BIO Web of Conferences **125**, 01008 (2024) https://doi.org/10.1051/bioconf/202412501008
ABS 2024

Assessment of soil erosion through spatial analyzing of soil properties using statistical-based functions

Narges Kariminejad[1*], *Vahid* Shafaie[2], and *Majid* Movahedi Rad[2]

[1]Department of Natural Resources and Environmental Engineering, College of Agriculture, Shiraz University, Shiraz, Iran
[2]Department of Structural and Geotechnical Engineering, Széchenyi István University, 9026 Győr, Hungary

Abstract. The significant geomorphological hazard of collapsed cavities (CC) causes notable environmental transformations. To address this issue, the pipe collapse pattern was examined using two statistical methods, the Density Correlation Function (DCF) and the Mark Coloration Function (MCF). Key predictor variables like organic carbon (OC), sodium adsorption ratio (SAR), and exchangeable sodium percentage (ESP) were utilized to comprehend their impact on spatial distribution over time. The study was found that lower OC levels increase susceptibility to CC, while higher SAR and ESP amounts enhance the potential for collapsed cavities. The methodology and discoveries of this research can offer valuable insights for land managers, stakeholders, and researchers.

1 Introduction

Soil erosion, a crucial element of land degradation, results in various adverse effects such as reduced water and soil quality, environmental hazards, financial setbacks, risks to human safety, and the transfer and deposition of sediment downstream [1,2]. From a broader perspective, collapsed cavities play a significant role in soil loss in watersheds with dry and semi-arid regions [3]. It is essential to highlight that collapsed cavities create substantial obstacles to effective land capacity management strategies and broader watershed management efforts [4]. Therefore, a key objective of sustainable land management is to improve long-term production quality while improving soil health and preventing degradation processes [5].

The collapsed cavities formed by concentrated water flow and sudden soil surface collapse are a specific reaction to subsurface flows. Subterranean gaps, typically created by water flow concentration, dissolution of soluble materials, and clay movement, are crucial in developing tunnel erosions or collapsed pipes. Often, subsurface water flow, particularly in the form of supercritical flow, triggers collapse in the roof, leading to the formation of visible surface tunnels. Despite the significance of studying tunnel erosions or collapsed pipes, this area poses significant challenges as it is mainly caused by subsurface erosion and requires

* Corresponding author: narges.karimi991@gmail.com

specialized geological tools. Consequently, research in this field has received relatively less attention compared to other erosion processes [6].

In addition, it is crucial to carefully choose the appropriate methodologies for analyzing data. Since numerous geomorphic systems are characterized by complex multivariate relationships, nonlinear effects, and feedback loops [7], it is essential to utilize statistical and data-driven techniques. These methods would play a vital role in reducing errors in decision-making, testing hypotheses, simplifying intricate relationships, and identifying the key factors that impact geomorphic processes. By employing statistical methodologies, researchers can ask relevant questions and develop predictive abilities to enhance their understanding of geomorphic systems [8].

Overall, the use of summary statistics methods including the MCF and DCF, can enhance the analysis of collapsed cavities by providing a systematic, quantitative, and comprehensive approach to studying the complex interactions in soil properties and erosion. Further, the main objective of this study is to conduct precise spatial analysis and identify the key factors contributing to collapsed cavities using summary statistics with satellite imagery. The objectives of this research include (a) analyzing the spatial distribution and patterns of CC in the province and (b) investigating the impact of SAR, ESP, and Soil Organic C (SOC) on the spatial distribution of CC.

2 Study area

The study area depicted in Figure 1, Shorluq (60́ 38° E and 36° 19́ N), is situated near to a village in Sarakhs City, Marzdaran region, covering an area of 79.5 hectares and located 54.1 kilometers southwest of Sarakhs City, Shorluq lies in proximity to the Sarakhs-Kashafrud River. The site ranges in elevation from 815 to 865 meters ASL and experiences a moderate and arid mountainous climate. The seasonal Shorluq River flows in proximity to this location, connecting to the Kashafrud River. The land on this site is primarily used for agriculture. The primary livelihood of the residents is agriculture and animal husbandry, with wheat and barley being the major crops cultivated.

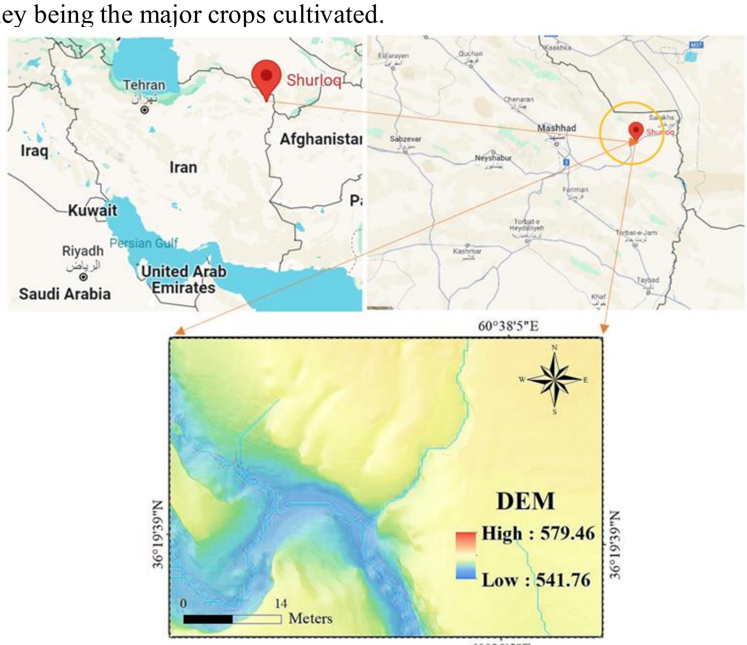

Fig. 1. The exact location of the study region in Khorasan Razavi, Iran

3 Material and methods

3.1 Data and information

The research methodology involved utilizing library resources, fieldwork (Figure 2), and laboratory techniques. To carry out this study, suitable approaches were employed to analyze the spatial distribution of CC and to map the precise locations of erosion features. The study's primary focus was preparing soil samples and analyzing various soil properties such as OC, SAR, and ESP. This research aimed to investigate how carbon content is distributed across the areas and to understand the impact of various soil properties like OC, SAR, and ESP. In this study examined 70 soil samples from the surface soil (0–30 cm) in the study region. These samples were taken to the lab, air-dried, and soil organic carbon was determined using the chemical method [9]. For this, the soil is mixed with concentrated sulfuric acid and bichromate, after the oxidation reaction is completed, the remaining bichromate is titrated with ferroammonium sulfate. The exchangeable sodium percentage was calculated to assess soil structural stability, and the sodium adsorption ratio was used to understand how sodium concentration affects cation exchange [10].

Fig. 2. The examples of collapsed calvities in the study area.

3.2 Statistical analyses

The DCF illustrates how the CC varies with soil characteristics density-dependently. It examines the relationship between each soil variable represented as a numerical value, and the density of CC found within a specific distance r. In other words, the DCF reveals how various soil characteristics influence the density of CC. It provides insights into how each soil factor correlates quantitatively with the density of CC within a specific distance *r*. By examining these relationships, the DCF helps us understand how different soil features impact the distribution and concentration of CC in a given area. It serves as a valuable tool for analyzing the complex interplay between the density of soil landforms and soil factors driving variations across different spatial scales. The function of the DCF is presented as follows [11]:

$$\frac{(m_i(\lambda K)_i(r))}{(\pi r)^2} \qquad (1)$$

https://doi.org/10.1051/bioconf/202412501008

Here, mi represents the attribute (such as different soil variables) of CC i, λ stands for the total density of CC at distance r, and Ki(r) refers to the related "local" K function. Since the correlation coefficients are not affected by scaling the data with a constant, the simplification is as follows:

$$C(m_i K_i(r)) = (m_i - \mu)[K_i(r) - K(r)] \qquad (2)$$

The MCF, denoted as k_{mm} (r), measures the mark interactions of two points within a marked point process at a separation of distance r, as detailed in [12]. This function extends beyond the traditional pair-correlation function $g(r)$ by analyzing the correlation in mark sizes, not merely the spatial proximity, at a given distance r. Specifically, $k_{mm}(r)$ evaluates the mean of the product $t_1(m_i, m_j)=m_i m_j$ for points i and j separated by distance r, and normalizes this by the average product of all point pairs, irrespective of their separation [13]. A value of $k_{mm}(r)=1$ signifies an absence of spatial mark correlation. A $k_{mm}(r)$ value below 1 implies that nearby points tend to have marks more minuscule than the overall average, while a value above 1 indicates that marks of proximal points are more significant than those of more distant points [13].

4 Results and discussions

Following a field survey in the studied region, the spatial distribution of CC was mapped using a GPS device. The soil's physical and chemical properties were assessed, and the collected data were analyzed using statistical methods. The analysis, based on the Cm, K(r) test, revealed that the SAR had a significant effect on CC density within distances ranging from 0.5 m to 17 m, indicating that SAR increased CC density (Figure 3A). Furthermore, a strong positive relationship was found between CC aggregation and ESP. Although the ESP appeared to cause an increase in CC aggregation, this impact did not reach statistical significance at a 0.05 level (Figure 3B). The study also suggested a correlation between CC accumulation and OC content, indicating that higher levels of organic matter resulted in lower CC density in the research area. The significant decrease in carbon density due to soil organic carbon was confirmed at a 95% confidence level, as shown by the observed line falling within the corresponding simulation intervals in Figure 3C.

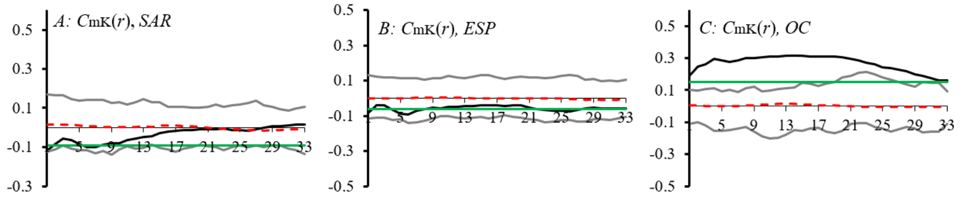

Fig. 3 Spatial effects of soil properties on the density of CC based on DCF.

In addition, concerning the MCF findings, the clustering of CC had a positive correlation with higher levels of ESP and SAR (Figure 4A and 4B). Additionally, the aggregation of CC was positively associated with lower organic carbon (OC) values across all scales (Figure 4C). This suggests that areas with higher OC content exhibited fewer occurrences of CC, indicating a negative relationship between organic matter and carbon content. Contrary to the findings of [6] suggesting non significant differences in chemical properties, our results indicated that higher OC content in CC locations may lead to the presence of poorly developed CC. Previous studies by other researchers have also noted the occurrence of soil piping in organic soils [14, 15]

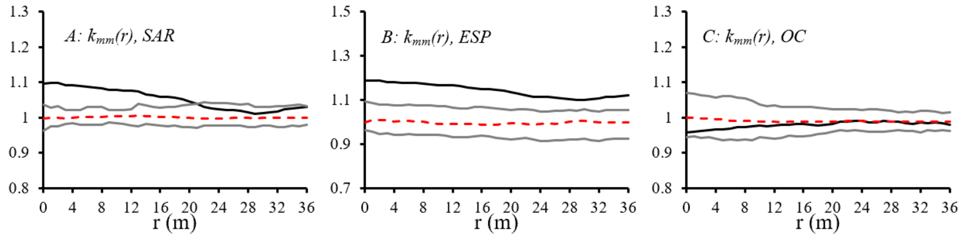

Fig. 4. The spatial analysis of collapsed cavities based on the MCF.

It was found that collapsed cavities in loess and semi-loess deposits exhibit a similar distribution pattern under the influence of various factors. This similarity is primarily attributed to the direct associations of specific environmental factors that impact certain areas within the range. The findings of this research align with a study by [15], investigated the spatial distribution of collapsed cavities in Golestan province over a 7-square-kilometer area, revealing a clustered pattern of pipe collapses across the entire study region. The efficacy of this method in quantitatively analyzing spatial relationships has been validated with other research studies [3]. Consequently, leveraging these functions can offer valuable insights into complex systems by facilitating the explicit modeling of intricate relationships between point processes.

Using this analytical method is essential for progressing quantitative geomorphology studies in dry and semi-dry areas, which have previously been overlooked. By utilizing statistical techniques, scientists can acquire in-depth knowledge on how different features are distributed and connected in the research area. This thorough comprehension enables the creation of specific management plans that can successfully manage and decrease the spread of these features in the region.

5 Conclusion

The statement is emphasizing the importance of using objective and statistical methods in analyzing a research site with varied land uses and intricate terrain. Subjective methods and individual knowledge may lead to differing interpretations and a lack of agreement due to the interconnected nature of geomorphic systems. By creating and testing hypotheses using statistical techniques, researchers can simplify complex relationships and explore the impact of collapsed cavities on environmental issues.

The findings from the study suggest that collapsed cavities do have an impact on environmental issues, highlighting the need for further research on the development of collapsed cavities. This research should involve the collection of precise data and the application of suitable spatial statistical methods to accurately analyze and understand the phenomenon. By taking a more objective approach and utilizing statistical methods, researchers can gain a better understanding of the complexities of the research site and its implications on the environment.

References

1. J. Syvitski, J.R. Ángel, Y. Saito, I. Overeem, C.J. Vörösmarty, H. Wang, D. Olago, Earth's sediment cycle during the Anthropocene. Nat. Rev. Earth Environ., **3**(3), pp.179-196 (2022).

2. A. Salhi, Y. El Hasnaoui, P. Pérez Cutillas, E. Heggy, Soil erosion and hydroclimatic hazards in major African port cities: the case study of Tangier. Sci. Rep., **13**(1), p.13158 (2023).
3. N. Kariminejad, M. Hosseinalizadeh, H.R. Pourghasemi, A. Bernatek-Jakiel, M. Alinejad, GIS-based susceptibility assessment of the occurrence of CCs and pipe collapses in a semi-arid environment: Golestan Province, NE Iran. Land Degrad. Develop. (2019).
4. C. Valentin, J. Poesen, Y. Li, Gully erosion: Impacts, factors and control. Catena. **63**, 132–153 (2005).
5. J. Zhao, Z. Yang, G. Govers, Soil and water conservation measures reduce soil and water losses in China but not down to background levels: Evidence from erosion plot data. Geoderma. **337**, 729-741 (2019).
6. A. Bernatek-Jakiel, E. Nadal-Romero, Can soil piping impact environment and society? Identifying new research gaps. Earth Surf. Proc. Landforms, **48**(1), pp. 72-86 (2023).
7. J. D. Phillips, Changes, perturbations, and responses in geomorphic systems. Prog. Phys. Geogr. **33**, 1–14 (2009).
8. M.A. Sekkeravani, O. Bazrafshan, H.R. Pourghasemi, A. Holisaz, Spatial modeling of land subsidence using machine learning models and statistical methods. Environ. Sci. Pollut. Res., **29**(19), pp.28866-28883 (2022).
9. A. Walkley, I.A. Black, 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci., **37**(1), pp.29-38.
10. R. Van de Graaff, R.A. Patterson, Explaining the mysteries of salinity, sodicity, SAR and ESP in on-site practice. In On-site '01 conference: advancing on-site wastewater systems, University of Armidale, New England, September, pp. 25-27 (2001).
11. M. Żywiec, M., J. Ledwoń Holeksa, P. Seget, B. Łopata, J.M. Fedriani, Rare events of massive plant reproductive investment lead to long-term density-dependent reproductive success. J. Ecol., **106**(3), pp.1307-1318 (2018).
12. S. Getzin, K. Wiegand, J. Schumacher, F.A. Gougeon, Scale-dependent competition at the stand level assessed from crown areas. Forest Ecol. Manag. **255**, 2478-2485 (2008).
13. T. Wiegand, K.A. Moloney, Handbook of spatial point-pattern analysis in ecology. CRC Press, New York, 538 p (2014).
14. J. Holden, T.P. Burt, Piping and pipeflow in a deep peat catchment. Catena, **48**(3), 163-199 (2002)
15. J. Holden, Sediment and particulate carbon removal by pipe erosion increase over time in blanket peatlands as a consequence of land drainage. J. Geophy. Res.: Earth Surf. **111**(F2) (2006).