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3D MODEL OF THE EROSION RISK LEVEL OF THE CHATKOL MOUNTAIN RANGE'S LAND SOILS

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Abstract

This article evaluates the spatial distribution and hazard levels of surface water erosion on rainfed soils of the Chatkal mountain range based on 3D modeling. The study employs remote sensing data, a digital elevation model (DEM), and geographic information system (GIS) technologies. Topographic factors, vegetation cover, and soil moisture conditions influencing erosion processes are analyzed in an integrated manner. Based on the obtained results, areas with low, moderate, and high erosion risk are identified. The developed 3D model has significant scientific and practical importance for visual assessment of erosion processes and for effective land resource management.

Keywords: Rainfed soils, erosion processes, 3D modeling, GIS technologies.

Introduction

Soil erosion is one of the main factors in the degradation of land resources in mountainous and foothill areas. In such areas, the intensity of rainfall, steep terrain and low vegetation cover enhance the processes of water erosion. In scientific research, the use of geographic information systems (GIS) and remote sensing data is widely used as an effective method for assessing erosion risk (Wischmeier & Smith, 1978; Renard et al., 1997).

In recent years, 3D modeling methods have become an important part of scientific research in the study of eroded soils. Since traditional 2D maps cannot fully reflect the complex spatial characteristics of erosion processes on the surface, 3D models allow for a comprehensive analysis of terrain, slope, exposure, and elevation factors. 3D visualization is especially effective in determining the development of erosion processes in vertical and horizontal directions in mountainous and hilly areas (Moore et al., 1991; Florinsky, 2012).

A number of scientific studies have been conducted on soil erosion in the conditions of Uzbekistan, in particular in mountainous regions such as the Chatkal mountain range. The studies emphasize that silty soils are highly susceptible to erosion due to relief factors and anthropogenic impact (Abdurakhmonov 2012; Djalilova, 2018; Juliev et al., 2024; Shadiyeva et al., 2023, However, the issues of comprehensive assessment of erosion risk in this region through 3D modeling have not been sufficiently covered. Therefore, visual and quantitative analysis of erosion-prone areas based on 3D models is scientifically and practically relevant.

Research object

The mountainous regions of Uzbekistan, including the Kibray, Parkent, and Bostanlyk districts of the Tashkent region, were selected. The object of the study is the soils belonging to the region of mountain and submountain soils formed in complex climatic and relief conditions.

Research results

To date, methods for creating 3D models of the earth's surface (LiDAR, photogrammetry, high-resolution satellite images, etc.) have developed dramatically. Such maps accurately reflect the entire appearance of the relief using contour lines, allowing you to measure changes in height and slope. For example, areas with dense contour lines indicate a decreasing slope of the relief, while widely spaced lines indicate a flat area. Since 3D topographic maps can be freely rotated, it is easier to intuitively understand and analyze the data.

Terrain accuracy: 3D maps depict terrain in a realistic way using contour lines. This helps to clearly show features such as the elevation and slope structure of an area, mountain ranges, valleys, and hills.

Identifying erosion zones: With the help of a 3D model, it is easier to identify areas where erosion is occurring. Areas that are experiencing rapid erosion – such as deep gullies or steep slopes – are clearly identified on the map.

Visualization and decision-making: 3D models allow reliance geospatial information and other data to be displayed together. This helps users better understand the data and understand complex topographic conditions.

Data integration: 3D maps can be overlaid with other data sources such as soil, vegetation cover, and irrigation systems. This allows for a comprehensive assessment of the erosion status of an area by linking the relief with various ecological and agronomic indicators.

Analysis of the map of the Kibray district.The relief of the Kibray district is located in the Chirchik River valley, and the ground level gradually rises from south to north and northeast. It is noted that the average height of the district is approximately 300–400 m (in fact, the lowland and hilly part of Kibray makes up this indicator). The map shows the Chirchik River valley on the southern border, and the Bozsuv, Zakh and Katta Karasuv canals on the northern and eastern edges. There are deep ravines and hills in the northeastern regions, and the depth of some ravines around Bozsuv reaches several tens of meters. This is the result of water flows and strong erosion processes: the contour lines along the map are especially dense in these regions, indicating a rapid slope of the earth's surface (Figure 1).

It is noteworthy that the soil cover in the Qibray 3D map is mainly composed of typical gray loamy (medium loamy) soils. The soils in the region are gray along the intersections, and a small part of them is also found in sandy, waterless areas. In general, the relief in the Qibray region is low and moderately sloping; the erosion risk is high in the depressions near the large hills, but significantly lower on the plains.

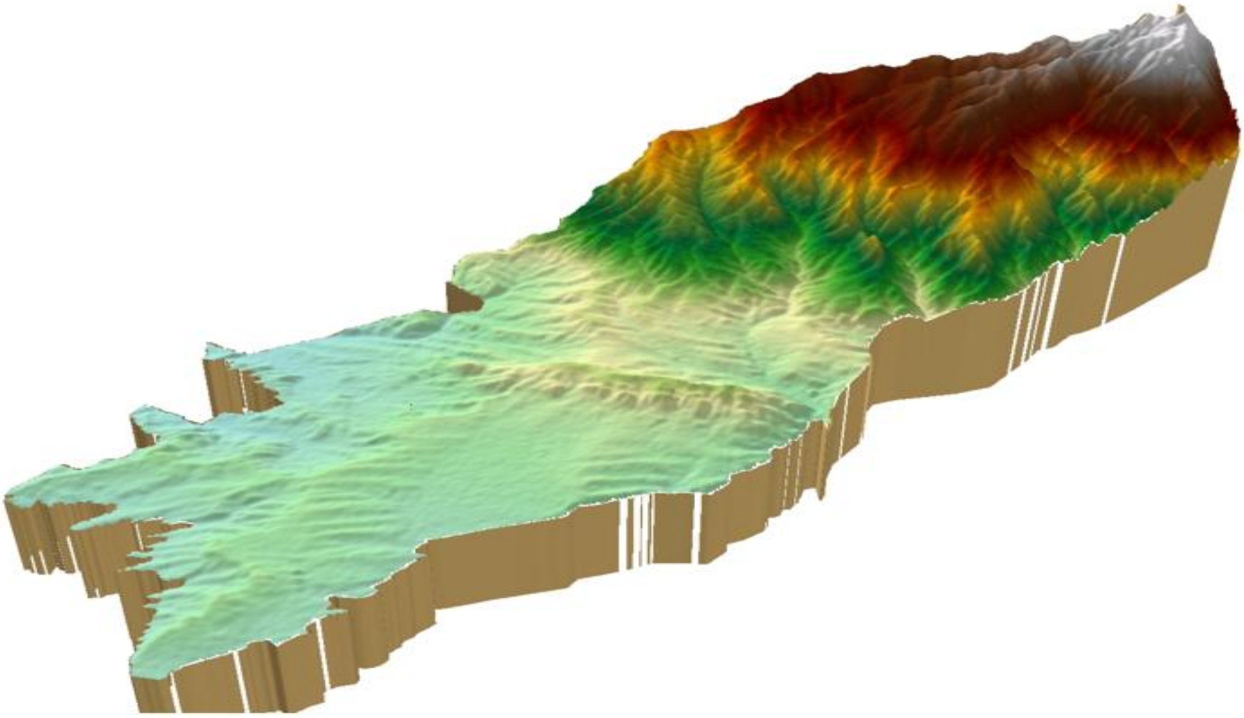

Figure 1. 3D model map of typical gray soils of the territory of the Turkestan Military District, Kibray district

Parkent district map analysis.Parkent district is located on the western slopes of the Middle Tien Shan (Chatkal) mountain range, that is, its relief consists of a foothill plain, hills and mountains. The map shows that the relief rises from west to east, and its highest point is the Kyzylnura peak (3627.8 m). The Kyzylnura peak is located mainly in the southern part of the Chatkal mountains, while the western part has a lowland. As can be seen from the map, the northern part of Parkent is higher than the other parts: there are many steps in the mountain zone and dense contour lines. For example, strong slopes and height differences are observed in the Zarkent massif. On the plains, the relief is rounded and flattened, and contour lines are widespread here. In the foothills and high mountains, there are steep hills, and the contour lines are arranged in a closed order.

Soil types in Parkent also depend on the relief: while the plains consist of gray soils (for example, near the city of Parkent), brown mountain soils are widespread on the hills and mountain slopes. Areas of erosion around large slopes are especially noticeable - they are depicted on the map as deep areas or sharp edges. Contour lines in such areas are dense and angular, indicating that the surface of the earth is twisted. In summary, the 3D map of Parkent reveals the landscape differences between the foothills and the mountain zone: the foothills in the west are flat and low-lying, while the elevation increases sharply in the east (Figure 2).

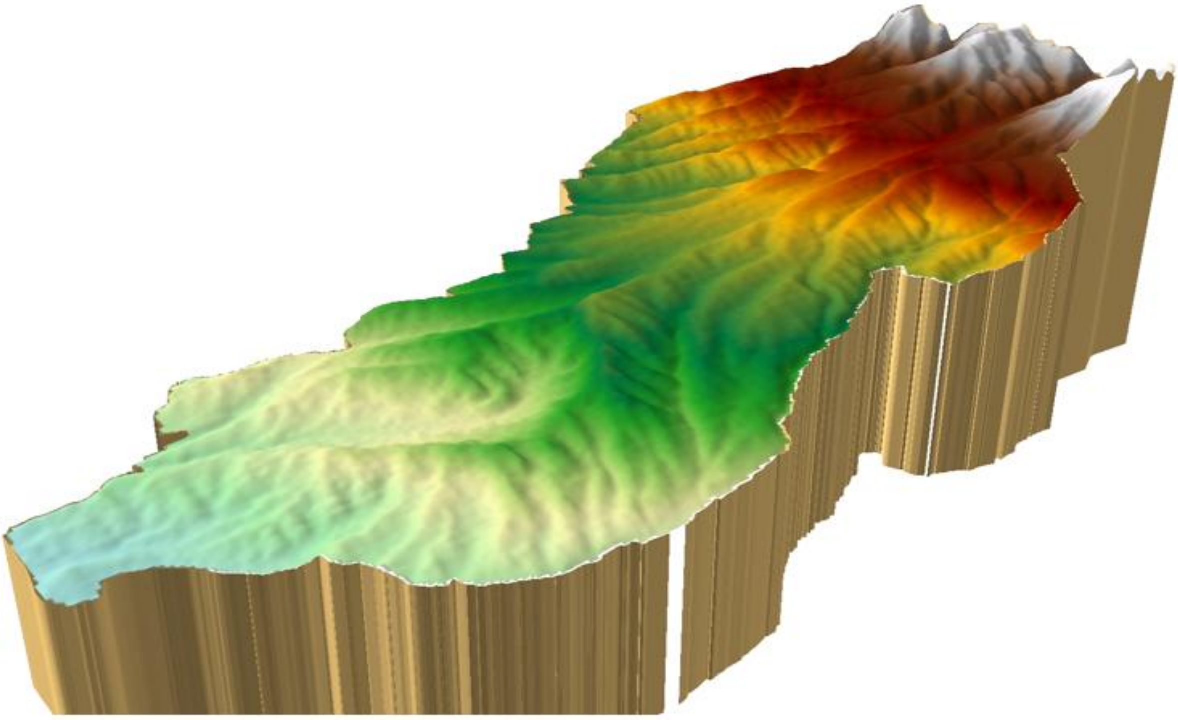

Figure 2. 3D model map of the Zarkent massif, Parkent district

Analysis of the map of Bostanlyk district. Bostanlyk district is typical for mountainous areas in Tashkent region, the relief is mainly made up of hills, medium and high mountains. As can be seen from the map, the western and southern parts of the district are saturated with lowlands (the part around Gazalkent); there are not many contour lines here, they are relatively flat. Other areas rise to the east and north, and the height varies between 1200–4000 m. The highest peak of the district is Adelunga (4301 m) on the Pskem ridge, and the second highest is Beshtor peak with a height of 4299 m. The map depicts the most famous relief elements, such as large peaks, such as Katta Chimgan (Bolshoy Chimgan), Kyzylnura, Mingbulok.

On the Bostanlyk map, the contour lines are extremely dense in the high mountains, located at a small distance from each other. This undoubtedly indicates that the region has a sharply sloping climate. For example, near the sandstone and loess layers in the hills, the edges of the land are quickly eroded by water runoff. Many hills (ravines) are visible on the map: their walls are hard and deep, and the acidity is strong downwards. Therefore, it is difficult to withstand erosion in such areas with sand and clay layers. In the foothills of Bostanlyk, the Chimgan plains are widespread - here the contour lines are relatively wide, and the relief is rounded. As for the soil, the map shows light brown meadow-steppe soils in the high mountains, and gray and red-brown soils on the hills and mountain slopes (Figure 3).

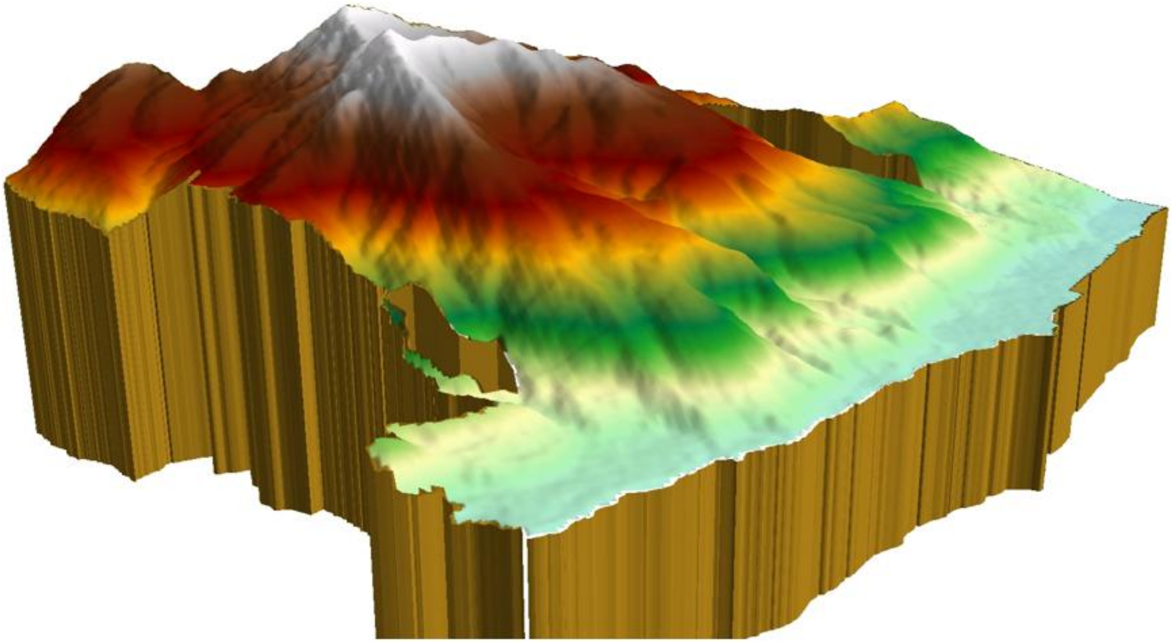

Figure 3. 3D model map of the Khojakent massif of Bostanlyk district

3D mapping technology is of great benefit for in-depth analysis of relief and soil conditions and for assessing erosion processes. With the help of such maps, it is possible to clearly see the height differences and foothill plains across the regions, which is of great importance in the design of sea level measurements, planning irrigation systems and agromanagement. Once erosion-prone zones (deep hills, steep slopes) are identified, it becomes easier to take soil conservation measures against them.

For example, in the United States, a high-resolution 3D map of the entire island was created to protect the coast of Alcatraz Island in San Francisco Bay from storm surges and weather changes. This practice demonstrates that 3D models can be used to accurately monitor erosion processes and plan measures appropriate for future climate conditions. As another example, in China, urban development projects are using 3D soil maps to identify unstable slopes and reduce the risk of landslides and earthquakes in advance.

The 3D map analysis conducted in the Qibray, Parkent and Bo'stanlyk districts clearly demonstrated that the spatial differentiation of relief and soil cover is a decisive factor in the formation and development of erosion processes. It was found that the Qibray district is dominated by relatively low and medium-sloped relief, and the erosion risk is mainly associated with hills and deep ravines. In the Parkent district, erosion processes were intensified as a result of a sharp increase in elevation and slope when moving from the foothills to the high mountain zones. The Bo'stanlyk district is characterized by high mountainous relief, large elevation differences and dense contour lines, and it was found that water erosion and mechanical fragmentation of the relief are at their highest level in this area.

Conclusion

The results of the study confirmed that 3D mapping technologies are an effective scientific and practical tool for identifying erosion-prone zones, assessing their morphological characteristics, and sustainably managing regional land resources. The combined analysis of relief, soil types, and erosion processes will allow for future planning of soil protection measures based on regional characteristics. In this regard, the results of this study serve as a solid theoretical and practical foundation for developing scientifically based recommendations aimed at forecasting erosion risks, rational use of alluvial soils, and ensuring ecological sustainability.

In the future, there are prospects for widespread use of 3D mapping in Tashkent region and other regions. This technology can be used in landscape planning, ensuring environmental sustainability, managing agriculture and water resources, as well as in decision-making in tourism and construction. 3D maps display complex geographic information in one place by integrating relief elements and soil properties, which ultimately creates opportunities for accurate and detailed analysis for researchers and practitioners.

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