Assessment of mountain soil erosion threat levels based on digital analysis

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Abstract. Soil erosion control plays an important role in preserving soil fertility and ensuring environmental sustainability. In assessing soil erosion, the use of modern technologies, especially geographic information systems (GIS) and remote sensing methods, yields significant results. This article examines the advantages of GIS technologies in identifying erosion-prone lands, their application, and their results. The study focuses on the changes in land cover and degradation processes in the mountain and submountain regions of the Tashkent region, which is situated in the western portion of the eastern Tien-Shan mountains. This region receives a lot of precipitation because of the climate. This research highlights the critical influence of terrain and precipitation on erosion rates, underscoring the necessity for modern soil conservation strategies in vulnerable areas. Dense vegetation significantly lowers the risk of erosion during heavy rainfall events. Even during intense rainfall on well-vegetated slopes, the risk of erosion can be far lower than during light rainfall conditions on poorly vegetated or barren slopes. GIS technologies help in monitoring such changes and developing effective solutions. The obtained results contribute to the development of the direction of combating erosion processes. They will also help to identify the centers of the most eroded lands in the country and outline the main anti-erosion measures to prevent them.

1 Introduction

A relevant and noticeable rise in soil erosion rates across landscapes has been caused by human activity, which also affects natural erosion processes (Poesen, 2018). The scientific community has been studying the mechanisms of soil erosion, the incidence of accelerated soil erosion, and the detrimental socio-environmental effects that result from it for more than a century [1-5]

Soil erosion is one of the main causes of soil degradation [6-10]. The term soil erosion originated in the early 20th century, and it means the loss of soil under the influence of water and wind. Later, this term was expanded by scientists and given a more accurate definition. Soil erosion refers to the erosion of the upper fertile layer of the field by wind and water [4,5].

Currently, numerous scientific studies are being conducted on the degree of soil erosion hazard and their improvement. Lal R. [3] noted erosion as the main cause of soil degradation.

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His research shows the negative impact of erosion on soil fertility and climate. Wischmeier and Smith (1978) developed a methodology for territorial analysis using the USLE (Universal Soil Loss Equation) formula for assessing soil erosion. Zhang and Li (2017) emphasize the importance of remote sensing data using GIS tools in analyzing the physical and geographical features of the Earth. Global databases and mapping methods are also widely used in global experience in land resource management by FAO (2022).

Today, worldwide research is being conducted on geoinformation analysis of erosion processes occurring in soils distributed under uneven relief conditions, focusing on several priority areas, including: developing digital methods and technologies for information analysis to determine the transition of soil mapping processes to a new stage; creating cartographic bases using various databases that increase research speed and reduce work costs in determining soil erosion hazards; improving methods for utilizing remote sensing data and aerospace imagery to obtain accurate and factual information for monitoring soil erosion processes [6-9].

The lands of mountainous areas are extremely susceptible to soil erosion due to their natural and geographical conditions. Preventing erosion in the use of land in mountainous areas of Uzbekistan is a pressing task. Modern digital technologies, including geographic information systems (GIS) and remote sensing methods, play an important role in assessing soil erosion. This research paper is dedicated to mapping the risk of erosion in mountainous areas based on digital analysis and assessing its level.

2 Study area

Eroded soils distributed in the mountainous regions of Uzbekistan, including the Parkent district, were investigated. The object of the research is the Sukoksai Basin, located in the northeastern corner of the Republic of Uzbekistan, on the western slopes of the Chatkal Range, which is the most significant formation of the Talas Alatau - the western part of the Tien Shan, one of the largest mountain systems on Earth in terms of length and height. From one of the branches of the Chatkal Range - Aktau, the Babay-Taudor branch branches off, which ends in the west with the Kyzyl-Nura uplift. The Sukoksai Basin is located between 410 13' and 410 16' north latitude and 690 48' and 690 53' east longitude. The Sukoksai Basin has the shape of a rectangle stretched from east to west [8].

Brown carbonate soils are rich in ephemeral plants, rosehips, pistachios, hawthorn, honeysuckle, and dark serozem soils are rich in walnut, almond, apricot, plum, apple, pear, cherry, and other trees. Among ephemeral plants, ziziphora and sage grow in large quantities.

3 Materials and methods

The classification of images used Google Earth Pro to analyze the study area is mountainous and ground data reference for visual interpretation. Changes in the study area were studied using additional geographic information systems using Sentinel-2 and satellite imagery, using the NDVI - Normalize Difference Vegitation Index. Landsat imagery has a spatial resolution of 30 meters. Images classified as mountainous and ground data reference for visual interpretation were analyzed using Google Earth Pro. ArcGIS ArsGIS 10.8.1 software packages and tools were used to finish the processing classification processes. As part of the data reprocessing procedures, the images' borders, coordinate system, and sub-setting were assigned according to the study area's polygon.

4 Results and discussion

This area is distinguished by the intensity of erosion processes. The Parkent district is located on the Northern slopes of the Eastern Tien-Shan mountain range, forming the eastern region of Tashkent. This study involved preparing remotely sensed land cover images for eight years (2023-2024) to suggest possible measures for the area's improvement based on land cover change. Serozems occupy the mountain slopes of the Western Chatkal ridges at an altitude of 450-700 m to 900 m above sea level in the research area, and with increasing elevation, these soils change to brown carbonate soils. As a result of research conducted in the soils of the Western Chatkal mountain system, the following subtypes of brown soils were distinguished:

- brown carbonate eroded soils
- brown typical soils
- brown decalcified soils

A characteristic feature of mountain brown soils is the carbonate content of the mineral part. The degree of carbonation and the limit of accumulation of carbonates depend on the stage of soil development. In carbonate soils, they are determined by the depth of their location on the surface, in typical and alkalized soils, and by the intensity of soil wetting by atmospheric precipitation.

Brown decalcified soils are distributed above the brown soils region, below which they change to brown typical soils, which gradually change to brown carbonate soils. The presence of soil and soil parts in different proportions makes it possible to distinguish them, and in this regard, the superiority of small-particle (fine soil) - skeletal differences is also clearly demonstrated [13].

Determining the geographical coordinates of soil profile locations using topographic and geodetic surveys. During our research, topographic and geodetic surveys were conducted to effectively determine the boundaries of soil distribution in the area, to collect qualitative, reliable, and operative information about the soil cover of the territory and the changes occurring in it. Modern GPS instruments are used in conducting topographic and geodetic surveys. GPS is the Global Positioning System, the determining element of which is based on measuring the relationship between points on the Earth's surface and the distance between them. Currently, artificial satellites of the Earth are used as intermediate points in determining the positional relationship of points on the Earth's surface, where the distance between the ground and the satellite is calculated.

The geographical coordinates of soil profiles were measured as a result of topographic and geodetic surveys (Table 1). The coordinates of soil profiles in key areas measured using a GPS device and the results of laboratory analysis of soil samples obtained from them will serve as the primary basis for characterizing erosion-prone areas of the studied region in the future. The principle behind determining coordinate points using a GPS device is based on calculating the known distance between the device and several artificial satellites.

If the distance A between an artificial satellite and the instrument is known, then the coordinates on the receiver cannot be determined, since this satellite can be located at any point on the sphere. Even if the distance between the second satellite and the receiver is V, determining the coordinates in this case will be difficult. The distance between the third satellite S reduces the uncertainty in the coordinates to two points (marked in two bold letters).

The following conventional designations are adopted in this work for the points being determined:

s - southern side;
n - northern side;
v - watershed (flat surface).

Based on the results of the topographic and geodetic work, the coordinates of the soil sections were obtained, which are given in Table 1.

Table 1. Coordinates of soil profiles in the Parkent and Zarkent regions

Number of soil sections	Geographical coordinates		Height, H (m)
	B (Lat)	B (Lat)	
s №1. brown carbonate soil	$41^0$15'12"N	$069^0$48"01'E	1201
n №2. brown carbonate soil	$41^0$15'777"N	$069^0$48'207"E	1143
v №3. brown carbonate soil	$41^0$15"802'N	$069^0$47"231'E	1157
v №4. dark serozem soil	$41^0$16"665'N	$069^0$43"488'E	906
v №5. dark serozem soil	$41^0$16"661'N	$069^0$43"421'E	909
s №6. dark serozem soil	$41^0$16"655'N	$069^0$43"513'E	904
n №7. dark serozem soil	$41^0$16"497'N	$069^0$43"937'E	898
n №8. dark serozem soil	$41^0$36"270'N	$069^0$53"937'E	756
s №9. typical serozem soil	$41^0$30"500'N	$069^0$32"54'E	711
n №10. typical serozem soil	$41^0$30"370'N	$069^0$31"31'E	702,2
n №11. typical serozem soil	$41^0$30"59'N	$069^0$31"53'E	655,06
n №12. typical serozem soil	$41^0$30"370'N	$069^0$31"31'E	693,08

This method is used to accurately measure the coordinates, since only one of the two points marked on the receiver is located on the Earth's surface or at a distance close to it, and the other is incorrect. It is located in a much deeper part of the Earth or much higher.

Therefore, for three-dimensional navigation, accurate determination of the distance from the receiver to the three satellites is theoretically correct.

One of the main tasks of geodesy is the precise determination of reference geodetic points (points) on the earth's surface, necessary for topographic surveys, taking out projects in kind and other works related to geodetic measurements on the ground. In practice, this task comes down to finding the numerical values of coordinates calculated in one or another system based on the results of field measurements. In addition to determining the coordinates of the elements of the situation, topographic large-scale plans are compiled [12].

Geodetic measurements using the Leisa System-300 GRS receiver were carried out in full daylight (from 6 a.m. to 6 p.m.), on a clear day with an average air temperature of +30°C and a light breeze.

The coordinates of soil sections determined as a result of topographic and geodetic work are presented in the table 2.

The level of erosion risk of lands is divided into 5 categories:

- Very low risk.
- Low risk.
- Moderate risk.
- High risk.
- Very high risk.

A 5-level hazard map has been created based on GIS technologies. It has been established that 40% of the land in the region is moderately dangerous, 25% is high-risk, and 10% is very high-risk.

Table 2. Area of the research territory by degrees of erosion

Category	Area (ha)	Total area ratio (%)
Very low risk	3,000	20%
Low risk	4,000	25%
Moderate risk	6,000	40%
High risk	3,500	25%
Very high risk	1,500	10%

Based on the data presented in this table, the degree of erosion hazard of the studied territory can be divided into 5 levels. The average hazardous land area was 40% and the area of high-risk land was 25%.

The NDVI index allows for the determination of soil surface moisture characteristics (indirectly) and the presence of healthy vegetation. Moisture is characterized by the brightness values of pixels (pixels with the highest values are represented by lighter areas on the map and indicate healthy vegetation, and correspondingly, the highest level of soil moisture).

These indicators depend on the natural and climatic conditions of the region and the processes occurring in them. The highest air temperature in 2024 was 36.1 °C in August, while the lowest was in December (-2.25 °C). The highest humidity level was observed in February (Table 3).

Table 3. NDVI indicators by months in 2024

Field name	Date	Data source	NDVI	Max Deg.C	Min Deg.C	Wind Speed (m/s)	Humidity (%)
Parkent district	December 2024	Sentinel 2	0,315	3,75	-2,25	2,375	74,625
Parkent district	Novembe r 2024	Sentinel 2	0,404	9,6	2	1,96	48,2
Parkent district	October 2024	Sentinel 2	0,445	12,079	4,162	2,131	51,99
Parkent district	Septembe r 2024	Sentinel 2	0,72	27,8	15,6	2,725	23,00
Parkent district	August 2024	Sentinel 2	0,75	36,1	22,9	3,37	20,56
Parkent district	July 2024	Sentinel 2	0,836	35,4	22,2	3,62	24,85
Parkent district	June 2024	Sentinel 2	0,882	33,3	20,6	3,01	30,5
Parkent district	May 2024	Sentinel 2	0,9025	27,0	15,25	2,575	47,25
Parkent district	April 2024	Sentinel 2	0,586	21,0	9,80	2,8	49,5
Parkent district	March 2024	Sentinel 2	0,288	11,2	1,60	2,54	58,0
Parkent district	February 2024	Sentinel 2	0,37	11,0	2,00	1,50	63,0
Parkent district	January 2024	Sentinel 2	0,365	9,50	1,00	2,80	50,75
Average			**0,571**	**19,81**	**9,57**	**2,617**	**43,93**

Comparing these indicators with data from 2023, the highest air temperature in June was 35.75 °C, while the lowest temperature was in January (-14.830 °C). The highest moisture content was observed in January (75.64 °C) (Table 4).

Table 4. NDVI indicators by months in 2023

Field name	Date	Data source	NDVI	Max Deg.C	Min Deg.C	Wind Speed (m/s)	Humidity (%)
Parkent district	December 202	Sentinel 2	0,267	9,33	0,66	3,633	56,66
Parkent district	November 2023	Sentinel 2	0,500	14,00	6,66	2,367	50,50
Parkent district	October 2023	Sentinel 2	0,494	23,4	12,60	2,3	28,2
Parkent district	September 2023	Sentinel 2	0,707	26,11	15,00	2,667	25,50
Parkent district	August 2023	Sentinel 2	0,736	33,18	18,81	2,909	21,13
Parkent district	July 2023	Sentinel 2	0,762	35,75	20,66	3,150	20,37
Parkent district	June 2023	Sentinel 2	0,831	34,87	18,62	3,288	19,81
Parkent district	May 2023	Sentinel 2	0,853	28,00	13,00	2,933	34,83
Parkent district	April 2023	Sentinel 2	0,758	22,00	7,66	2,467	46,91
Parkent district	March 2023	Sentinel 2	0,427	21,83	9,83	2,983	45,58
Parkent district	February 2023	Sentinel 2	0,320	13,0	0,50	2,900	48,75
Parkent district	January 2023	Sentinel 2	0,260	-3,66	-14,83	2,200	75,66
Average			**0,576**	**21,48**	**9,09**	**2,81**	**39,49**

Comparing data from 2023 and 2024, it can be observed that the average air temperature in 2023 was 21.48°C, in 2024 - 19.810°C, the average humidity in 2023 was 39.49%, in 2024 - 43.93%, i.e., in 2024 compared to 2023, the air temperature was slightly cooler and the humidity level was higher (Figure 1).

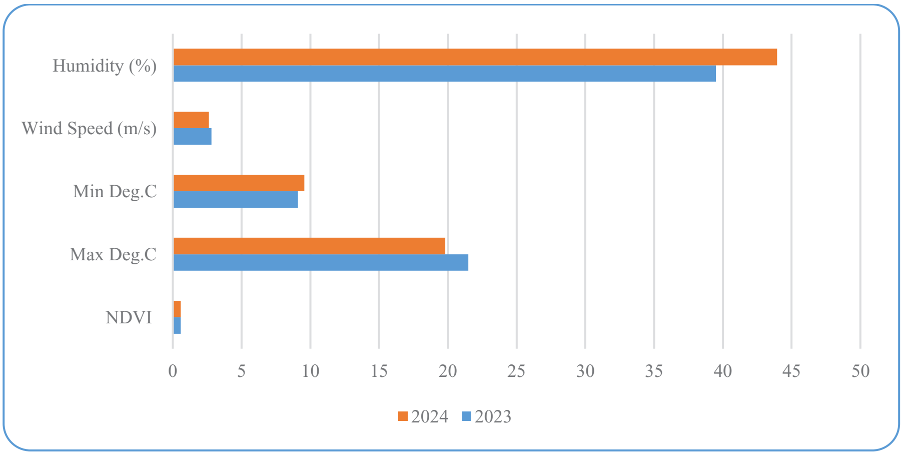

Fig. 1. The natural and climatic conditions of the study area for 2023-2024 and the NDVI index.

Research by many scientists shows that vegetation cover is one of the most important measures against the occurrence and development of erosion. When the surface of the earth is well covered with vegetation, erosion processes slow down even with an increase in precipitation.

The NDVI (Normalized Difference Vegetation Index) is the most widely used plant index, defined in 1973 by Rouse B.J. [2] and introduced in 1969 by Kriegler F.J.

The normalized difference vegetation index (NDVI) is a widely used metric for quantifying the health and density of vegetation using sensor data. It is calculated from spectrometric data at two specific bands: red and near-infrared. The spectrometric data is usually sourced from remote sensors, such as satellites.

The metric is popular in industry because of its accuracy. It has a high correlation with the true state of vegetation on the ground. The index is easy to interpret: NDVI will be a value between -1 and 1. An area with nothing growing in it will have an NDVI of zero. NDVI will increase in proportion to vegetation growth. An area with dense, healthy vegetation will have an NDVI of one. NDVI values less than 0 suggest a lack of dry land. An ocean will yield an NDVI of -1.

Negative values of NDVI (values approaching correspond to water. Values closezero generally correspond to barren areas of rock, sand, or snow. Lastly, low, positive values represent shrub and grassland (approximately 0.2 0.4), while high values indicate temperate and tropical rainforests (values approaching 1).

It receives positive values for plants, and the greater the amount of green phytomass, the higher it is. Index values are also influenced by the species composition of the plant, its density, condition, excretion and slope of the surface, and the color of the soil under sparse vegetation. The main advantage of vegetation indices is the ease of obtaining them and the breadth of tasks that can be solved with their help.

The NDVI indicator in the study area, i.e., in the Parkent region, was also studied for 2023 and 2024. According to him, the greenliness of the mountainous region averaged 0.571 percent in 2023 and 0.576 percent in 2024. The coolness of the area in this area negatively affects the thickness of vegetation. The sparseness of the vegetation cover leads to the acceleration of erosion processes and a decrease in the level of greenery of the area. (Figure 2).

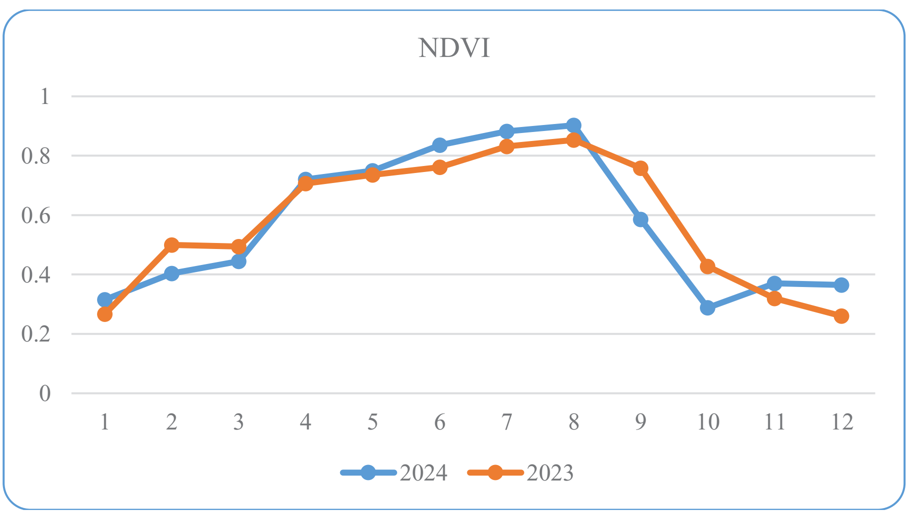

Fig. 2. NDVI indicator of the study area

In mountainous areas, where there are specific physical and geographical conditions: absolute altitude, exposure and steepness of slopes, on which the flow of solar radiation and thermal regime depend, as well as the position in relation to the prevailing transfer of air masses, plant communities of different types are formed.

5 Conclusions

A useful tool for environmental management is the efficient mapping of the spatial distribution of water erosion using GIS and remote sensing models. It is advised that the mountain area adopt water erosion prevention measures in light of the findings. There are recommendations for tactics like encouraging landscape farming, expanding tree plantations, and creating thick vegetation cover in pre-pasture and pasture areas. These actions can greatly slow down erosion processes, especially when combined with a decrease in livestock grazing and a shift to more sustainable farming methods. It is also essential to abandon traditional farming methods and adopt new technologies and techniques in agriculture [13].

Therefore, NDVI is often used as one of the more complex types of analysis, as a result of which it is possible to create maps of the fertility of forests and agricultural lands, maps of landscapes and natural zones, soil, arid, phyto-hydrological, phenological and other ecological and climatic maps

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