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# SOIL-FORMING PROCESSES ROLE IN SHAPING SOIL FERTILITY PARAMETERS IN THE KEDABEK REGION, AZERBAIJAN

**R.A. SADIGOV[1*], A.Z. HAJIYEVA[2], D. MUHAMMAD[3], N.O. MAMMADOVA[1], and S.M. ABBASOVA[1]**

[1]Department of Engineering and Applied Sciences, Azerbaijan State University of Economics, Azerbaijan
[2]Department of Public Administration and Social Innovation, Azerbaijan State University of Economics, Azerbaijan
[3]Department of Soil and Environmental Sciences, University of Agriculture, Peshawar, Pakistan
[*]Corresponding author's emails: ramil_sadigov@unec.edu.az, ramil_sadiqov-1983@mail.ru
Email addresses of co-authors: afaq.adiu@mail.ru, dost@aup.edu.pk, nika.mamedova.75@mail.ru, uzeirqasimli@yandex.ru

## SUMMARY

This study aimed to investigate the erosion processes effect on fertility parameters of mountainous chernozem-black soils in the Kedabek Region of Azerbaijan. The research area was characteristically of a predominantly mountainous relief, where surface erosion was widespread and represents a significant challenge to sustainable soil use and crop productivity. The collected soil samples from experimental plots revealed varying degrees of erosion for evaluating its extent and the prevailing effect on key fertility parameters. The presented results indicate that erosion disrupts the soil structure, reduces the functional capacity of arable lands, and eventually leads to a considerable decline in soil quality. Analytical results showed an increase in bulk and particle densities in eroded soils, which signified a correlation with the soil granulometric composition variations. Additionally, a consistent decrease in humus content and total nitrogen was evident across the soil profiles subjected to erosion. These variations underscore the detrimental effects of erosion on soil fertility and emphasize the need for targeted soil conservation and rehabilitation strategies in the studied region.

**Keywords:** Soil fertility parameters, soil erosion, humus and nitrogen content, predominantly mountainous relief, soil structure, soil conservation

**Key findings:** In the mountainous chernozem soils of the District Kedabek, soil erosion significantly affects the key fertility parameters. Eroded soils exhibited increased bulk and particle density, which has linkages with variations in soil granulometric composition. However, a marked decline prevailed in humus and nitrogen content across the soil profiles altered by erosion.

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## INTRODUCTION

Soil fertility plays a pivotal role in ensuring crop productivity and food security, especially in regions with the highest dependency on local farming systems. Soil preservation and its sustainable use and improvement in its fertility parameters proved crucial for meeting the growing food demands of the current population worldwide. In this context, the expansion of fertile lands and the restoration of degraded soils appeared to be the critical components of national agricultural strategies. Recognizing this, the Government of Azerbaijan has prioritized soil management as a key element in the current food security policy. According to the State Program on Reliable Provision of Food Products to the Population of the Azerbaijan Republic (Presidential Decree No. 3004, dated August 25, 2008), various crucial measures have succeeded their implementation between 2008 and 2015. These aimed at improving the soil quality and expanding the productivity of natural pastures (FAO, 2014).

The said program focused on the reclamation of degraded soils, particularly solonetzic and sulfurous types of soils, and emphasized the enhancement of their fertility parameters through sustainable land-use practices. Special consideration centered on combating soil erosion and degradation caused by both natural processes and human activities (Sadigov, 2018; Sadigov and Mustafayev, 2024).

With the rapid intensification of modern agriculture, the pressure on soil natural resources has significantly increased. Expansion in cultivated areas and improper land management practices has accelerated soil erosion, leading to a considerable decline in fertility and reduced crop productivity. Soil erosion, particularly in mountainous regions such as the Kedabek Region, disrupts the soil structure, depletes essential nutrients, and negatively affects the soil’s water-holding capacity. These undesirable and substantial soil variations pose a serious threat to long-term crop sustainability and productivity in the said region (Kovda, 1973; Amanova *et al.,* 2024).

Historically, societies have understood the values of fertile soils, recognizing their essential role in successful crop cultivation and production. Traditional agricultural communities intuitively assessed soil productivity based on the final yields of cultivated crops. In contemporary science, the soil fertility definition is the capacity of soil to provide essential nutrients and support plant growth and development until maturity under favorable environmental conditions. Therefore, soil fertility has become one of the most crucial parameters of soil health and agronomic potential (Hasanov, 2015).

Soil fertility evaluation and monitoring, particularly under the worst conditions of soil erosion and degradation, are imperative. It is crucial to assess how erosion alters the physical and chemical properties of soil, including organic matter content, nitrogen level, bulk density, and soil texture. This type of assessment helps inform targeted soil management and conservation practices. In regions like Kedabek, where mountainous terrain makes the soil especially vulnerable to erosion, understanding these processes becomes even more vital.

This study aimed to determine the effects of erosion on soil fertility parameters in the mountainous chernozem soils of the Kedabek Region. The research focused on identifying key variations in soil composition and structure caused by erosion and developing recommendations for improving and preserving soil productivity. These results will likely contribute to ongoing national efforts toward sustainable agricultural development and food security in Azerbaijan.

## MATERIALS AND METHODS

The concerned study focused on determining the erosion-affected mountainous chernozem and mountainous gray-brown soils in the Kedabek Region of Azerbaijan. These soil types are commonly prevalent in sloped and elevated terrains and are particularly vulnerable to degradation processes, primarily surface erosion. The research’s core objective was to assess the extent to which erosion influences the key soil fertility parameters and propose effective measures for the preservation, rehabilitation, and enhancement of soil productivity (Figures 1 and 2).

Achieving this aim undertook several research tasks. First, the representative experimental plots entailed identification across the different locations in the District Kedabek, with each exhibiting varying degrees of erosion intensity. These sites were options to provide a comparative basis for evaluating variations in soil fertility under both mild and severely eroded conditions. The site selection process relied on the topographical features, land use practices, and visual indicators of soil erosion (Sadigov, 2022b).

Soil sample collection occurred at different depths within each experimental plot, ensuring coverage of the full soil profile. These soil samples sustained comprehensive chemical analyses to determine key fertility indicators, including humus content, total nitrogen, pH level, and soil granulometric composition. Additionally, physical properties, such as bulk and particle densities, incurred assessment to understand the soil structural variations associated with erosion.

**Figure 1.** Erosion process in the territory at Plankand village.

**Figure 2.** Erosion process in the territory at DuzRasullu village.

All laboratory analyses proceeded in accordance with standard soil analysis methodologies, ensuring consistency and scientific reliability of the results. Special attention focused on correlating the severity of erosion with the degree of decline in soil fertility parameters. This helped in identifying the most critical factors influencing soil degradation in the said region. Laboratory analyses continued in the certified laboratory at the Institute of Soil Science and Agrochemistry, Ministry of Science and Education, Azerbaijan, as well as at the Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan (FAOSTAT, 2020).

According to the World Reference Base for Soil Resources (WRB), the studied soils reached classification and correlation with the National Soil Classification System of Azerbaijan. A comprehensive soil map's development used ArcGIS 10.3, integrating soil survey data with digital elevation data to illustrate the spatial distribution and variations of alluvial meadow-forest soils across the basin. The accuracy and consistency of the analytical results attained confirmation using mathematical-statistical analysis based on the methodology of Dospekhov (1984). This ensured the reliability of both field and laboratory data for further interpretation (Kachinsky, 1970; State Standard of the Republic of Azerbaijan, 2013).

A new digital elevation model (DEM) with low distortion succeeded its creation by interpolating elevation data derived from historical topographic maps. Likewise, the generation of slope gradient maps in ArcGIS 10.3 assessed erosion risk zones and supported land-use planning. Soil erosion processes began to initiate at slope gradients of 2°–3°, making slope mapping critical for sustainable soil management (Ministry of Agriculture of Azerbaijan State Land Management Project Institute, 2020; Mammadov *et al*., 2025).

Furthermore, the study examined the relationship between land management practices and the observed variations in soil quality. Based on these findings, a proposed set of targeted soil conservation and fertility restoration measures emerged. These measures include recommendations for improved agricultural practices, erosion control techniques, and land rehabilitation strategies suitable for the region's mountainous terrain.

The promising research will contribute valuable data on the effect of erosion on soil systems in the Lesser Caucasus and support the broader national efforts aimed at sustainable soil management. The outcomes will provide a scientific basis for local land-use planning and serve as a reference for implementing effective soil protection policies under erosion-prone conditions. Therefore, the presented study will address both the environmental and agricultural priorities, aiming to enhance the resilience of soil resources in the Kedabek Region, Azerbaijan.

## RESULTS AND DISCUSSION

The Kedabek District sits in the northeast of the Lesser Caucasus and represents a geologically and geomorphologically complex region of Azerbaijan. The said region shares borders with Tovuz on the north, Shamkir and Dashkesan to the east and southeast, and the Republic of Armenia on the west, southwest, and northwest. The region is predominantly mountainous, with a highly variable topography that plays a critical role in shaping the local soil formation and erosion dynamics (Sadigov, 2022a).

The processes of denudation, weathering, and surface erosion are primarily responsible for the relief of the territory. These geomorphological factors have resulted in a distinctly stratified landscape. Based on the geological structure and elevation, the region underwent division into four main geomorphological zones, i.e., alpine zone, middle mountainous zone, low mountainous zone, and inclined plains, ranging in elevation from 500 to 1200 meters above sea level. Overall, the Kedabek District elevation ranged from approximately 300 to 3400 meters, contributing to the considerable climatic and ecological variations across the territory (Ibrahimov, 2013).

Soil studies have started at various intervals in this region. One of the earliest large-scale investigations, as carried out by Ibragimov (2013), involved comprehensive soil-erosion mapping at the scale of 1:500000, focusing on analyzing slope characteristics, soil depth, and the exposure of terrain. However, based on these studies, the production of detailed erosion maps succeeded, with practical recommendations proposed for controlling erosion. Subsequent research has expanded on these findings, focusing particularly on the degradation of mountainous chernozem soils. These studies examined the degree of erosion and its influence on humus content, nutrient retention, and morphological variations in soil structure (Ibrahimov, 2013).

The Kedabek Region’s climate has a moderately arid classification, characterized by dry summers and cold and dry winters. Summers are generally cool, while winters can be severely cold. The average annual temperature ranges between 0 °C and 20 °C. Typical January temperatures ranged from −2 °C to −10 °C, whereas July temperatures ranged between 10 °C and 20 °C. The broad elevation range across the region contributes to the presence of multiple microclimates, which further affect soil formation and vegetation patterns (Gumbatov *et al*., 2024).

According to Ibragimov (2013), in 31.49% of the region's territory area (49,493.00 hectares), the depth of the local erosion base was 100–300 meters, and the erosion process was weak and moderate. The area with a local erosion base depth of 300–800 meters covers 89,618.50 hectares (56.99%) of the total area, where the erosion process was almost intense. An area with a local erosion base depth of more than 800 meters constitutes 8.62% (13,572.00 hectares) of the total area. However, in these areas, the erosion process occurs with varying degrees.

In the integration of complex topography, active erosion processes and diverse weather conditions make Kedabek as an ideal region for studying soil degradation, particularly with the effect of erosion on soil fertility parameters. The region’s dynamic landscape and environmental gradients provide valuable opportunities for investigating the interactions between geomorphology, climate, and land use in shaping soil health and productivity. The hydrological network has an uneven distribution in the Kedabek Region, with the river density significantly varying across the different zones. In this area, mostly the rivers received a combination of underground water sources, snowmelt, and precipitation. This diverse hydrological input contributes to the region's complex surface runoff patterns and supports the varied ecological zones throughout the territory (Ministry of Agriculture of Azerbaijan State Land Management Project Institute, 2020; Sadigov, 2022a).

The Kedabek Region also has characteristically rich and diverse vegetation. As elevation gradually decreases from the high-mountain zone to the inclined plains, the distinct vegetation belts are evident, with a clear transition between the different plant communities. Typical meadow species include white clover (*Trifolium repens*), wild barley (*Hordeum spontaneum*), and other native grasses, showing ecological gradients across the altitudinal zones. Geologically, the region is notable for the widespread presence of volcanic deposits dating back to the Jurassic period. Rock formations, such as porphyrite and alum-porphyrite, are dominant across the larger areas and play a crucial role in affecting soil development and composition. These geological features considerably contribute to the heterogeneous soil profiles observed in this area (Sadigov *et al*., 2024).

In the Kedabek Region, a study based on soil distribution and characteristics commenced through both fieldwork and laboratory analysis. For spatial orientation and planning, large-scale (1:500000) topographical maps entailed development and utilization to delineate the district’s boundaries and plan field routes. Soil sampling sites were notable under field conditions, with representative soil profiles (soil sections) totaling 20 established across the region (Table 1). Each soil profile reached a systematic description and documentation using standard pedological

**Table 1.** Geographic coordinates in soil sections.

| No. | Section number | X-coordinate (East longitude) | Y-coordinate (North latitude) |
|---|---|---|---|
| 1 | Soil section 15 | X.46° 17′ 25″ E | Y.40° 54′ 59″ N |
| 2 | Soil section 13 | X.46° 13′ 22″ E | Y.40° 55′ 15″ N |
| 3 | Soil section 14 | X.46° 13′ 59″ E | Y.40° 54′ 47″ N |
| 4 | Soil section 8 | X.46° 15′ 17″ E | Y.40° 54′ 38″ N |

**Table 2.** Breakdown of the results by soil types.

| No. | Soil types | Physical clay (%) | Silt fraction (%) | Hygroscopic humidity (%) | Absorbing bases (mg-eq) | Humus content (%) | Total nitrogen (%) |
|---|---|---|---|---|---|---|---|
| 1 | Mountainous Gray-Brown Soils | 56.80÷ 71.48 | 17.60÷ 32.80 | 5.72÷ 6.75 | 24.00÷ 45.15 | 0.62÷ 4.51 | 0.072÷ 0.316 |
| 2 | Mountainous Chernozem Soils | 58.40÷ 67.60 | 19.20÷ 34.80 | 5.31÷ 7.78 | 26.05÷ 49.70 | 0.66÷ 6.11 | 0.076÷ 0.416 |
| 3 | Typical Mountainous Chernozem Soils | 57.48÷ 66.40 | 20.24÷ 30.96 | 5.36÷ 6.12 | 24.55÷ 42.15 | 0.61÷ 4.30 | 0.073÷ 0.303 |

forms. The data recorded on various soil characteristics included depth, color, granulometric composition, structural features, density, and other soil morphological parameters. The soil sampling aimed to investigate the variations across different geomorphological and ecological zones (Khalilov *et al*., 2023; Mammadov *et al*., 2025).

The collected soil samples underwent laboratory analyses to evaluate their physical and chemical properties. The studied soil parameters included measurements of hygroscopic moisture, specific gravity, total porosity, particle size distribution (granulometry), humus content, total nitrogen, mobile phosphorus, exchangeable calcium, and the composition of the exchangeable (absorbing) cation base complex. The studied soil variables were options to provide a complete picture of soil fertility status and degradation trends under the influence of erosion and other environmental factors (Khalilov *et al*., 2023). The study has organized and presented laboratory analyses results in tabular format for further interpretation and discussion. In the Kedabek Region, the field and laboratory investigation results revealed significant variations in the physical and chemical properties of studied soils, particularly for erosion-affected mountainous chernozem and gray-brown soil profiles (Table 2).

Across the soil profiles, the physical clay proportion (particles <0.01 mm) ranged from 56.80% to 71.48%, while the silt fraction (<0.001 mm) varied between 17.60% and 34.80% within the genetic horizons. These values revealed a predominantly fine-textured soil composition, which considerably influenced the water retention ability and nutrient availability. Hygroscopic moisture content ranged from 5.31% to 7.78%, reflecting the soil's capability to retain water under low atmospheric humidity conditions (Tables 3 and 4). From past studies, the physical clay proportion (particles <0.01 mm) across the soil profiles ranged from 52.39% to 69.72%, while the silt fraction (<0.001 mm) varied between 14.79% and 36.41% within the genetic horizons (Ibragimov, 2013). Hygroscopic moisture content ranged from 4.64% to 7.22%, suggesting the soil's capacity to retain more water under low atmospheric humidity conditions.

The sum of exchangeable (absorbing) bases varied widely, ranging from 24.00 to 51.25 mg-eq, indicating differing levels of base saturation and cation-exchange capacity (CEC) across the different soil types. Soil reaction (pH) ranged from 6.1 to 7.0, placing these soils in the slightly acidic to neutral category,

**Table 3.** The methods and instruments used for measuring analyses (Kashinsky, 1970; Kovda, 1973; Dospekhov, 1984; State Standard of the Republic of Azerbaijan, 2013; and FAOSTAT, 2020).

| No. | Diagnostic parameters | The methods |
|---|---|---|
| 1 | Humus Content | Determined using the I.M. Tyurin wet oxidation method |
| 2 | Total Nitrogen (N) | Assessed by the Kjeldahl method |
| 3 | Carbonate Content ($CaCO_3$) | Measured by calcimetry and titration |
| 4 | Total Phosphorus (P) | Quantified using ICP-MS (Agilent) |
| 5 | Total Potassium (K) | Quantified using ICP-MS (Agilent) |
| 6 | Granulometric Composition | Determined using the N.A. Kachinsky pipette method |
| 7 | Cation Exchange Capacity (CEC) | Assessed by the D. Ivanov method (absorbed cations) |
| 8 | Hygroscopic Moisture | Determined thermally at 105 °C |
| 9 | Soil Reaction (pH) | Measured in a 1:5 soil-to-water suspension using a pH meter |
| 10 | Nitrogen Forms | Absorbed Ammonium: Kononov method<br>Water-Soluble Ammonia: Nesler method<br>Nitrate ($NO_3^-$) Content: Grandal-Lyaju method |

**Table 4.** Main indices of the soils of the research area (granulometric composition, humus, nitrogen, carbonate $CaCO_3$, hygroscopic humidity, and pH).

| Soil section No. | Depth (cm) | Granulometric composition | | Humus (%) | Nitrogen (%) | Carbonate $CaCO_3$ (%) | Hygroscopic humidity (%) | pH |
|---|---|---|---|---|---|---|---|---|
| | | 0.001 (%) | <0.01 (%) | | | | | |
| Mountainous meadow-serozem sandy soils (moderately eroded) | | | | | | | | |
| 15 | 0-23 | 25.20 | 56.80 | 4.51 | 0.316 | Not anal. | 6.71 | 6.8 |
| | 23-50 | 17.60 | 57.20 | 2.96 | 0.220 | Not anal. | 6.71 | 6.6 |
| | 50-76 | 24.54 | 63.38 | 1.44 | 0.135 | Not anal. | 6.59 | 6.5 |
| | 76-104 | 32.80 | 69.60 | 0.80 | 0.085 | Not anal. | 6.75 | 6.3 |
| | 104-128 | 31.32 | 71.48 | 0.62 | 0.072 | Not anal. | 5.72 | 6.1 |
| Washing-off mountainous chernozems (13-weakly eroded, 14-natural) | | | | | | | | |
| 13 | 0-26 | 19.20 | 58.40 | 5.22 | 0.361 | Not anal. | 6.41 | 6.9 |
| | 26-56 | 22.60 | 59.64 | 3.30 | 0.241 | Not anal. | 7.44 | 6.8 |
| | 56-77 | 29.60 | 60.00 | 1.62 | 0.136 | Not anal. | 6.30 | 6.8 |
| | 77-105 | 24.56 | 63.40 | 1.90 | 0.153 | Not anal. | 5.98 | 6.9 |
| | 105-132 | 34.80 | 66.00 | 0.72 | 0.080 | Not anal. | 5.31 | 6.9 |
| 14 | 0-28 | 22.60 | 59.64 | 6.11 | 0.416 | Not anal. | 6.62 | 7.0 |
| | 28-54 | 26.17 | 60.90 | 3.18 | 0.233 | Not anal. | 7.28 | 7.0 |
| | 54-80 | 30.96 | 62.64 | 1.57 | 0.133 | Not anal. | 7.78 | 6.9 |
| | 80-111 | 29.04 | 64.12 | 0.86 | 0.088 | Not anal. | 6.24 | 6.8 |
| | 111-117 | 30.40 | 67.60 | 0.66 | 0.076 | Not anal. | 6.24 | 6.8 |
| Typical mountainous chernozems (weakly eroded) | | | | | | | | |
| 8 | 0-26 | 19.20 | 58.40 | 5.22 | 0.361 | Not anal. | 6.41 | 6.9 |
| | 26-56 | 22.60 | 59.64 | 3.30 | 0.241 | Not anal. | 7.44 | 6.8 |
| | 56-77 | 29.60 | 60.00 | 1.62 | 0.136 | Not anal. | 6.30 | 6.8 |
| | 77-105 | 24.56 | 63.40 | 1.90 | 0.153 | Not anal. | 5.98 | 6.9 |

which was generally favorable for nutrient uptake and plant growth (Table 3). According to Ibragimov (2013), the sum of exchangeable (absorbing) bases varied widely, ranging from 18.43 to 44.08 mg-eq, signifying diverse levels of base saturation and CEC across diverse soil types.

In the latest study, the main focus was on the humus content due to its crucial role in soil fertility, nutrient cycling, and plant development. Humus is not only a biochemical and biological component of soil but also an important ecological factor, influencing soil structure, microbial activity, and nutrient assimilation. The humus horizon formation appeared to be closely associated with vegetation turnover and organic matter decomposition, along with plant cover, playing an essential role in developing optimal ecological and nutrient conditions in the soil profile. Across the studied soil profiles, the total humus content ranged from 0.61% to 6.71%, while total nitrogen content varied between 0.072% and 0.416%, indicating a direct and close relationship between erosion intensity and nutrient depletion (Tables 3, 4, and 5). According to previous studies, the total humus and nitrogen content stretched from 0.58% to 6.16% and 0.065% to 0.386%, respectively, across the studied soil profiles (Ibragimov, 2013).

The results confirmed the close interdependence among soil texture, organic matter content, and soil fertility level. In more eroded soil profiles, the decline in humus and nitrogen levels highlighted the detrimental impact of erosion on the long-term productivity of these soils. Maintaining vegetation cover and implementing erosion control measures proved to be essential in sustaining soil health and crop potential in the Kedabek Region. It is well established that soil erosion, particularly the leaching of the upper fertile layers, significantly contributes to the decline in soil fertility in various landscapes. In the mountainous regions of Azerbaijan, especially in the Kedabek Region, water erosion has caused widespread degradation of fertile soils, reducing their suitability for cultivation and hay production. This process both decreased the agronomic potential of the soil and, in severe cases, led to complete destruction of the soil cover (Khalilov *et al*., 2023; Mammadov *et al*., 2025).

**Table 5.** Main indices of the soils of the research area (Absorbing $P_2O_5$, exchangeable potassium, sum of the absorbing bases, from a sum of the absorbing bases by the Ca, Mg, and Na).

| Soil section No. | Depth (cm) | Absorbing $P_2O_5$ (mg/kg soils) | Exchangeable potassium (mg/kg) | A sum of the absorbing bases (mg-ekv) | From a sum of the absorbing bases (mg-ekv) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Ca | Mg | Na |
| Mountainous meadow-serozem sandy soils | | | | | | | |
| 15 | 0-23 | 34.7 | 456 | 45.15 | 36.0 | 8.5 | 0.65 |
| | 23-50 | 30.4 | 410 | 41.10 | 32.0 | 8.5 | 0.60 |
| | 50-76 | 29.1 | 341 | 33.60 | 26.0 | 7.0 | 0.60 |
| | 76-104 | 11.5 | 286 | 25.00 | 17.0 | 7.5 | 0.50 |
| | 104-128 | 8.81 | 267 | 24.00 | 15.5 | 8.0 | 0.50 |
| Washing-off mountainous chernozems | | | | | | | |
| 13 | 0-26 | 40.4 | 512 | 49.70 | 39.5 | 9.5 | 0.70 |
| | 26-56 | 32.1 | 473 | 44.65 | 34.0 | 10.0 | 0.65 |
| | 56-77 | 20.5 | 388 | 38.10 | 29.5 | 8.0 | 0.60 |
| | 77-105 | 14.1 | 315 | 31.55 | 24.0 | 7.0 | 0.55 |
| | 105-132 | 12.5 | 262 | 26.05 | 18.0 | 7.5 | 0.55 |
| 14 | 0-28 | 38.7 | 498 | 51.25 | 40.5 | 10.0 | 0.75 |
| | 28-54 | 34.4 | 481 | 46.70 | 35.5 | 10.0 | 0.70 |
| | 54-80 | 21.2 | 375 | 37.15 | 28.5 | 8.0 | 0.65 |
| | 80-111 | 12.3 | 310 | 28.10 | 19.0 | 8.5 | 0.60 |
| | 111-117 | 10.7 | 257 | 34.55 | 16.5 | 7.5 | 0.55 |
| Typical mountainous chernozems | | | | | | | |
| 8 | 0-26 | 40.4 | 512 | 49.70 | 39.5 | 9.5 | 0.70 |
| | 26-56 | 32.1 | 473 | 44.65 | 34.0 | 10.0 | 0.65 |
| | 56-77 | 20.5 | 388 | 38.10 | 29.5 | 8.0 | 0.60 |
| | 77-105 | 14.1 | 315 | 31.55 | 24.0 | 7.0 | 0.55 |

Field observations have also confirmed that erosion leads to substantial alterations both in the fertility and morphological characteristics of soils. In the presented study, representative soil cuts bore examination in the areas dominated by leached mountainous chernozems, previously used for sowing and haymaking. These soil cuts provided valuable insights into the morphological structure and agrochemical composition of the soils under varying degrees of erosion. Morphological descriptions of the soil profiles clearly revealed visible signs of erosion. These signs include horizon thinning, loss of organic-rich topsoil, and soil structural degradation. The decline in fertility parameters, such as humus and nitrogen content, further confirmed the negative effect of erosion on soil productivity. Such soil deterioration requires urgent and comprehensive management interventions for rehabilitation (Jafarova and Hajiyeva, 2024; Sadigov *et al*., 2024).

Recommending several agronomic and soil conservation measures helps combat ongoing degradation and ensure effective use of eroded soils. These soil protective measures include the cultivation of erosion-resistant crops, proper tillage practices, and the application of optimal doses of mineral and organic fertilizers. Additionally, the implementation of meliorative measures—such as terracing, contour plowing, and the establishment of vegetation buffers—can also significantly mitigate further erosion. In weakly sloped areas of the Kedabek District, the introduction of one to two cycles of grassland rotation is advisable. This strategy promotes soil structure recovery and reduces erosion rates. On medium-sloped lands with considerable erosion, increasing the proportion of fields allocated to perennial grasses in the crop rotation is crucial. The deep root system of the grass species enhances soil aggregation, improves water permeability, and increases infiltration capacity, thereby reducing surface runoff and erosion risk (Khalilov *et al*., 2023; Mammadov *et al*., 2025; Ramil *et al*., 2025).

Fertilization practices also play a key role in restoring soil fertility on eroded lands. Minimizing nutrient leaching caused by rainfall requires fertilizer application using banding methods. Uniform distribution of nutrients across the field is essential to avoid uneven delay in plant growth and development. Proper and site-specific nutrition with mineral fertilizers is particularly important in eroded soils, where depleted nutrient reserves already exist. In this study, the primary soil types examined include mountainous meadow-serozem soils and various subtypes of washed-off mountainous chernozems, which occurred to be most susceptible to degradation. The main physical and chemical characteristics of typical mountainous chernozems have entailed analysis in the study area, as presented in tabular format (Sadigov *et al*., 2024; Mammadov *et al*., 2025; Khudaverdi *et al*., 2025).

Overall, these results underscore the critical need for integrated erosion control and soil fertility management strategies in the Kedabek Region. The results revealed the studied areas have experienced varying degrees of erosion. This erosion process has significantly diminished soil fertility, primarily through reduction in humus content and nutrient availability. Across the study area, the analysis of soil physical and chemical properties detailed that physical clay content ranged between 56.80% and 71.48%, silt fraction was from 17.60% to 34.80%, hygroscopic moisture was from 5.31% to 7.78%, and the sum of exchangeable bases ranged between 24.00 and 49.70 mg-eq. Humus content emerged to vary from 0.61% to 6.71%, total nitrogen from 0.072% to 0.416%, and the soil pH was generally ranging from slightly acidic to neutral (6.1 to 7.0) (Tables 3, 4, and 5). With targeted interventions, it is possible to halt further soil degradation and restore eroded lands to productive agricultural use (Jafarova and Hajiyeva, 2024; Khudaverdi*et al*., 2025; Ramil *et al*., 2025).

A soil erosion map of the Kedabek District appears in Figure 3. The map illustrates the spatial distribution and intensity of erosion processes across the region, highlighting areas most affected by surface and gully erosion. Zones with minimal erosion primarily sit on gentle slopes and well-vegetated areas, whereas moderate to severe erosion shows

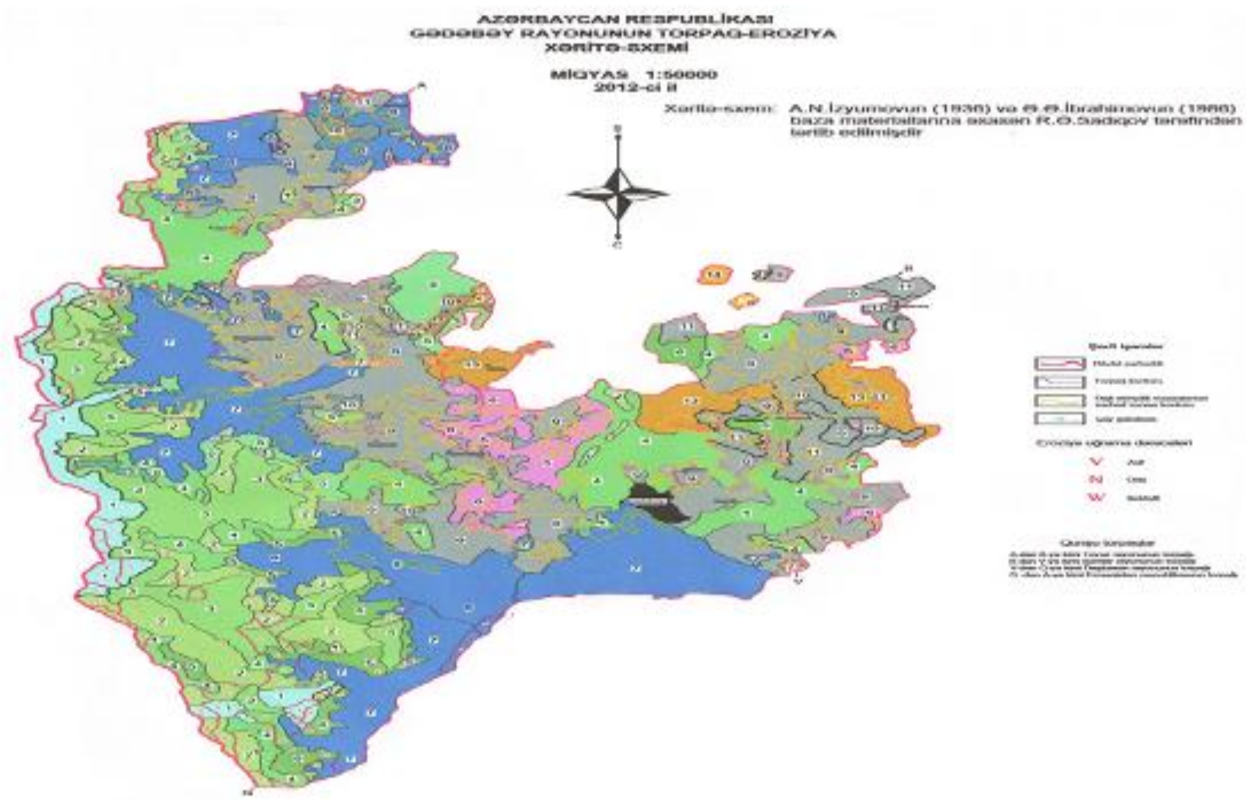


**Figure 3.** Soil erosion map of Kedabek district.

concentration on steep terrains with sparse vegetation cover and intensive land use. This spatial differentiation provides valuable insight into the relationship between topography, land management, and erosion intensity. Overall, the map serves as an essential tool for identifying vulnerable areas and supporting the development of effective soil conservation and land management strategies in the Kedabek District.

Diagnostic indicators characterizing the natural, weakly eroded, and moderately eroded types of mountainous chernozem (black) soils in the Kedabek Region are available in Figure 4. The natural soil type exhibits well-developed structural horizons, high humus content, and optimal physical properties that support fertility and biological activity. In contrast, the weakly eroded soils show initial signs of surface degradation, including slight reductions in organic matter and subtle compaction of the upper layers. The moderately eroded soils display more pronounced structural disruption, decreased humus and nitrogen levels, and increased bulk density, reflecting advanced stages of erosion-induced degradation. These progressive changes clearly demonstrate the adverse impact of erosion on soil morphology and fertility status. Overall, the figure highlights the transition from healthy, productive soils to increasingly degraded conditions under the influence of erosion processes.

**Detailed assessment of specific soil types**

***Mountainous meadow-serozem soils***

In these soils, the physical clay content ranged from 56.80% to 71.48%, silt fraction from 17.60% to 32.80%, hygroscopic moisture from 5.72% to 6.75%, exchangeable bases between 24.00 and 45.15 mg-eq, humus content from 0.62% to 4.51%, total nitrogen from 0.072% to 0.316%, and pH values varied from 6.1 to 6.8 (Tables 3 and 4).

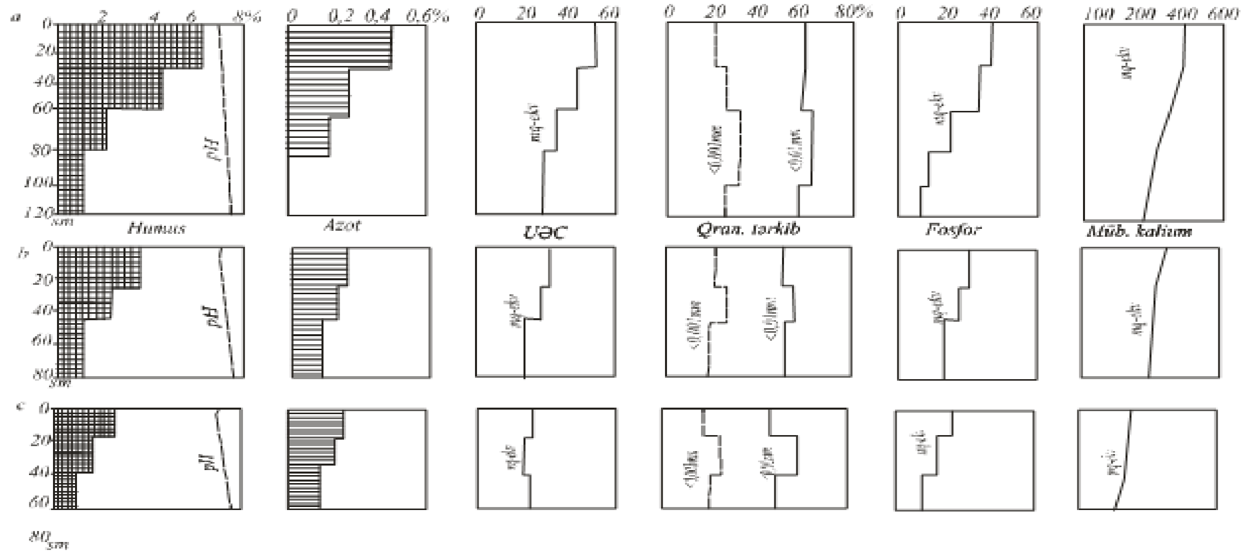


**Figure 4.** Diagnostic indicators of (a) natural, (b) weakly eroded, and (c) moderately eroded types of mountainous chernozem (black) soils in the Kedabek region.

***Mountainous chernozem soils***

In these types of soils, the physical clay content varied between 58.40% and 67.60%, the silt fraction from 19.20% to 34.80%, hygroscopic moisture from 5.31% to 7.78%, and exchangeable bases from 26.05 to 49.70 mg-eq. Moreover, humus content ranged from 0.66% to 6.11%, total nitrogen from 0.076% to 0.416%, and pH was slightly acidic to neutral, ranging from 6.8 to 7.0 (Tables 3 and 4).

***Typical mountainous chernozem soils***

In these soils, the physical clay content ranged between 57.48% and 66.40%, while the silt fraction was from 20.24% to 30.96%, hygroscopic moisture from 5.36% to 6.12%, and exchangeable bases from 24.55 to 42.15 mg-eq. Additionally, humus content was from 0.61% to 4.30%, total nitrogen from 0.073% to 0.303%, and pH values varied from 6.8 to 6.9 (Tables 3 and 4).

In the studied Kedabek Region, to effectively mitigate erosion and restore soil fertility, the following agrotechnical interventions were the study recommendations:

- Application of fertilizer regimes tailored to meet the specific nutritional requirements of plants, thereby promoting healthy growth of the plants and facilitating soil recovery.
- Stabilization of slopes and ravines by filling and implementing appropriate land contouring on cultivated lands.
- Restoration and maintenance of continuous vegetative cover to protect the soil surface against erosive forces.
- Prevention of uncontrolled and excessive grazing by livestock to avoid further soil degradation.

The implementation of these measures proved crucial for preserving soil fertility, preventing ongoing erosion, and ensuring the sustainable agricultural utilization of the region's soils.

## CONCLUSIONS

The beneficial research highlighted that erosion has notably impaired soil fertility across the Kedabek Region, primarily by reducing humus content and nutrient availability. Soil physical and chemical properties with considerable variations necessitate the targeted soil management practices for rehabilitation. Implementing tailored fertilization, slope stabilization, vegetation restoration, and controlled grazing proved to be essential strategies to mitigate erosion and sustain soil productivity. These measures will support the long-term agricultural viability of the region.

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