by the road standards of the National Department of Transport Infrastructure (DNIT) through the standards: Mini-MCV dynamic compaction test - ME 258 (DNER, 1994b); and Immersion mass loss test - ME 256 (DNER, 1994a). Bastos et al. (2000) classify the erodibility of soil based on two parameters: the sorption coefficient (s) obtained in the infiltration rate test; and mass loss due to immersion (Pi), one of the MCT steps. Soils are classified as erodible when the Pi/s ratio is greater than 52. Pejon (1972) considers a soil to be erodible when the Pi/s ratio is greater than 40.

Checking four profiles of residual soils from highway and road cuts in the Alto

Paraopeba region, in the State of Minas Gerais, in natural and pre-moistened conditions, Silva et al. (2015) analyzed that it is possible to make an indirect assessment of the erodibility of a given material using the proposal of Bastos et al. (2000). In this study, only two profiles showed greater susceptibility to erosion.

For Couto and Gomes (2020), it is possible to verify the potential for soil erodibility with the MCT Methodology. Analyzing soil samples from highways in Minas Gerais, the authors verified the potential for soil erodibility through the values of mass loss through immersion and the absorption values through capillarity of samples in their natural state and air-dried, through parameters defined by Pejon (1992). The results indicate that soils with a higher degree of weathering are less susceptible to water erosion. They concluded that the MCT presents a promising application to check soil erosion on slopes, mainly through the test of mass loss through immersion, but that it presents limitations regarding the original structure of the soil.

To analyze a soil of tropical residual origin located in the city of Guarne (Colombia), Valencia-González et al. (2015) carried out characterization and erodibility tests on samples. They found that the soil behaves like a clayey lateritic soil, being resistant to hydraulic erosion when properly compacted, however, in its natural and unprotected state, it is fragile to surface erosion (Bastos et al., 2000). The authors verified the erodibility of the soil with the pinhole test, showing that the soil does not present internal erosion.

Rain Simulator

For Confessor, Silva, and Rodrigues (2021), rain simulators, with different configurations, have long been used for studies normally linked to understanding water dynamics. According to Zivanovic et al. (2022), soil erosion processes are a global problem, and the rain simulator (Figure 11) is a very useful tool for studies of soil resistance in terms of erodibility (Confessor, Silva & Rodrigues, 2021).

Figure 11

Rain simulator: on-site analysis

Source: Zivanovic et al. (2022)

Through a rain simulator adapted to a sloped area of 7° and 15° and adopting parameters of rain intensity equal to 1.7 and 1.9 mm/min; droplet diameter equal to 1.2 mm; and Christiansen uniformity coefficient of 92.23%-93.70%, Zivanovic et al. (2022) concluded that the simulator proved to be effective for analyzing erosion and can be successfully implemented in research that aims to determine resistance to erosion processes, infiltration and sediment production in soils.

Intending to spread the use of a simple and portable rain simulator in areas with soil erosion processes, Confessor, Silva, and Rodrigues (2021) found that through the equipment it can be illustrated: how much natural erosion can revitalize areas; how much the transported material may or may not benefit areas; and how much human actions can affect the dynamics of the environment, accelerating the erosion process. They concluded that rain simulators can be applied in education and research, with a focus on education, stimulating environmental awareness, and showing the consequences and impacts generated by erosion.

Conclusions

In this analysis it was observed that Brazil is the country that suffers the most with the erodibility potential of soil (with 10 studies; however, it is a subject of global interest, as the 36 studies analyzed are spread across 14 countries.

It can be seen that there are several tests to check how resistant a soil is to erosion, through direct tests (Inderbitzen and rain simulator) and indirect tests (use of UAV, Crumb test, pinhole test, MCT), all important for monitoring risk areas.

It appears that the most used methods are older ones, such as the Crumb test, pinhole test, and MCT; however, more technological analyses are used to monitor areas, such as rain simulator, use of UAV (drone), on-site Inderbitzen, and automated crumb testing.

In the essay by Inderbitzen, Rocha (2021) makes some considerations about the test: while the original methodology is capable of covering different flows and slopes in an acceptable way, the new methodology is also capable of simulating the rain process in an acceptable way, with observable removal of material at the droplet impact sites. Therefore, compared to the original test, the new test model is able to add the direct impact factor of rain on the sample, presenting superior realism in simulating the erosion process. In this test, the methodology can partially reproduce the natural characteristics of surface flow, with limitations regarding the slope of the ramp.

As for the Pinhole test, Moraes (2022) mentions that this test is likely to identify highly erodible soils, which can be confused with dispersive soils. It is important to note that all high-sodium soils can be erodible, but not all erodible soils are necessarily dispersive. According to Bell and Walker (2000), the diameter of the orifice at the end of the test proves to be the most reliable indicator for recognizing dispersity. This, however, should not be the only determining factor for identifying dispersity, as the pinhole diameter of erodible soils will increase more than for dispersive soils. The nature of the effluent plays a vital role in the testing procedure – not only the color but also the type of sediment/material present in the water. Soil effluent may be highly turbid as it leaves the test but is not necessarily dispersive. If the soil is dispersive, the effluent must remain cloudy for a prolonged period, as the clay particles will remain in suspension, while the suspension in purely erodible materials will only be established in an initial phase, followed by the sedimentation of the solids, and thus the solution will become clear (or possibly stained if the soil contains certain elements like iron or organic matter).

Paula et al. (2020) report that the MCT classification test makes it possible to infer, in a very reliable way, the genesis of tropical soils, especially the fine-textured laterites that cover a large part of the national territory, when compared to the tests and classification systems originating from American standards. The MCT-M classificatory abacus highlights the transitional character that soils present between laterite and saprolite genesis, therefore identifying partially evolved soils. This is important for evaluating the geotechnical behavior expected in studies, projects, and execution of works of road infrastructure. Verifying the relationship between the degree of weathering and the MCT-M classification can add greater knowledge on the subject, in order to make the concept of transitional soils within the scope of tropical soils more pragmatic.

Regarding drone monitoring, Parreiras (2021) describes that the use of this equipment allows landslides to be identified within gullies in less time than with traditional methods. The author observed that long and consecutive rains are associated with more significant changes, such as the filling of cavities and the widening of erosive grooves, possibly due to the ability to form currents. On the other hand, rains separated by periods of drought are associated with surface erosion features, apparently without great capacity to carry sediment. In this sense, the application of aerial imaging by drones can be a robust method for estimating the erosional advance of gullies on annual time scales. In this way, it can be emphasized that all methods were considered effective for analyzing soil erodibility.

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