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STUDY OF GEOLOGICAL PROCESSES IN SOUTHERN KAZAKHSTAN UNDER THE INFLUENCE OF CLIMATE CHANGE

Abstract. The article presents the results of a study of geological processes occurring in the territory of Southern Kazakhstan. The analysis of the spatial and temporal dynamics of water and wind erosion, mudflow formation, landslides and slope deformation is carried out. Based on stratigraphic, paleotectonic and lithological data, the characteristic of the geodynamic development of the region is presented. The accumulation of thick sedimentary rock strata in intermountain depressions and the transformation of tectonic relief, the activation of exogenous processes in the context of modern climatic changes are noted. The work highlights the importance of the geological approach for forecasting modern geological risks and sustainable development of natural resources. The results can be applied in the design and operation of engineering structures in seismically active and erosion-hazardous areas of Southern Kazakhstan.
Key words: *Southern Kazakhstan, geological processes, climatic changes, erosion, tectonics, paleogeography, stratigraphy.*

Климаттық өзгерістердің әсерінен Оңтүстік Қазақстанның геологиялық процестерін зерттеу

Аңдатпа. Мақалада Оңтүстік Қазақстан аумағында болып жатқан геологиялық процестерді зерттеу нәтижелері келтірілген. Су және жел эрозиясы, селдің пайда болуы, көшкін және беткейлердің деформациясы процестерінің кеңістіктік-уақыттық динамикасына талдау жүргізілді. Стратиграфиялық, палеотектоникалық және литологиялық мәліметтер негізінде аймақтың геодинамикалық дамуының сипаттамасы келтірілген. Тау аралық ойпаттарда шөгінді жыныстардың қуатты қабаттарының жинақталуы және тектоникалық рельефтің өзгеруі, қазіргі климаттық өзгерістер контекстінде экзогендік процестердің белсендірілуі байқалды. Жұмыс қазіргі геологиялық тәуекелдерді болжау және табиғи ресурстарды тұрақты игеру үшін геологиялық тәсілдің маңыздылығын көрсетеді. Нәтижелер Оңтүстік Қазақстанның сейсмикалық-белсенді және эрозиялық-қауіпті аудандарындағы инженерлік құрылыстарды жобалау және пайдалану кезінде қолданылуы мүмкін.
Түйінді сөздер: *Оңтүстік Қазақстан, геологиялық процестер, климаттық өзгерістер, эрозия, тектоника, палеогеография, стратиграфия.*

Изучение геологических процессов Южного Казахстана под влиянием климатических изменений

Аннотация. В статье представлены результаты исследования геологических процессов, происходящих на территории Южного Казахстана. Проведен анализ пространственно-временной динамики процессов водной и ветровой эрозии, селеобразования, оползней и деформации склонов. На основе стратиграфических, палеотектонических и литологических данных представлена характеристика геодинамического развития региона. Отмечено накопление мощных толщ осадочных пород в межгорных впадинах и трансформации тектонического рельефа, активизацией экзогенных процессов в контексте современных климатических изменений. Работа подчеркивает значимость геологического подхода для прогнозирования современных геологических рисков и устойчивого освоения природных ресурсов. Результаты могут быть применимы при проектировании и эксплуатации инженерных сооружений в сейсмоактивных и эрозионно-опасных районах Южного Казахстана.
Ключевые слова: *Южный Казахстан, геологические процессы, климатические изменения, эрозия, тектоника, палеогеография, стратиграфия.*

Introduction

South Kazakhstan is a region with diverse geological structures that are affected by climate change. In recent decades, there has been a clear climate change that affects ecological and geological processes, including soil erosion, changes in water resources, mudslides, and other geodynamic phenomena. In this regard, the study of the geological processes of Southern Kazakhstan in the context of climate change is of great importance for understanding how climate change affects the sustainability of natural systems and infrastructure in the region [1].

Geological processes such as the activation of mudflows, changes in the water balance of rivers, intensive destruction of rocks and soil erosion are closely related to climatic factors such as rising temperatures, changes in precipitation and the frequency of extreme climatic events. These processes can lead to serious consequences for ecosystems, as well as for the economic activities and livelihoods of the population.

Research in this area is important for developing strategies for adaptation to climate change, effective management of water resources, improving infrastructure to prevent natural disasters, as well as for implementing measures to conserve the region's natural resources. With the help of such studies, it is possible not only to assess current geodynamic changes, but also to predict possible consequences for future generations, contributing to the sustainable development of Southern Kazakhstan in a changing climate [2].

In connection with the above, this study aims to identify the relationship between climate change and geological processes, as well as to develop recommendations for minimizing risks and adapting the region to new climatic conditions.

The purpose: to study the impact of climate change on the geological processes of Southern Kazakhstan in order to identify patterns of changes in natural processes, assess their impact on the ecological and socio-economic state of the region, as well as develop recommendations for minimizing risks associated with climatic fluctuations and effective management of natural resources in a changing climate.

The characteristic of the geological appearance of Southern Kazakhstan, caused by climatic changes, can be given taking into account multiple aspects. South Kazakhstan is a territory that includes the Turkestan, Zhambyl, Kyzylorda regions and the south of Zhetysu. The area is characterized by a continental, arid climate with hot summers and cold winters. There is little precipitation, which affects all geological and natural processes [3].

The arid climate promotes intensive physical weathering of rocks, especially in foothill and desert areas (Kyzylkum, Moyinkum). Heavy rains, although rare, cause pronounced erosion processes – gullies and gullies form, and the upper soil layers are washed away. The wind increases deflation – which is the blowing of small particles, especially in desert areas, which leads to the formation of dunes and sandy massifs. Rivers (Syrdarya, Shu, Talas) in arid climates bring a large amount of sedimentary material – alluvium. This contributes to the formation of fertile valleys, but also changes the structure of geological strata. When the climate changes (for example, during periods of cooling or warming), riverbeds move, which deposits new soil layers and changes the geological structure of valleys [4, 5].

Under evaporation conditions (at high temperatures and rare precipitation), salt marsh and gypsum deposits form, especially in areas of former lakes and depressions. This reflects the geochemical evolution of the region. During the Quaternary period (Pleistocene and Holocene), the climate of Southern Kazakhstan changed several times. This led to:

- regressions and transgressions of ancient lakes (for example, the Aral Sea);
- the formation of loess deposits in the foothills of the Tien Shan;
- the formation of terraces along rivers that record the alternation of wet and dry epochs [6].

Modern climatic and geological threats include: desertification of territories due to rising temperatures and lowering ground water levels; dust storms as a result of soil erosion; activation of mudflow processes in the mountains in case of short-term rains. The geological appearance of Southern Kazakhstan is largely shaped and continues to change under the influence of climate. Aridity, sudden temperature fluctuations and rare but powerful precipitation contribute to active processes of weathering, erosion, precipitation accumulation and changes in the geomorphology of the region.

The valley of the Syrdarya River with climatic and geological changes. The Syrdarya is the largest river in the region and plays a key role in the formation of alluvial deposits. Climatic fluctuations (especially droughts) led to: the movement of the riverbed and the creation of ancient riverbeds – «yailov»; drainage of swamps and estuaries, which are now represented as salt flats; terraces formed around the valley, indicating the ancient phases of fluctuation of the water level. Geological consequences: the growth of thick layers of sandy-clay alluvium; formation of fertile but saline soils [7].

The foothills of Karatau are located at the junction of the desert and the mountainous climate. The influence of climatic factors (high temperature fluctuations, rare showers) causes physical weathering of rocks, mudflows after heavy rains, accumulation of loess and detrital material at the foot of the slopes. Geological consequences the formation of loess covers – loose, easily eroded. Activation of landslide processes at high humidity. The development of erosive relief forms – gullies [8].

Methods and materials

In the framework of this study, an integrated approach was used, including both materials from traditional geological methods and the theory of modern spatial analysis technologies. Lithological and stratigraphic analysis is used to study the sequence of sedimentary and igneous rocks in geological sections of Southern Kazakhstan, with the identification of rock characteristics by geological era. Paleotectonic analysis is used to reconstruct the tectonic evolution of a region in various geological periods, taking into account the formation of folded systems, faults and rift structures. Analysis of scientific, archival and stock materials – using data from the Geological Survey of Kazakhstan [9, 10]. The comparative geochronological method is used to establish the sequence of geodynamic events and compare processes in different structural and tectonic zones of the region. The research covered key geological regions of Southern Kazakhstan, including the foothills of the Tien Shan, the Karatau Range and other large geostructural units.

Results

The geological structure of the southern region of the Republic of Kazakhstan (RK) is diverse and complex (fig. 1). This region covers such regions as Turkestan, Zhambyl, Kyzylorda and partially Almaty regions. Southern Kazakhstan is located at the junction of various tectonic structures, including folded and platform zones. A brief overview of the geological structure.

1. *Tectonic structures.* The south of Kazakhstan is a part of the Tien Shan folded region and partly of the South Kazakhstan Plate. The following main tectonic zones are distinguished here. The Northern Tien Shan is a folded system formed as a result of Hercynian and later Alpine tectonics. It is represented by the Karatau, Talas Alatau and other ridges. The Turanian plate (platform) is a relatively stable structure covered by a sedimentary cover located in the west and southwest of the region. The Ferghana Trough is an intermountain depression that partially enters the southern regions of Kazakhstan.

Figure 1. Map of the geological structure of the Earth's surface in the southern region of the Republic of Kazakhstan.
Сурет 1. ҚР оңтүстік өңірінің жер беті құрылымының геологиялық құрылымының картасы.
Рис. 1. Карта геологической структуры строения земной поверхности южного региона РК.

2. *Lithological composition.* Precambrian and Paleozoic formations predominate in mountainous areas (for example, Karatau), and include metamorphosed shales, quartzites, limestones, and granites. Mesozoic and Cenozoic – widespread in the foothills and plains, especially in the basins of the Syrdarya and Chu rivers. Sandstones, clays, conglomerates and alluvial deposits predominate here. Sedimentary cover – within the Turanian plate, its thickness reaches several kilometers, and includes oil and gas horizons.

3. *Minerals.* Southern Kazakhstan is rich in mineral resources:

– *phosphorites (Karatau);*
– *uranium (deposits of Issyk-Kul, Yuzhny Inkul, etc.);*
– *polymetals (lead, zinc, silver);*
– *building materials (gypsum, limestones, clays);*
– *groundwater and thermal waters.*

4. *Modern geological processes.* Seismicity – southern Kazakhstan is located in a zone of increased seismic activity. Karst processes are characteristic of Karatau limestone rocks. Erosion and deflation are active in desert and semi-desert areas, especially in the Kyzylorda region.

This is a brief diagram of the geological structure of the southern region of the Republic of Kazakhstan. It shows the main tectonic and geological elements. The Turanian plate is located in the west, covered by a powerful sedimentary cover. The Northern Tien Shan and Karatau are folded mountain ranges in the central and eastern parts. The Ferghana Trough is an intermountain depression in the southeastern edge. Tectonic boundaries are dotted. The Turan platform is a large geostructural unit covering the west and south-west of Kazakhstan (Kyzylorda region and part of Turkestan). It is a stable area of the earth's crust with a thick sedimentary cover (table 1).

The Kumkol group of deposits – large deposits of oil and gas in the Jurassic sandstones. Aryskum, Aktobe, Yuzhny Turgay – promising oil and gas exploration areas. Reservoirs porous sandstones of Jurassic and Cretaceous. Tires, clay and salt deposits of the Cenozoic. Tectonic stability: little disturbed by faults, slow vertical movements. It is prone to precipitation accumulation, especially in the interfluves of the Syr Darya and Arys rivers.

The Turan Platform is one of the largest platform structures in Central Asia, covering a significant part of Western and Southern Kazakhstan. Its stratigraphic column reflects a long geological evolution from the Precambrian to the Cenozoic and is characterized by a pronounced platform sedimentary sequence (fig. 2).

Precambrian – the basement of the platform is represented by deep-lying metamorphosed complexes of the Archean-Proterozoic age, consisting mainly of gneisses, crystalline schists and granitoids. They do not come out on the surface, they are studied using seismic and drilling data. Paleozoic – the Paleozoic era is represented in a limited way in the column. Devonian and Carboniferous deposits are mainly developed in the southern and eastern parts of the platform, represented by terrigenous and carbonate strata, including limestones and dolomites. They indicate the development of marine basins and reef structures during a period of relative tectonic stability. Mesozoic – Triassic, Jurassic, and Cretaceous sediments are widely developed. Triassic it is mainly represented by conti-

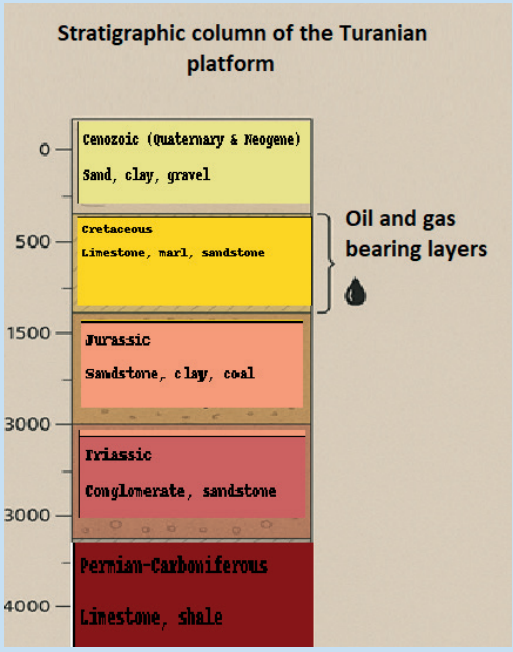

Figure 2. Sequence of geological layers of the stratigraphic column of the Turanian platform.
Сурет 2. Тұран платформасының стратиграфиялық бағанының геологиялық қабаттарының реттілігі.
Рис. 2. Последовательность геологических слоев стратиграфической колонки Туранской платформы.

Table 1

The structure of the sedimentary cover

Кесте 1

Шөгінді платформаның құрылымы

Таблица 1

Строение осадочной платформы

The geological period	Depth of occurrence, м	The main breeds	Characteristic
Cenozoic (Quaternary, Neogene)	0–500	Clays, sands, pebbles, Alluvial and Aeolian deposits	Modern precipitation, often aquifers
Cretaceous (Cretaceous system)	500–1500	Limestones, marls, and sandstones	Hydrocarbon Reservoir sites
Jurassic	1500–3000	Sandstones, clays, coals	Major oil and gas horizons (for example, in the Kumkol area)
The Triassic	3000–4000	Conglomerates, sandstones	Deep reservoirs, sometimes with oil/gas residues
Perm and carboniferous (in places)	> 4000	Limestones, shales	Residual sections of the foundation

nental terrigenous deposits – sandstones and siltstones. Jurassic characterized by alternating marine and lagoon facies with a predominance of coal-bearing layers, which is associated with the formation of swampy conditions. Chalk it is represented by thick strata of sandstones, clays and marls, including those of marine origin, which indicates transgression. Cenozoic – the most powerful part of the sedimentary cover. Paleogene represented by marine clays, limestones, phosphorites. Neogene and Quaternary period: expressed in the form of continental Alluvial, Lacustrine and Aeolian deposits. During this period, precipitation actively accumulated in an arid climate and the modern stage of tectonic uplift and erosion began. Features

The total thickness of the sedimentary cover reaches 5–8 km in the troughs and intermountain depressions. The column is well stratified, especially in oil and gas bearing areas, which makes the region important from the point of view of geological exploration. Here is the stratigraphic column of the Turanian platform. It shows the sequence of geological layers from the Cenozoic to the Carboniferous/Permian, indicating the depths, rock types and oil and gas horizons (fig. 3).

3D figure of the section of the Turan platform: the sedimentary cover layers are presented indicating the geological periods (from the Cenozoic to the Permian), as well as hydrocarbon deposits in the Jurassic and Cretaceous sandstones. Aquifers of the Turan platform, especially in the south of Kazakhstan (Kyzylorda and Turkestan regions) (table 2).

The Syrdarya Valley is the most water-rich area with a developed upper alluvial horizon. Arys-Turkestan region has a developed shallow aquifer used for household needs and irrigation. Kyzylorda region – lenticular horizons of fresh water in saline sediments are frequent and require local study. Hydrogeological significance: the main horizons are used for centralized and decentralized water supply; agriculture (irrigation); for drinking and technical needs. Waters often have high pressure (pressure horizons), especially at depths > 300 m.

The modern geological structure of the Karatau plate (Karatau ridge/anticlinorium), located in the southern region of the Republic of Kazakhstan, is part of the complex tectonic

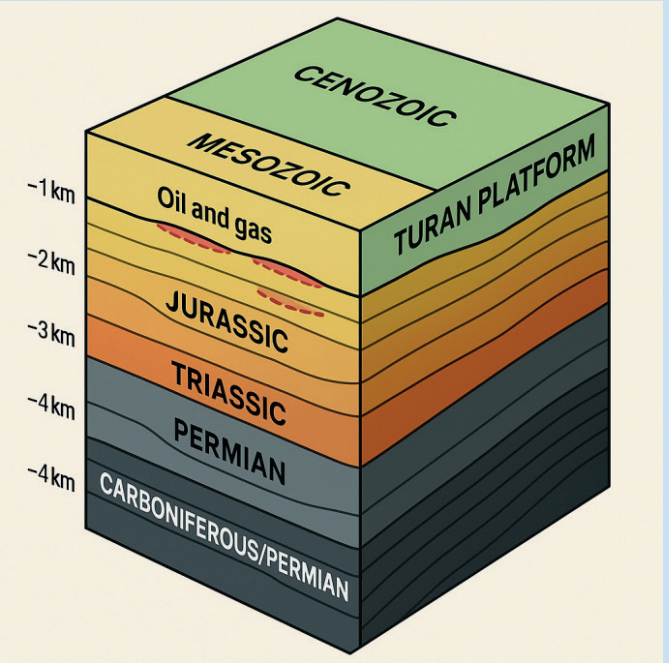

Figure 3. Total thickness of sedimentary rock of the Turanian platform.
Сурет 3. Тұран платформасының шөгінді жыныстарының жалпы қуаты.
Рис. 3. Общая мощность осадочной породы Туранской платформы.

and structural framework of the Tien Shan orogenic belt. Lies in the transitional zone between the Turan Platform (west) and the Tien Shan orogen (east). Extends NW-SE across Turkistan and Zhambyl regions. Karatau is a Paleozoic fold system forming an anticlinorium structure. It is uplifted and deformed, with numerous thrusts and faults. Represents a structural high, separating deep sedimentary basins.

Changes in the geological structure of the earth's surface in the southern region of the Republic of Kazakhstan under the

Table 2

The main aquifers of the Turan platform

Кесте 2

Тұран платформасының негізгі Сулы қабаттары

Таблица 2

Основные водоносные горизонты платформы Туран

Geological level	Depth of occurrence, м	Type of waters	Characteristic
Quaternary (Cenozoic)	0–50	Fresh (HCO_3-Na, HCO_3-Ca)	Alluvial-delta and floodplain deposits along the Syr Darya. The main source of water supply.
Pliocene–Miocene (Neogene)	50–300	Slightly Mineralized	Sandy-clay strata are often used for land reclamation.
Cretaceous (Cretaceous system)	300–600	Fresh and slightly mineralized	Interplastic horizons, occur in sandstones and limestones.
Jurassic	600–1500	Brackish – mineralization up to 5–10 g/l	Deep waters are found in areas with fractured reservoirs.
Triassic and below	> 1500	Highly mineralized	They are practically not used because of the salinity and depth.

influence of climatic factors are an important aspect of modern geomorphology and engineering geology.

Changes in the geological structure under the influence of climate. 1. Aridization (increased aridity): South Kazakhstan belongs to the zone of arid and semiarid climate, which leads to increased wind erosion (Aeolian processes – dunes, sand ridges); deflation and blowing of fine earth from the surface of the sedimentary cover; formation of salt marshes and dry lake basins (like Sarykamys). 2. Fluctuations in groundwater and surface water levels: climate change affects water exchange in aquifers reduction of groundwater level → shallowing of springs and wells; the salinity of soils increases with the rise of saline groundwater; clay shrinkage and fracturing in Cenozoic sediments. 3. Surface processes (modern geodynamic changes): landslides and landslides in clay and loess rocks with rare but heavy rainfall; karst processes in limestones (especially in areas of Cretaceous deposits); fluvial processes – processing of Syrdarya, Arys, and Chu river valleys formation of new river terraces; activation of riverbed erosion 4. Climatic cycles of the Quaternary period: traces of glacial and interglacial epochs are pronounced fluctuations in the thickness of Quaternary sediments; alternating humus and barren horizons. The changes are most noticeable in the Ferghana and Chu-Sarysui basins – weathering, deflation, carbonate crusts; the foothills of Karatau and Talas Alatau – active talus, mudflows; in Kyzylkum – progressive desert with shifting sands (fig. 4).

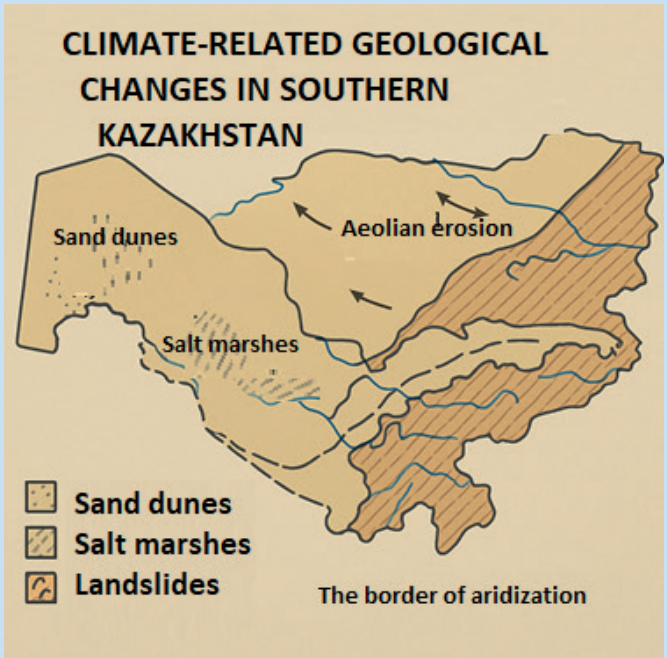

Figure 4. Geological climate-induced changes in the southern region of Kazakhstan.
Сурет 4. Қазақстанның оңтүстік өңіріндегі климаттан туындаған геологиялық өзгерістер.
Рис. 4. Геологические изменения, вызванные климатом, в южном регионе Казахстана.

Climate-related geological changes in Southern Kazakhstan are associated with the impact of climate change on natural processes occurring in the geological environment. The following major climate-related geological changes are observed in the region. Due to the intensification of dry periods and rising temperatures, as well as changes in precipitation distribution, the erosion process is significantly enhanced. This leads to the loss of fertile soils, deterioration of land quality and reduction of agricultural potential.

Soil moisture after heavy rains, as well as changes in precipitation patterns, lead to the activation of mudslides, landslides and other geodynamic processes. These phenomena are becoming more frequent and destructive, threatening agriculture, infrastructure and the population. Climate changes, such as decreased precipitation and rising temperatures, affect the region's water resources. This leads to a decrease in the level of rivers, lakes, and reservoirs, as well as changes in the hydrological regime, which in turn affects geological processes such as coastal erosion and riverbed changes. Due to rising temperatures and changing wind conditions, the frequency of sandstorms is increasing in the southern region, which increases the processes of sand drifting and soil destruction. This affects agricultural land and may threaten residential areas. These climate-related changes require the development of effective measures to protect the ecosystem and infrastructure of the region, including the management of water and land resources, as well as the creation of early warning systems for possible natural disasters (fig. 5).

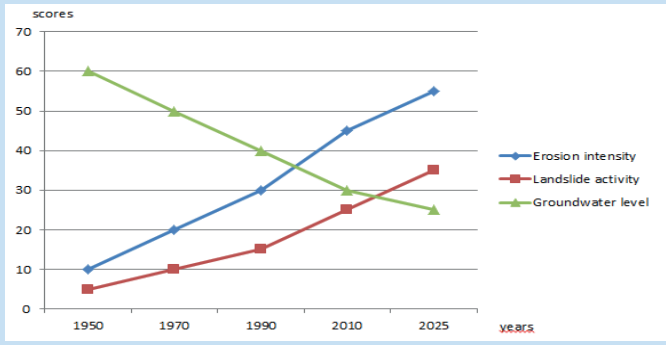

Figure 5. Graph of dynamic changes in the geological structures of Southern Kazakhstan.
Сурет 5. Оңтүстік Қазақстанның геологиялық құрылымдарының динамикалық өзгеру сызбасы.
Рис. 5. График динамических изменений геологических структур Южного Казахстана.

The graph reflects changes in geological processes over time due to the influence of climatic factors. The graph shows such parameters as:

– the frequency and intensity of mudslides and landslides – there has been an increase in recent decades, especially in mountainous areas (Tien Shan, Karatau).

– the level of soil erosion shows a steady upward trend, especially in dry years with severe rain events.

– riverbed changes – displacements and washouts are recorded, especially due to melting glaciers and seasonal floods.

– the rate of degradation of the landscape is gradually increasing, as can be seen from the expansion of desertification zones and a decrease in groundwater levels.

The graph shows that since the 1990s, in parallel with rising global temperatures and changing precipitation patterns,

geological processes in the region have become more active and destructive, which requires attention from scientists, environmentalists and natural resource management authorities.

Conclusions

Southern Kazakhstan is characterized by a complex geological structure that includes diverse geomorphological units such as mountain systems, plains, steppes, and deserts. These structures determine the tectonic activity of the region, as well as the availability of natural resources such as minerals, water and soil, which makes this region important from an economic point of view. The climatic conditions of the region significantly affect the dynamics of geological processes. Rising temperatures, changes in precipitation patterns, increased dry periods, and an increase in the frequency of extreme climatic events (such as rains, mudslides, and sandstorms) contribute to accelerated soil erosion, rock destruction, and disruption of hydrological cycles. Climate change leads to a reduction in the volume of water resources in the region, which affects water supply for both agriculture and human settlements. Rivers, lakes, and reservoirs do not have enough water, which leads to changes in their geological activity (changes in water levels, waterlogging, etc.).

Geological processes activated by climate change increase the risks to the region's ecosystems. Erosion processes, changes in riverbeds and mountain slopes, as well as the intensification of mudslides and landslides can threaten the sustainability of agriculture, infrastructure and residential areas. Natural disasters such as floods and landslides are becoming more frequent and destructive.

In the context of climate change, adaptation strategies must be developed that include integrated management of water and land resources, improvement of infrastructure to protect against natural disasters, and creation of a system for monitoring and forecasting geological processes caused by climate change. The geological processes of Southern Kazakhstan are closely interrelated with climate change, and for the effective use of the region's natural resources, as well as to minimize risks, it is necessary to take these changes into account when planning the sustainable development of the region. It is important to continue research to better predict the impact of climate change and develop adaptation measures.

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