ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2025, 10 (1): 141-150 doi: 10.28978/nesciences.1642292

Examining the Influence of Climatic Variability and Rainfall Intensity on Soil Erosion Dynamics

Dr. Kunal Meher [1*], Nagraj Patil [2], A. Geetha Bhavani [3], Arpit Arora [4]

[1*] Assistant Professor, Department of uGDX, ATLAS SkillTech University, Mumbai, Maharashtra, India. E-mail: kunal.meher@atlasuniversity.edu.in

[2] Associate Professor, Department of Mechanical Engineering, Faculty of Engineering and Technology, JAIN (Deemed-to-be University), Ramnagar District, Karnataka, India. E-mail: nagaraj.patil@jainuniversity.ac.in

[3] Professor, Department of Chemistry, Noida International University, Greater Noida, Uttar Pradesh, India. E-mail: geetha.bhavani@niu.edu.in

[4] Assistant Professor, Chitkara University Institute of Engineering and Technology, Centre for Research Impact and Outcome, Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India. E-mail: arpit.arora.orp@chitkara.edu.in

Abstract

An important environmental issue, as soil erosion is prominent in those areas exposed to heavy rain falls, as well as variability in the climatic measures. Research was carried out concerning the effect that intensity of rainfall and variability in climate have on soil erosion dynamics, especially how their combination brings about soil loss from different places. 79 plots from three distinct regions that vary in terms of climatic conditions were surveyed, and soil samples and erosion rates were measured. Five replicates of soil sample collections were made from each plot to measure erosion rates, while automated rain gauges were used to monitor rainfall intensity and duration. Time-series satellite remote sensing data were used to detect changes in land cover over time, and the effects of severe weather on erosion were measured through extreme rain gauges that recorded amount and duration. IBM SPSS software (version 27.0) was used to apply the information, and multiple regression analysis was utilized to examine the influence of rainfall intensity, duration, and climate variation on rate of soil erosion. Additionally, correlation analysis was performed to examine the direction of the correlations between rainfall intensity and erosion rates. ANOVA was utilized to confirm the consequences on the environment and find out whether there were any notable variations in erosion rates across various weather conditions. The results show that only climatic variability apart from rainfall intensity can significantly contribute to increased soil erosion, with higher effects in areas with weaker land management practices. The research emphasizes that there must be consideration

*Corresponding Author: Dr. Kunal Meher, E-mail: kunal.meher@atlasuniversity.edu.in

of climatic factors in design plans of soil conservation in an effort to decrease the properties of soil erosion about modification in weather and precipitation forms.

Keywords:

Soil erosion, extreme rainfall condition, land cover changes, climatic variability, rainfall intensity, heavy rainfall.

Article history:

Received: 25/10/2024, Revised: 26/12/2024, Accepted: 14/01/2025, Available online: 31/03/2025

Introduction

Soil erosion can threaten agriculture seriously since it means losing organic carbon, nutrients, and soil. Therefore, soil erosion modeling is one of the stages of identifying erosion hotspots and preparing soil conservation strategies (Mahdiraji et al., 2019). The primary agent of such degradation is soil erosion, which is brought about by excessive surface runoff followed by the removal of the topsoil and organic matter along with the nutrients it contains (Bezak et al., 2021; Du et al., 2022). A major danger to soil functioning, soil erosion has several off-site impacts and lowers land production. It is essential to identify soil erosion patterns and locations that are susceptible to erosion to comprehend the factors that drive soil erosion and to provide basic standards for planning water and soil conservation. To address the environmental problems, climate change adaptation and the sustainable advancement of the human community is facilitated, which is very beneficial to examine local soil erosion (Borrelli et al., 2023; Tian et al., 2023). Rain and wind are two examples of the many elements that contribute to soil erosion, and destroy the upper layer of soil (Saidova et al., 2024). In addition to decreasing land productivity and increasing the probability of hurricanes, droughts, and floods, soil erosion can degrade land assets. Furthermore, it has been estimated that soil erosion costs the world's socioeconomic sector billion per year (Ma et al., 2021). Because of intense rainfall and steep slopes, severe soil erosion frequently happens throughout agricultural regions with conservation tillage (Radmanovic et al., 2018). The rainfall-runoff process includes surface depression storage, which is impacted by the soils' surface micro relief features. Therefore, on sloping ground, surfaces with greater storage capacity have a greater impact on reducing runoff and silt. However, the real storage capacity of cultivated surfaces is typically restricted during rains because of erosion and the effects of slope gradients (Zhao et al., 2021). Changes in temperature, soil, and terrain, vegetation, and conservation practices can all contribute to the spatiotemporal inconsistency in soil erosion (Sharipov et al., 2024). The primary indicators of rainfall's effects on erosion are rainfall intensity and effectiveness, which are represented in rainfall erosive (Abioghli, 2016). It is crucial to determine the dominating causes and measure their contribution rates to offer data for soil erosion management, given that the aspects influencing soil erosion are varied in both location and period. Plant variety improves other ecosystem functions, lowers soil erosion, and increases the soil's capacity to store water (Jin et al., 2021; Senanayake et al., 2022). The objective of the research is to explore the impact of weather variation and rainfall intensity on the dynamics of soil erosion in three distinctive areas. It seeks to determine how these elements affect soil loss and provide guidance for soil conservation measures.

(Alsafadi et al., 2024) investigated the spatial alterations in soil erosion over Syria’s entire Coastal Basin (CB) from 2000 to 2018 to produce a map of the examined area’s soil water erosion hazard. (Zhao et al., 2022) examined dependence on satellite-based information and simulations, which could not adequately represent regional differences in soil erosion, is one of its limitations. The findings could offer useful geographical understanding for plans of regeneration for Syria's post-war period. The source utilized a substantial record of runoff and erosion observations to analyze the impacts of agriculture practices, slope range, slope length, and average yearly precipitation on soil loss and runoff across China. Differences in soil types and anthropogenic interferences, apart from those dependent on land use classification, are not addressed. It has been established that property use is the primary driver of sand degradation and overflow, with plant coverage significantly decreasing rates compared to farmland. Doulabian et al., (2021) presented the Research Universal Soil Loss Equation (RUSLE) approaches historical and forecast rainfall data to predict future instances of eroded soil by assessing the impressions of changed climates on soil erosion within Iran. The findings indicate that soil erosion and rainfall erosivity have generally decreased in the majority of provinces. According to the research, soil erosion and rainfall erosivity have generally decreased in the majority of provinces, but have significantly increased in certain places, especially in the provinces to the north. Martey & Kuwornu, (2021) examined the variables affecting Ghana's implementation of Integrated Soil Fertility Management (ISFM) techniques, with an emphasis on climatic variability and shocks affecting farmer choices. The availability of thorough data on farmers' attitudes and encounters with climatic variability, as well as the results' applicability to other sub-Saharan African locations, could limit the research outcome. The findings demonstrate the risk-averse choices and mitigation techniques used by farmers. He et al., (2024) leveraged the Integrated Ecosystem Services and Tradeoff Assessment (InVEST) framework; an objective evaluating eroded soil and soil dynamics conservation was conducted in the southeast Chinese region of the Ganjiang River Basin (GRB). According to the results, the simulated values of sedimentation export and soil erosion both first declined and then rose between 2000 and 2020; nevertheless, the overall rises over the previous 20 years were 14% and 18.18%, respectively. (Behailu et al., 2021) evaluated farmers' views of climatic variability and extremes, which were compared to meteorological data using a descriptive approach. According to the research's findings, farmers' perceptions align with the pattern and variation analysis of meteorological information. Given the results, it is advised that the community be given regular and adequate details regarding emerging and existing manifestations of variability in the climate that are pertinent to farming decisions. (Pal et al., 2021) discussed the first small-scale soil erosion mapping based on geographical dispersion with the view of actual data and questioning other research on the average yearly soil erosion across the nation. According to the estimates of anticipated soil loss, research calculated that the actions of humans and climate change are not regulated. The portions of the land surface that have lost topsoil would reach 13.14% in 2100 years, or roughly 9.88%, at 80 Mg. (Belay & Mengistu, 2021) assessed soil degradation in the Muga watershed in the eastern Blue Nile Basinin light of ancient and anticipated weather modification and LULC denotes Land Use and Land Cover. The outcome of the research could assist with developing appropriate land use management and investment strategies to lessen the negative impact of LULC on soil loss. Furthermore, to attempt to diminish the detrimental effects of the changing climate on soil loss, strong, appropriate conservation policies and expenditures are required. Climate variation will also make the current soil erosion problem worse. (Masroor et al., 2022) examined the connection between erosion of soil and scarcity in the central sub-basins of the river Godavari in India. Nonetheless, significant differences were noted in the spatial correlation dispersion. Among other factors, it was found that slope length and elevation were the key factors of eroded soil in the sub-basins. Therefore, the research recommends legislative measures to moderate the properties of eroded soil and drought. (Li et al., 2022) determined by the mainland administration and climate factors affecting historical geographical variations in the rate of erosion on the Chinese Loess Plateau from 1901 to 2016. The research is exclusively on the longitudinal and sequential trends of erosion, without specifically evaluating the long-term effects of several land management performances on sand health. According to the research, erosion rates increased dramatically between the 1930s and the 1970s then declined until recently, rising again around 2010 and 2016, mostly due to heavy rains. The analysis of climate change and rainfall intensity of soil erosion is divided into various categories are represented in Figure 1.

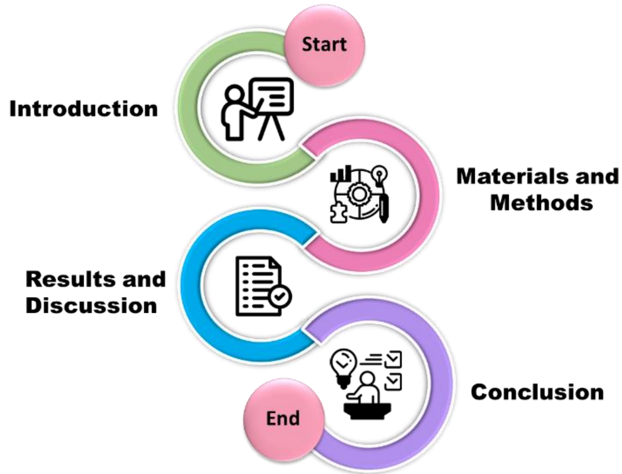

Figure 1. Schematic representation of the flow of the analysis

Material and Methods

Soil erosion is the main factor that is affected by rainfall length and weather change. This can be analyzed with lands of three different locations and five soil samples were incorporated in the research. The data are obtained from satellite remote sensing data, which is used to evaluate erosion rate and intensity of rainfall. Statistical analysis was used with the help of the SPSS tool to examine the meteorological condition and effect of rainfall.

Research Area

The analysis contains 79 plots spread throughout three different locations, each with its specified climate. These areas were chosen to record a wide variety of climatic variances, such as variations in rainfall patterns, humidity, and temperature. The research area, which is around 120 square kilometers in size, is located in the area that lies between a semi-arid dry environment and a semi-humid tropical climate. Loess deposits created the yellow-brown soils that makeup all soils in the research area. About 58% soil (50–2000 μm), 30% sediment (2–50 μm), and 12% mud (less than 2 μm) make up the average soil composition. The greater percentage of sand in this soil texture is a major factor in the soil's vulnerability to deterioration, which is further impacted by the climate and amount of rainfall in the area. The research area's land cover modifications were observed with satellite remote sensing information, and the consequences of high rainfall events on eroded soil were examined using automated rain gauges. These techniques provide light on the connection between extreme weather events and the gradual deterioration of land.

Data Collection

The method of data collection involved taking five replicate soil samples from each plot to measure the erosion rate and monitoring the rainfall intensity and duration using automated rain gauges. Table 1 shows chemical constituents affecting soil erosion in five different soil samples, emphasizing as pH values and biological carbon content with the additional levels of calcium, magnesium, phosphorus, nitrogen, and potassium. These factors affect the soil's stability, as well as its erosion patterns. For example, having a strong structure in the soil can reduce the risk of erosion. This occurs when there are balanced ratios of essential nutrients, like phosphorus and nitrogen, and greater organic carbon. Lower soil organic matter and imbalanced nutrient levels increase the possibility of decomposition, particularly under heavy rains.

Table 1. Impact of Soil Chemicals on Erosion Processes under Climatic Change

Sample ID	pH Level	Organic Carbon (%)	Nitrogen (N, %)	Phosphorus (P, ppm)	Potassium (K, ppm)	Calcium (Ca, ppm)	Magnesium (Mg, ppm)
1	6.5	1.2	0.15	10	250	1500	300
2	5.8	0.8	0.18	8	210	1400	280
3	7.0	1.5	0.20	12	260	1550	320
4	6.2	1.0	0.12	9	230	1450	310
5	5.5	0.7	0.10	7	200	1300	270

Rainfall Erosivity (R factor): Duration and intensity of rainfall could be estimated over time from satellite data obtained through remote sensing such as Moderate Resolution Imaging Spectroradiometer (MODIS) or Tropical Rainfall Measuring Mission (TRMM), which are crucial to calculate the rainfall contributing to soil erosion. Calculating the R factor in such a large area is crucial, and Equation (1) can be used to express this data.

$$Q = \sum(O_j \times J_j) \tag{1}$$

Where O_j is the amount of rainfall in millimeters for storm$j$.For the j^{th} storm,$J_j$is theintensity of rainfall in mm/h.

Soil Erodibility (K factor): K factor or soil corrosion susceptibility is computed by monitoring satellite images like Landsat or Sentinel, mapping them into the terrain, plant coverage, and soil characteristics shown in Equation (2).

$$L = \frac{1}{3}\left(\frac{12 \times (1-n) \times T}{D}\right) \tag{2}$$

Where n is the fraction of soil silt. T is a measure of the soil's structure, which is determined by how resistant it is to erosion. D is the soil's cohesion factor or organic matter content.

Vegetation Cover (C factor): Satellite data from sources such as MODIS or Landsat's Normalized Difference Vegetation Index (NDVI) is used to evaluate soil protection by plant density and its effect on soil erosion rate can be displayed as Equation (3).

$$D = \frac{B_{bare}}{B_{total}} \tag{3}$$

Whereas an area of bare soil that is subject to rainfall is called B_{bare}. $B_{total}$is the total plots of the whole region under investigation.

Topographic Factor (LS factor): Topographic information such as slope and aspect is provided by Digital Elevation Models (DEMs) produced by satellites. Such an aspect is critical to obtaining the LS factor and understanding how topography modulates erosion, which could be analyzed by Equation (4).

$$KT = \left(\frac{K}{22.1}\right)^n \times (sin\theta)^m \tag{4}$$

Where K stands for slope dimension in meters, $\theta$is an angle of gradient in degrees, and Exponent values are denoted by$n$ = 0.5 and m = 1.3.

Influence factors: The key factors that influence soil erosion are rainfall intensity, rainfall length, climatic variability, soil type, land use or land cover, vegetation coverage, and human activity. Rainfall intensity and length will be independent variables that directly affect the dependent variable soil erosion rates.

Climatic variability as an independent variable contributes towards erosion based on the change in the patterns of precipitation as well as temperature. Soil type, which is another independent variable, will help to decide the susceptibility of soil erosion due to the varying texture and structure. The independent variables of land and vegetation cover will either keep the soil protected or expose it to the erosive forces of nature. Human activity, as a general term that covers deforestation and poor land management, is considered to play a significant role as independent variables in combination with erosion rates as the dependent variable. Highlighting the crucial influence of both natural and human-induced factors on the dynamics of soil erosion.

Statistical analysis

The research applied statistical analysis using IBM SPSS software (version 27.0) to assess the properties of climate change and the intensity of rainfall on soil erosion. The properties of rainfall length, intensity, and variability on soil erosion were investigated using multiple regression analysis. The degree of the associations between rainfall intensity and erosion rate was determined using correlation analysis. ANOVA evaluates any of the meteorological condition differences that had significant effects on erosion rates, properties of rainfall-induced and climate-induced changes on soil corrosion dynamics.

Results and Findings

IBM SPSS software version 27.0 statistical package is used to analyze results from the research, which was directed towards establishing the impact of rainfall intensity, duration, and climate variability on soil erosion rates, especially by using multiple regression analysis to investigate relationships between input variables and climatic parameters associated with erosion. Finally, correlation analysis was utilized to determine the direction and magnitude of relationships between erosion rates and rainfall intensity. ANOVA was also performed to identify any difference in erosion rates among various weather conditions.

Impact of weather change and rainfall intensity calculation using ANOVA

The ANOVA outcome with the meteorological factors, such as rainfall duration, intensity, and climatic variability, significantly affects soil erosion rates. Table 2 shows the situations meteorologically produced an F-value of 7.12, a Sum of Squares (SS) of 150.12, and a p-value of 0.002 that indicated highly statistically significant effects on erosion. Rainfall length was produced with an F-value of 10.28, a p-value of 0.004, and an SS of 72.89, indicating a strong bearing. Rainfall intensity recorded an SS of 115.65 with an F-value of 15.60 and was found to have a highly significant effect (p-value of 0.001). Similarly, climatic variability showed a significant effect with an SS of 60.32, F-value, of 8.14, and p-value, of 0.003. Moreover, the erosion rate factor also analyzed in two categories showed significant differences with an F- value of 6.70, SS of 95.46, and a p-value of 0.001. As a result, every factor involved seemed to give rise to statistically significant effects on soil erosion.

Table 2. Statistical analysis of the effect of rainfall and climatic variation on soil erosion dynamics

Source of Variation	SS	Degrees of Freedom (df)	Mean Square (MS)	F-value	p-value
Meteorological Situations	150.12	3	50.04	7.12	0.002
Rainfall Length	72.89	1	72.89	10.28	0.004
Rainfall Intensity	115.65	1	115.65	15.60	0.001
Climatic Variability	60.32	1	60.32	8.14	0.003
Erosion Rate	95.46	2	47.73	6.70	0.001

Multiple Regression Analysis

Multiple regression analysis regarding the climatic variability and rainfall intensity on soil erosion revealed that the regression model was found statistically significant, also having F=8.34 and p=0.001 show that a large amount of the variance in corresponding soil erosion rates would be explained by the independent factors. Among these individual factors, Rainfall Length (RL) proved to be significantly and positively influential on erosion rates (F=10.67, p=0.003), followed by Rainfall Intensity (RI), which also demonstrated a strong association (F=12.56, p=0.002). Climatic Variability (CV) was another significant predictor (F = 6.02, p = 0.016) whereas Soil Type (ST) exhibited a marginally significant effect (F = 4.00, p = 0.05). Thus, it revealed the verified results of the high involvement of rainfall and climatic characteristics on soil erosion dynamics, which proved to have a robust model fit for most of the explained variations shows in table 3.

Table 3. Source of Variation and Statistical Significance of Factors Influencing Soil Erosion Dynamics

Factors	SS	df	$MeanSquare$	F-value	p-value
Regression (Method)	250.65	4	62.66	8.34	0.001
Rainfall Length (RL)	80.35	1	80.35	10.67	0.003
Rainfall Intensity (RI)	95.20	1	95.20	12.56	0.002
Climatic Variability (CV)	45.10	1	45.10	6.02	0.016
Soil Type (ST)	30.00	1	30.00	4.00	0.05

Correlation Analysis

A correlation matrix is a tool to evaluate several variables in terms of the strength of their relationship by providing a correlation coefficient between each pair of variables. In the research, the application of the matrix correlated the power and direction of the connection between soil erosion rates and factors of climatic dimensions like rainfall intensity, rainfall length and climatic variability. It is noted that those parameters under consideration include values for rainfall intensity, rainfall length, variations in climate, and erosion rates. The correlation results strongly demonstrate a positive correlation between rainfall intensity and soil erosion rates, which implies that with the increase in rainfall intensity, the soil erosion increase. Rainfall length and climate variability also had strong positive correlation values with soil erosion, indicating that higher amounts of rainfall and fluctuating weather conditions could facilitate the processes of soil erosion as presented in Figure 2.

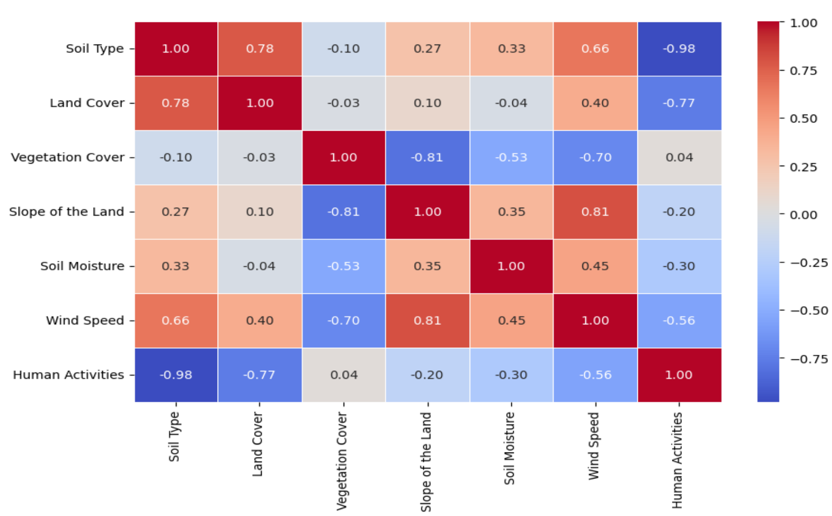

Figure 2. Correlation Analysis of Rainfall Intensity, Climatic Variability, and Soil Erosion Dynamics

Discussion

The result of multiple regression and ANOVA is referred to the outcome of rainfall and climactic variation concerning soil erosion. The ANOVA results confirm meteorological factors statistically affect the intensity, duration, and variability of rainfall on soil erosion levels (p=0.001). Further corroboration is lent to these observations by the multiple regression analysis, which confirms that rainfall duration, intensity, and climatic variability are all important indicators of soil erosion, rainfall duration being the most significant (p = 0.003). These results emphasize the important function played by climatic variables for soil erosion, particularly in environments undergoing climatic transitions and unpredictable patterns of rainfall. The implications of these findings indicate that successful soil conservation from erosion in highly vulnerable areas is due to shifting climates. However, depending entirely on data from three different regions is likely to limit the scope of the research and its prospects for truly representing the diversity in climates across the world. Further, the observation with soil type was marginally relevant and could also indicate that some other factors, such as land management practices, need further consideration.

Conclusion

The implications of climate changes, rainfall length, and intensity, on soil erosion rates were assessed in the research. There were very strong relationships inferred from erosion rates and intensity of rainfall, while longer rainfalls and stronger ones are associated with erosion activities. The research provided that region-specific methods have been employed in soil erosion reduction in three areas and noted the significance of long-term monitoring of landscape changes using advanced technologies like satellite remote sensing. Chemical constituents affecting erosion in five different soil samples from different regions are recognized in the research. Multiple regression and correlation analyses were carried out to measure the association of rainfall duration and intensity with the dynamics of soil erosion. Restricting the geographic extent of the research area has always been important in generating results that are representative of global soil erosion variability, while it could ignore some regional environmental aspects. Future research should factor in finer-scale environmental parameters in other locations and focus on long-term climatic effects on erosion rates.

References

Abioghlia, H. (2016). Numerical Analysis of Reinforced Soil Walls with Finite Element Method. *International Academic Journal of Science and Engineering*, *3*(3), 70-76.

Alsafadi, K., Bi, S., Abdo, H. G., Al Sayah, M. J., Ratonyi, T., Harsanyi, E., & Mohammed, S. (2024). Spatial–temporal dynamic impact of changes in rainfall erosivity and vegetation coverage on soil erosion in the Eastern Mediterranean. *Environmental Science and Pollution Research*, *31*(28), 40511-40529. https://doi.org/10.1007/s11356-022-24012-6

Behailu, G., Ayal, D. Y., Zeleke, T. T., Ture, K., & Bantider, A. (2021). Comparative analysis of meteorological records of climate variability and farmers' perceptions in sekota woreda, Ethiopia. *Climate Services*, *23*, 100239. https://doi.org/10.1016/j.cliser.2021.100239

Belay, T., & Mengistu, D. A. (2021). Impacts of land use/land cover and climate changes on soil erosion in Muga watershed, Upper Blue Nile basin (Abay), Ethiopia. *Ecological Processes*, *10*, 1-23. https://doi.org/10.1186/s13717-021-00339-9

Bezak, N., Mikoš, M., Borrelli, P., Alewell, C., Alvarez, P., Anache, J. A. A., ... & Panagos, P. (2021). Soil erosion modelling: A bibliometric analysis. *Environmental research*, *197*, 111087. https://doi.org/10.1016/j.envres.2021.111087

Borrelli, P., Panagos, P., Alewell, C., Ballabio, C., de Oliveira Fagundes, H., Haregeweyn, N., ... & Robinson, D. A. (2023). Policy implications of multiple concurrent soil erosion processes in European farmland. *Nature Sustainability*, *6*(1), 103-112. https://doi.org/10.1038/s41893-022-00988-4

Doulabian, S., Toosi, A. S., Calbimonte, G. Doulabian, S., Toosi, A. S., Calbimonte, G. H., Tousi, E. G., & Alaghmand, S. (2021). Projected climate change impacts on soil erosion over Iran. *Journal of Hydrology*, *598*, 126432. https://doi.org/10.1016/j.jhydrol.2021.126432

Du, X., Jian, J., Du, C., & Stewart, R. D. (2022). Conservation management decreases surface runoff and soil erosion. *International soil and water conservation research*, *10*(2), 188-196. https://doi.org/10.1016/j.iswcr.2021.08.001

He, X., Miao, Z., Wang, Y., Yang, L., & Zhang, Z. (2024). Response of soil erosion to climate change and vegetation restoration in the Ganjiang River Basin, China. *Ecological Indicators*, *158*, 111429. https://doi.org/10.1016/j.ecolind.2023.111429

Jin, F., Yang, W., Fu, J., & Li, Z. (2021). Effects of vegetation and climate on the changes of soil erosion in the Loess Plateau of China. *Science of the Total Environment*, *773*, 145514. https://doi.org/10.1016/j.scitotenv.2021.145514

Li, P., Chen, J., Zhao, G., Holden, J., Liu, B., Chan, F. K. S., ... & Mu, X. (2022). Determining the drivers and rates of soil erosion on the Loess Plateau since 1901. *Science of the Total Environment*, *823*, 153674. https://doi.org/10.1016/j.scitotenv.2022.153674

Ma, X., Zhao, C., & Zhu, J. (2021). Aggravated risk of soil erosion with global warming–A global meta-analysis. *Catena*, *200*, 105129. https://doi.org/10.1016/j.catena.2020.105129

Mahdiraji, E. A., & Ramezani, N. (2016). The Influences of Soil Ionization in the Grounding System and Corona Phenomena on the Injection Lightning Current of 1000 KV UHV Transmission Line. *International Academic Journal of Science and Technology*, *3*(9), 1-12. https://doi.org/10.9756/IAJSE/V6I1/1910004

Martey, E., & Kuwornu, J. K. (2021). Perceptions of climate variability and soil fertility management choices among smallholder farmers in northern Ghana. *Ecological Economics*, *180*, 106870. https://doi.org/10.1016/j.ecolecon.2020.106870

Masroor, M., Sajjad, H., Rehman, S., Singh, R., Rahaman, M. H., Sahana, M., ... & Avtar, R. (2022). Analysing the relationship between drought and soil erosion using vegetation health index and RUSLE models in Godavari middle sub-basin, India. *Geoscience Frontiers*, *13*(2), 101312. https://doi.org/10.1016/j.gsf.2021.101312

Pal, S. C., Chakrabortty, R., Roy, P., Chowdhuri, I., Das, B., Saha, A., & Shit, M. (2021). Changing climate and land use of 21st century influences soil erosion in India. *Gondwana Research*, *94*, 164-185. https://doi.org/10.1016/j.gr.2021.02.021

Radmanovic, S., Djordjević, A., & Nikolić, N. (2018). Humus composition of rendzina soils in different environmental conditions of Serbia. *Archives for Technical Sciences*, (19), 57-64. http://dx.doi.org/10.7251/afts.2018.1019.057R

Saidova, K., Abdullayeva, S., Yakubova, D., Gudalov, M., Abdurahmonova, K., Khudoykulova, H., ... & Zokirov, K. (2024). Assessing the Economic Benefits of Climate Change Mitigation and Adoption Strategies for Aquatic Ecosystem. https://doi.org/10.70102/IJARES/V4S1/4

Senanayake, S., Pradhan, B., Huete, A., & Brennan, J. (2022). Spatial modeling of soil erosion hazards and crop diversity change with rainfall variation in the Central Highlands of Sri Lanka. *Science of the Total Environment*, *806*, 150405. https://doi.org/10.1016/j.scitotenv.2021.150405

Sharipov, S., Gudalov, M., Nematov, O., Tovbaev, G., Kasimov, N., Mirzaeva, A., & Khazratqulov, K. (2024). Effects and Consequences of Climate Change on the Natural Conditions of Mirzachol District. *Natural and Engineering Sciences*, *9*(2), 257-269. https://doi.org/10.28978/nesciences.1574448

Tian, P., Tian, X., Geng, R., Zhao, G., Yang, L., Mu, X., ... & Liu, Y. (2023). Response of soil erosion to vegetation restoration and terracing on the Loess Plateau. *Catena*, *227*, 107103. https://doi.org/10.1016/j.catena.2023.107103

Zhao, J., Wang, Z., Dong, Y., Yang, Z., & Govers, G. (2022). How soil erosion and runoff are related to land use, topography and annual precipitation: Insights from a meta-analysis of erosion plots in China. *Science of the Total Environment*, *802*, 149665. https://doi.org/10.1016/j.scitotenv.2021.149665

Zhao, L., Fang, Q., Hou, R., & Wu, F. (2021). Effect of rainfall intensity and duration on soil erosion on slopes with different microrelief patterns. *Geoderma*, *396*, 115085. https://doi.org/10.1016/j.geoderma.2021.115085