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GEOSPATIAL MODELING AND REGIONAL ANALYSIS OF SOIL EROSION RISKS IN ALBANIA

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Abstract

Soil erosion poses a significant threat to Albania's environment and economy, impacting agricultural productivity, food security, public health, and infrastructure. This study conducts a regional assessment of soil erosion risks, identifying the most affected areas, underlying causes, and potential mitigation strategies. According to the World Bank, approximately 70% of Albania's land is affected by erosion, with an estimated soil loss of 20 tons per hectare per year, while only 10% remains minimally impacted. Over 60 million tons of sediment are transported to the Adriatic Sea annually, exacerbating land degradation and reducing agricultural sustainability. In regions such as Fier, where 80% of drainage systems are operational but half of the irrigation infrastructure is damaged, erosion-related flooding further deteriorates land productivity. This study integrates field measurements with geospatial analysis using the Revised Universal Soil Loss Equation (RUSLE) and Geographic Information Systems (GIS) to model erosion risks and propose effective land management strategies. The findings emphasize the urgent need for sustainable land use practices, afforestation efforts, and policy interventions to mitigate erosion and preserve soil resources for future generations.

Key words*: sustainability, soil erosion, land degradation, GIS, land management.*

INTRODUCTION

Soil erosion refers to the detachment, transport, and deposition of soil particles caused by both natural and anthropogenic factors (Nan, Q.J., 2003). Accelerated erosion, which results from deforestation, overgrazing (Yassoglou et al., 1998), and inappropriate agricultural practices (Li, 2008), has been widely documented for its negative effects on soil productivity, biodiversity, and water quality (Wu et al., 2015). On a global scale, soil erosion is recognized as a major environmental issue that threatens sustainable development (Sartori et al., 2019).

To date, a large number of scientific studies on soil erosion have been published, focusing mainly on its impact on agricultural production (Lal, 1998), environmental quality, and ecosystem health (Pimentel, 1998; Duran et al., 2008), as well as comprehensive analyses of soil erosion at different research scales and regions (Wu et al., 2015). The Global Soil Partnership, led by FAO, estimates that approximately 75 billion tons of soil are eroded yearly, resulting in financial losses of up to $400 billion (GSP, 2017). This assessment of soil erosion dates back to 1993 when it was first reported by Myers (1993) and has been cited in several subsequent studies (Eswaran et al., 2001). Soil erosion has also been described as a major degradation process and identified as a key priority for action under the Soil Thematic Strategy of the European Commission (2006a; 2015).

Soil erosion, particularly topsoil loss, has been recognized as a warning sign of a global food crisis and has been recently reviewed (Kaiser, J., 2004). The challenge of feeding a growing population, with increased demand for livestock products, undoubtedly intensifies the pressure on fertile soils (Montanarella, 2015), further exacerbating the erosion problem. The Mediterranean region is especially prone to erosion due to its long dry periods followed by heavy, erosive rainfall storms, leading to significant soil loss. Erosion losses of 20-40 t/ha during storms, which may occur once every two or three years, are commonly recorded in Europe, with losses exceeding 100 t/ha during extreme events (Morgan, 1992). Albania is particularly vulnerable to soil erosion due to its heavy and prolonged rainfall throughout the year, particularly in autumn and winter, as well as its predominantly steep, hilly-mountainous terrain. This process is further accelerated by inappropriate land management (Grazhdani S. & Shumka S., 2007). Studies estimate that about 24% of the territory of Albania is affected by erosion, with annual soil losses reaching 37 t/ha (Zdruli & Lushaj, 2012).

Also, studies conducted on the sediment assessment of the Erzen and Vjosa watersheds (Kucaj, 2022; Lushaj & Kucaj, 2024) show that the river network transports more than 60 million tons of sediments each year (Laze & Kovaci, 1996).). In this study, in addition to the assessment of soil erosion with direct measurements, (at monitoring stations) the use of predictive models is necessary to assess soil loss based on the causal parameters of the studied areas. The objective of this paper was to evaluate soil erosion data collected from study areas in Albania, comparing it with soil loss estimates at measuring stations.

There are several models used to assess erosion risk, with the most widely used being the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) and its improved version, the Revised Universal Soil Loss Equation (RUSLE), developed by Renard et al. (1997). With the advancement of geospatial technologies, such as Geographic Information Systems (GIS), spatial interpolation techniques, and an ever-increasing range of environmental data, soil erosion models are playing an increasingly important role in the design and implementation of soil management and conservation strategies (Panagos et al., 2015).

MATERIALS AND METHODS

A combination of field monitoring and geospatial modeling was used to assess soil erosion risks. Field measurements were conducted through direct erosion assessments at selected monitoring stations across Albania. Albania is located in the southwestern part of the Balkan Peninsula, with most of the country covered by hills and mountains and an average altitude of 708 m. This study focuses on visible soil erosion, its assessment in specific areas (such as plots or fields), and the associated deposits (measured by the mass of eroded soil in each plot). The primary goal is to collect and use environmental data that can be applied to other studies of an environmental nature, such as biotope inventory, atmospheric pollution, water pollution, soil erosion, or soil quality. The surface erosion assessment stations in Albania are located in Kallmet (Lezha), Qafshul (Librazhd), and Vithkuq (Korca), as shown in Figure 1.

Experimental stations (4 plots at each monitoring station) with different vegetation covers, the same width between stations, and consistent variants within stations, as well as a slope of 12%, are used to measure the rate of erosion. At the end of each plot, containers are placed to collect the amount of eroded soil material for each variant. For the development of this study, we present the results of an in-depth review of the scientific literature on soil erosion modelling by colleagues. Periodic assessments and measurements of erosion in plots are valuable tools for studying its flow and erosion dynamics, as well as for comparing the relative differences between vegetation cover, land use, and agricultural practices.

The assessment is repeated three times per year, in the periods January-May, June-September, and September-December, with results calculated for the entire year. The collected sediments are weighed, dried, and converted to per-hectare values. The results are expressed in tons/ha/year. The main characteristics (pedological, chemical, organic, topographical, etc.) of the soils at the measurement sites were determined through field studies.

Geospatial analysis was performed using the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), applied using GIS tools to estimate soil loss in different regions. The impact of factors on soil surface erosion from a quantitative point of view was calculated using the Universal Soil Loss Equation (USLE), using the formula: $A = R \times K \times LS \times P \times C$

The factors influencing the erosion rate according to this model include: rainfall erosivity (R factor), soil erodibility (K factor), land cover and management practices (C factor), slope and length (LS factor), and support or conservation practices (P factor).

Land cover data in the studied areas was obtained from the Copernicus Climate Service and the State Geospatial Information Authority (ASIG). Data on rainfall amounts, as well as minimum, maximum, and average temperatures for the period 2020-2023 (IGJEO, 2024), soil moisture and its conditions, vegetation types, and other relevant factors were evaluated to measure the erosion rate.

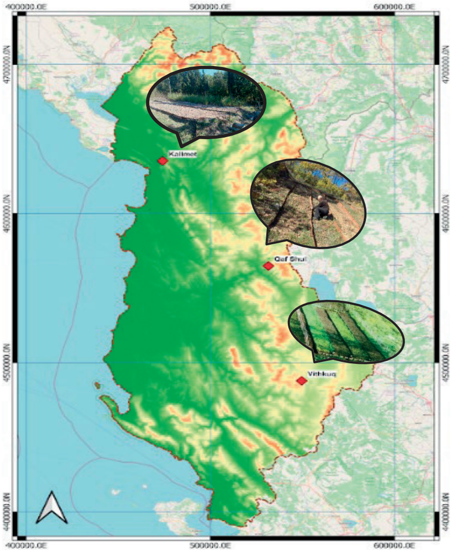


Figure 1. Monitored areas/surface erosion stations in Albania

RESULTS AND DISCUSSIONS

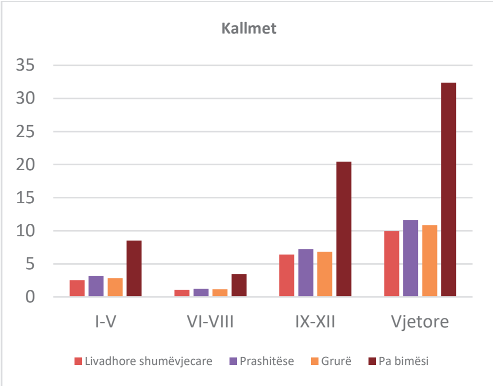
Evaluation of pedological, topographic, and climatological indicators for the monitoring station

Obtaining and evaluating soil erosion (surface erosion) results obtained at the erosion monitoring station in Kallmet-Lezha for the period 2018-2022 (Figure 2).

Figure 2. Erosion monitoring station Kallmet-Lezhë

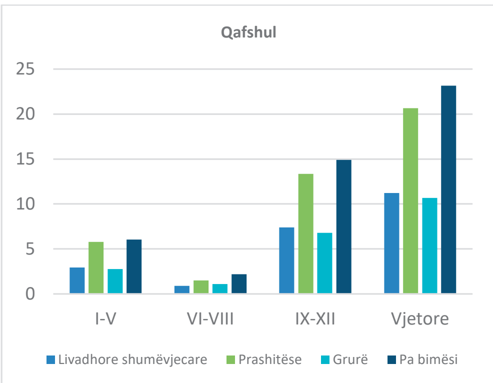
Below are graphical representations of the amount of soil eroded at the Kallmet, Qafshul, and Vithkuq erosion monitoring stations, based on data from the four plots over the five-year analysis period (2018-2022).

From the assessments and monitoring, soil loss was highest in the plot without vegetation (fallow plot), with an average of 32.4 tons/ha/year, and in the perennial meadow plot, with a loss of 9.96 tons/ha/year at the Kallmet-Lezhë station (Graph 1).



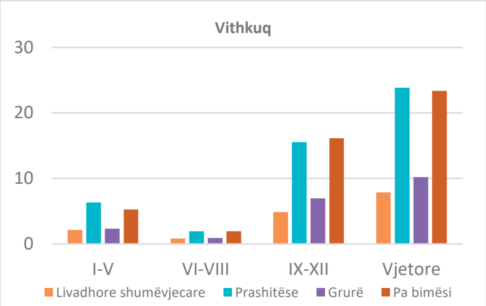
Graph 1. Graphical presentation of erosion for the Kallmet-Lezhë station for the five years 2018-2022

This monitoring point represents the areas of Lezhë, Shkodra, and the surrounding regions, extending to the vicinity of Durrës and Tirana. For the Qafshul - Librazhd station (Graph 2), soil loss was highest in the plot without vegetation, with an average of 23.14 tons/ha/year, followed by the fallow plot, with an average of 20.64 tons/ha/year.



Graph 2. Graphical presentation of erosion for the Qafshul station for the five years 2018-2022

This monitoring point represents the areas of Librazhd, Elbasan, and the surrounding regions, extending to the vicinity of Prrenjas and Burrel.



Graph 3. Graphical presentation of erosion for the Vithkuq-Korça station for the five years 2018-2022

From the assessments and monitoring conducted at the Vithkuq-Korçë station (Graph 3), soil loss was highest in the fallow plot, with an average of 23.84 tons/ha/year, followed by the plot without vegetation, with an average of 23.36 tons/ha/year. The perennial meadow plot had a loss of 7.88 tons/ha/year. This monitoring point represents the areas of Korçë, Voskopoja, and Erseka. The Kallmet study area, located in the Lezhë district, lies below the Vela mountain range in the Shkodër-Lezha plain, also known as Zadrima. Due to its geographical location and predominantly low relief, Lezhë experiences a mild Mediterranean climate. This climate is characterized by hot and dry summers and mild, wet winters in the lowlands and city areas, while the mountainous regions experience wet and cold winters. The average annual temperature for the district is 15°C, with January averaging around 7°C and July reaching 24-25°C. The average annual rainfall is between 1500-2000 mm (Climatic Bulletin, IGJEO, 2023). The average number of days with rainfall above 10 mm varies between 45 and 50 days. The soils are shallow, consisting of Cambisols and Gleysols textures.

Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) measures the erosive force of rainfall and runoff. Rainfall of mild intensity may cause minimal erosion, while heavy annual rainfall can result in significant soil loss. The R factor is estimated by considering the erosive effects of storms and plays a crucial role in calculating soil loss. The rainfall erosivity factor (R) is determined using the following equation:

$$R = I_{30}\,(9.28P - 83.83)/1000$$

where:

I30 = 75 mm/hour (Wischmeier & Smith, 1978).

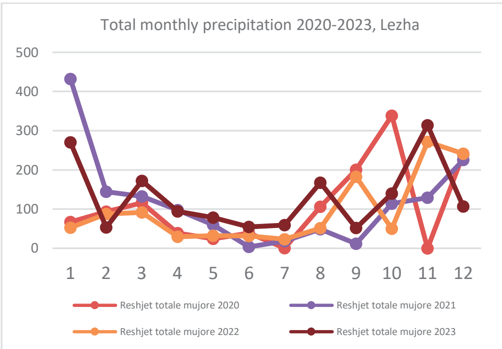
P is the average annual precipitation (in mm) over the past few years.

The "R" factor is the most important element of the Universal Soil Loss Equation. This factor, which largely determines the potential risk of soil erosion, is primarily influenced by the intensity and duration of precipitation. The latest annual precipitation data have been provided by the Institute of Geosciences.

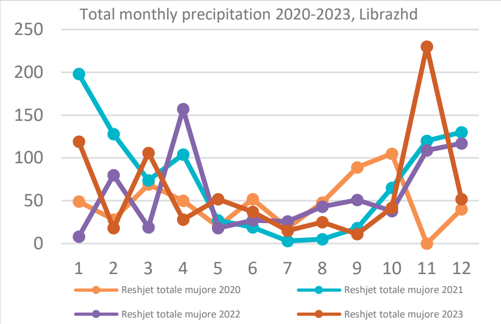
Data on total monthly precipitation for the period 2020-2023 are presented in Graphs 4-6. The calculated R factor values, shown in Table 1, demonstrate a high correlation with the average annual precipitation recorded at the meteorological stations nearest to the experimental stations.

Table 1. Value of the "R" factor

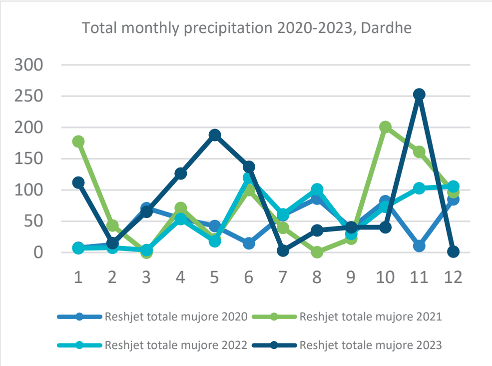
Name	Coef. R	Average precip. mm	Days with precipit.>10 mm	Days with snow
Kallmet	71.3	1346.1	35-45	0-5
Vithkuq	40.1	800.4	25-45	> 100
Qaf-Shul	35.6	721.9	45-55	> 100



Graph 4. Total monthly precipitation for the period 2020-2023 for the Lezhë study area



Graph 5. Total monthly precipitation for the period 2020-2023 for the Librazhd study area



Graph 6. Total monthly rainfall for the period 2020-2023 for the Dardhe study area

Soil erodibility factor (K)

The soil erosion factor (K) is the degree of susceptibility of soil particles to erosion per unit of the rainfall erosivity factor (R). K factor values (Foster et al., 1981) were calculated using the pedological values of the soils from the study area taken as part of the assessment of this factor, using the following equation:

$$100\ K = 2.8 * 10 - M1.14\ (12 - OM) + 4.3 * 10 - 3\ (S - 2) + 3.3 * 10 - 3\ (P - 3)$$

To assess the impact of soil composition on erosion, as the value of the "K" factor in the Universal Soil Loss Equation, data on the particle size composition of the soils of the monitored areas were used. The K factor values calculated for each soil type indicate that Cambisol soil is more fragile due to its high clay content, and less sensitive to water detachment and transfer, as shown in Table 2.

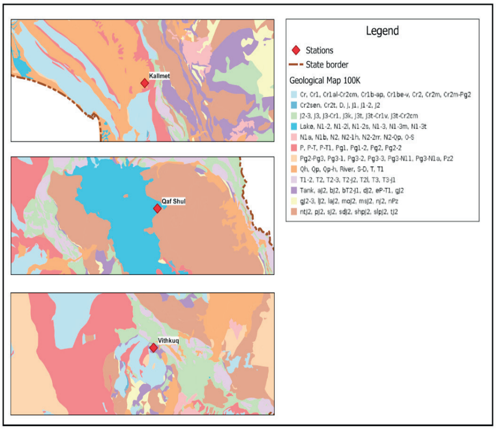


Figure 3. Geological age map of the study areas

Table 2. Value of the "K" factor and some ground indicators at the experimental stations

Experimental Areas	Texture in %			Soil Erosion Class	Coef. K
	Sand	*Silt*	*Clay*		
Lezhë (Kallmet)	46.5	27.6	25.9	2 (medium sensitivity)	0.35
Librazhd (Qaf-Shul)	45.8	28.4	25.8	2 (medium sensitivity)	0.32
Korçë (Vithkuq)	47.28	26.48	26.24	2 (medium sensitivity)	0.38

Topographic Factor Determining the influence of slope and length of steep slope ("LS" Factor)

The slope length factor LS is calculated using the following equation:

$$LS = (0.065 + 0.0456*\lambda + 0.0065 *\lambda^2\ (\lambda/22.1)^{0.5}$$

Based on our assessments, the study areas were classified into 10 different elevation and slope classes, ranging from 0 to 84.21. The dominant elevation values are represented by the first four classes, as 80% of the study areas have a slope of up to 20 degrees. The LS factor map shows that the maximum LS factor values occur in the steepest areas, close to watercourses (Figure 4). Data on LS factor values for the erosion monitoring areas are presented in Table 3.

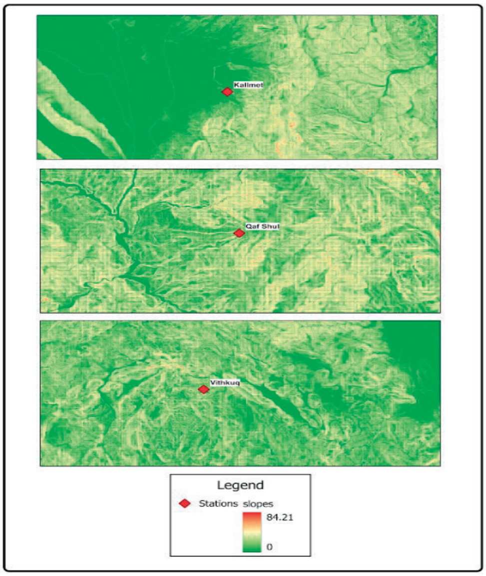


Figure 4. Map of LS Slope in the study areas

Table 3. “LS” factor values

Monitoring areas	Slope length x (m)	Slope S (%)	LS Factor
Kallmet	10	9	0,527
Qaf-Shul	10	30	5,011
Vithkuq	10	20	1,152

Determining the impact of vegetation cover (factor “C”)

Factor C is calculated based on the equation:

$$C= A/R \times K \times LS \times P$$

Starting with the erosion values measured in the monitored areas, we calculated the effect of plant cover on erosion by comparing the amount of soil eroded in a vegetated area to the soil eroded in unplanted land (considered as 1 unit). This ratio is used to calculate the “C” factor in the Universal Soil Loss Equation (U.S.L.E.). The data obtained from these calculations are presented in Table 4.

Table 4. Value of the factor “C”

Name	Kallmet	Qaf-Shul	Vithkuq	Averadge
Plot planted with meadow (Alpha-alpha) alpha	0.36	0.37	0.42	0.38
Plot planted with wheat	0.64	0.41	0.46	0.51
Plot planted with corn	1.20	1.22	0.92	1.13
Plot without vegetation (fallow)	1.00	1.00	1.00	1.00

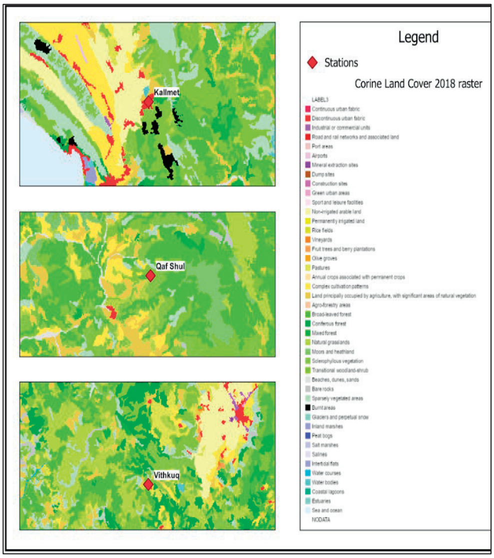


Figure 5. Land cover map in the study areas

For all plots planted with meadow vegetation, the soil receives almost the same level of protection. Planting with crops also provides excellent protection. The protective ability in the eastern and southern mountainous regions, where winter precipitation is mainly in the form of snow, is significantly higher than in the coastal lowland regions, where precipitation during the autumn-winter period is more intense and primarily in the form of rain.

Table 4 shows the influence of plant cover factors for each area. Autumn precipitation, which coincides with the early stages of plant development, affects the coefficient values of these plants in the regions mentioned above (Figure 5).

Assessment of potential soil erosion risk according to the “Corine” method

To estimate soil loss, data for each rainfall event that caused erosion during the period 2018-2022, obtained from measurements in the study area, were used. They were compared with the corresponding erosion values, using basic statistics and indices based on statistical estimates. This method helped create a detailed and reliable assessment of erosion risk for each study area.

Soil erodibility index

Soil erodibility refers to the susceptibility of soil to erosion. Based on the chosen methodology, the erodibility index (EI) is calculated with the following formula:

IE (Erodibility Index) = Texture x Depth x Rock Content

Soil texture is divided into 12 groups and classified according to the size of the soil particle diameter, which is further divided into fractions based on the proportion they occupy in the total soil composition. Soils with particles smaller than 0.002 mm are classified as Clay (C), those with a diameter between 0.002 and 0.05 mm are classified as Silt (S), and those with particles ranging from 0.05 to 2.00 mm are classified as Sand (S). The determination of soil texture is made using the American Soil Triangle, where each side of the triangle represents a specific soil texture.

In the Kallmet area, soils with a sandy-silty texture dominate. Soil depth was estimated by analyzing the depth of the soil profile (from the surface to the parent material). Soils with a depth of up to 25 cm are highly susceptible to erosion, while those with a depth ranging from 25 cm to 75 cm have a medium sensitivity to erosion. The Kallmet study area has a soil profile depth of 68 cm, classifying it as having medium erosion sensitivity. The content of stones is another factor, estimated based on the percentage of the soil surface covered by stones. This is classified into two levels: up to 10% and over 10%. Based on this, the soil sensitivity to water erosion is assessed in two classes.

The resulting Soil Erodibility Index falls within the range of > 0 to 3, indicating low sensitivity.

Soil Erosivity Index

Erosivity is a second element for determining the potential risk of soil erosion. This index is a result of climatic conditions, where rainfall intensity is considered the main determinant of erosivity and as a consequence of the use of the USLE method.

Erosivity Index = Fournier Index x Bagnouls-Gaussen Index

The Fournier Index (FI) is an analysis of total monthly and average annual precipitation and is expressed in the formula:

$$FI = \sum (P_i^2 / P_{annual})$$

Data on total monthly and average annual precipitation for the period 2020-2023, used to estimate the Fournier Index for the Albanian territory, were provided by the Institute of Geosciences, Department of Meteorology. The result falls within the FI limits of 60-90, indicating low sensitivity to erosion. To further strengthen the assessment of erosivity, the Bagnouls-Gaussen Drought Index (BGI) is also used. This index considers not only precipitation but also the average monthly temperatures. It is expressed by the following formula:

$$BGI=\sum(2T-P) *K$$

The Bagnouls-Gaussen index values for the Kallmet area survey are described as "dry".

Slope steepness index

The topographic factor is the third element in determining the potential risk of surface soil erosion. In the USLE methodology, this factor reflects the influence of slope angle and length, with the rate of soil erosion increasing as slope steepness increases, while the volume of erosion grows with slope length.

The slope angle, expressed as a percentage, ranges from 5% to 15%, indicating a mild level of erosion risk.

Land cover index

This index is considered one of the most important elements in erosion modeling, as it is the only factor on which humans have a direct influence. Table 5 shows the ratio of land cover to erosion, a ratio that was used in the project methodology according to the corresponding index.

Table 5. Vegetation cover assessed according to erosion sensitivity

Name	**Erosion**	**Type of vegetation cover**
Plot planted with meadow (Alpha-Alpha)	Full protection	Meadow, dense protective vegetation
Wheat plot	Partial protection	Wheat, medium impact cover
Corn plot	Partial protection	Corn, medium impact cover
Plot without vegetation (fallow)	Unprotected	Cultivated land, bare land

In this table, "Partial protection" is used for plots planted with wheat and corn, as these plants do not provide complete protection against erosion, but can affect its reduction to a certain extent. For the plot without vegetation (fallow plot), the category "Unprotected" is assigned, as this land is bare and has a high risk of erosion.

CONCLUSIONS

Integrating field data with geospatial modeling provides a comprehensive approach to identifying high-risk areas and developing targeted soil conservation strategies. The study on soil loss from erosion at three stations over the period 2018-2022 reveals the following findings:

1. The level of erosion shows significant differences between types of vegetation cover, seasonal periods, and terrain. Specifically, at the Vithkuq station, during the September-December period, soil loss in the variant without vegetation cover is 16.14 tons/ha/year, accounting for 37% of the annual soil loss.
2. At the same stations, in the same period, soil loss in the variant with perennial meadows is 6.4 tons/ha/year, representing 35.7% of the annual soil loss.
3. In the September-December period, soil loss in the variant with vegetation plants is 7.22 tons/ha/year, or 37.9% of the annual soil loss.
4. Similarly, during the September-December period, soil loss in the variant with wheat plants is 6.81 tons/ha/year, or 36.9% of the annual soil loss.

Using the USLE and CORINE models, soil loss was estimated for the study areas in Kallmet, Albania. The most critical months for four main land use categories were also identified. The quantitative results (t/ha) helped determine the most vulnerable sites, critical periods, and the impact of land use on erosion. Based on the implementation of these models, soil loss in the study areas, depending on vegetation cover, was found to be moderate for wheat and corn cover, high in areas without vegetation cover, and relatively lower in areas with perennial vegetation cover. Regarding erosion monitoring in the study areas, assessments were conducted every 3-4 months over the 5-year study period from January 2018 to December 2022. These data revealed that the risk of erosion ranged from moderately high to high across the study areas. In nearly all four plots at the monitoring stations, significant erosion-related problems were encountered, with recent years showing a more dominant emergence of this phenomenon due to changing climatic conditions.

The USLE and CORINE models proved to be highly adaptable, effectively integrating alternative model-supported algorithms with the available datasets. They also demonstrated their efficiency in this study by providing all the expected results in a clear, systematic, and consistent manner. Key recommendations include implementing sustainable soil management practices, such as encouraging the use of cover crops and improved tillage techniques to reduce soil loss. Strengthening erosion control infrastructure, including the enhancement of irrigation and drainage systems, is also essential. Additionally, reinforcing national soil conservation policies and promoting incentives for sustainable agricultural practices are crucial steps. Finally, establishing long-term monitoring stations and advancing GIS-based erosion models will improve risk assessments and mitigation strategies.

REFERENCES

Copernicus program, Global Land Service, http://land.copernicus.eu/global/products/FCover (last accessed: March 2015).

Durán Zuazo, V.H., & Rodríguez Pleguezuelo, C.R. (2008). Soil erosion and runoff prevention by plant covers: A review. Agronomy for Sustainable Development, 2*8*, 65–86.

European Union (COM2012 46 final), http://ec.europa.eu/environment/soil/three_en.htm (last accessed: March 2015).

Eswaran, H., Lal, R., & Reich, P. F. (2001). In Responses to Land Degradation (Eds. Bridges, E. M. et al.), 20–35. Oxford Press, New Delhi.

Foster, G.R., & Meyer, L.D. (1981). A closed-form soil erosion equation for upland areas. In: H.W. Sten (Ed.), Sedimentation symposium in honor of Prof. H.A. Einstein (pp. 12.1–12.19). Fort Collins, CO: Colorado State University.

Grazhdani, S., & Shumka, S. (2007). An approach to mapping soil erosion by water with application to Albania. *Desalination, 213*(1-3), 263–272.

GSP. (2017). Global Soil Partnership endorses guidelines on sustainable soil management. Retrieved from http://www.fao.org/global-soil-partnership/resources/highlights/detail/en/c/416516/.

IGJEO. (2024). Instituti Gjeoshkencave, 2020-2021, Buletini Mujor Klimatik mbi te dhena meteorologjike.

Kaiser, J. (2004). Wounding Earth's fragile skin. Science, 304, 1616–1618.

Kucaj, E. (2022). Rehabilitation technology for the protection of the Erzen River from erosion. TOENA Publications, Tirana. ISBN: 978 9928 376 28 2.

Lal, R. (1998). Soil erosion impact on agronomic productivity and environment quality. *Critical Reviews in Plant Sciences, 17*, 319–464.

Laze, P., & Kovaci, V. (1996). Soil erosion and physico-chemical nature of eroded materials. 9th Conference of the International Soil Conservation Organization (ISCO), Bonn, Germany. Extended Abstracts.

Li, Z.B., Zhu, B.B., & Li, P. (2008). Advancement in study on soil erosion and soil and water conservation. *Acta Pedologica Sinica, 45*, 802–809.

Lushaj, S., & Kucaj, E. (2024). Soil erosion in the Vjosa River watershed in Albania: Problems and protective measures. E3S Conferences ICED2024, 585, 09004. https://doi.org/10.1051/e3sconf/202458509004.

Montanarella, L. (2015). Agricultural policy: Govern our soils. Nature, 528, 32–33.

Montanarella, L., et al. (2015). The world's soils are under threat. Soil, 2, 1263–1272.

Montgomery, D. R. (2007). Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences USA, 104, 13268–13272.

Morgan, R.P.C. (1992). Soil erosion in the Northern Countries of the European Community. EIW Workshop: Elaboration of a Framework of a Code of Good Agricultural Practices, Brussels, 21-22 May 1992.

Myers, N. (1993). Gaia: An atlas of planet management. Journal of Academic Librarianship, 19, 200.

Nan, Q.J., & Hua, L. (2003). Recent progress of soil erosion in the world. Journal of Capital Normal University, 2, 86–95. (In Chinese).

Panagos, P., Karydas, C. G., Borrelli, P., Ballabio, B., & Meusburger, K. (2014). Advances in soil erosion modeling through remote sensing data availability at European scale. Proceedings of SPIE, 9229, 92290I.

Pimentel, D., & Kounang, N. (1998). Ecology of soil erosion in ecosystems. Ecosystems, 1, 416–426.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE) (Agricultural Handbook 703) (p. 404). Washington, DC: US Department of Agriculture.

Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L., & Panagos, P. (2019). A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. Land Use Policy, 86, 299–312.

Wischmeier, W.H., & Smith, D.D. (1978). Predicting rainfall erosion losses: A guide for conservation planning (Agriculture Handbook 537). US Department of Agriculture.

Wu, F.Q., Lin, Q.T., Lu, P., & Wang, Y. (2015). Research progress of soil erosion influence factors in sloping fields in China. Science of Soil and Water Conservation, 13, 1–11.

Yassoglou, N., Montanarella, L., Govers, G., Van Lynden, G., Jones, R.J.A., Zdruli, P., Kirkby, M., Giordano, A., Le Bissonnais, Y., Daroussin, J., & King, D. (1998). Soil erosion in Europe. European Soil.

Zdruli, P., & Lushaj, S. (2012). Problems of soil degradation and alternative control measures for soil protection in Albania. Poster presentation, Book of Abstracts. EUROSOIL2012, Bari, Italy.