Гидрометеорология и экология

Scientific article

THE IMPACT OF CLIMATE CHANGE ON THE LANDSCAPE DYNAMICS OF TURKESTAN REGION: SPATIO-TEMPORAL ANALYSIS

Dana Akhmetova[1*], Zhanar Ozgeldinova[1] PhD, Nurgul Ramazanova [1] PhD, Aigul Yeginbayeva[1] PhD, Rabiga Kenzhebay[2] candidate of pedagogical sciences

[1]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan; akhmetovadanaaa@mail.ru (DA), ozgeldinova@mail.ru (ZhO), nurgulram@gmail.com (NR), aeginbaeva@mail.ru (AYe)
[2]Auezov South Kazakhstan State University, Shymkent, Kazakhstan; mega.rabiga@list.ru (RK)
Corresponding author: Dana Akhmetova, akhmetovadanaaa@mail.ru

KEY WORDS

climate change
spatiotemporal analysis
palynological analysis
plant communities
climate adaptation
paleoclimatic research
stratigraphic data
historical transformation of vegetation
Turkestan region

ABSTRACT

This study focuses on analyzing the long-term development of landscapes in the Turkestan region and the impact of climate change on regional landscapes. Through palynological and stratigraphic analyses, the influence of climatic fluctuations on plant communities and landscape structure from the Oligocene to the Holocene was identified. The research revealed that the vegetation cover in the Turkestan region has developed adaptation mechanisms to cope with climatic changes. It was determined that the current landscapes of the Turkestan region were shaped as a result of historical climatic instabilities, forming the foundation for the resilience of the region's vegetation. The findings enhance our understanding of the evolution of regional landscapes and provide insights into developing strategies for sustainable adaptation to climate change. It has been established that the present-day landscapes of the Turkestan region formed as a result of adaptation to historical climatic changes. These findings are essential for devising strategies for preserving regional vegetation cover and ensuring sustainable adaptation to climate change. The results obtained deepen our understanding of the landscape evolution and resilience mechanisms in the Turkestan region, providing a basis for assessing the region's future ecological stability.

About article:
Received: 10.11.2024
Revised: 21.03.2025
Accepted: 28.03.2025
Published: 31.03.2025

For citation :
Akhmetova D., Ozgeldinova Zh., Ramazanova N., Yeginbayeva A, Kenzhebay R. The impact of climate change on the landscape dynamics of Turkestan region // Гидрометеорология и экология, №1 (116), 2025, 100-115.

1. INTRODUCTION

In the present era, global climate change has emerged as one of the foremost ecological threats, adversely affecting the stability of natural environments and the preservation of biodiversity. The persistent rise in temperatures, shifts in the geographical distribution of atmospheric precipitation, and intensifying water scarcity are particularly evident in arid and semi-arid regions. These ecosystems exhibit heightened sensitivity to climatic fluctuations due to their dependency on water resources and the reduced ecological stability of natural systems, which is further exacerbated under anthropogenic pressure. In this context, the desert and semi-desert landscapes of the Turkestan region are of particular significance for research, as they serve as a clear example of the impact of climate change [1].

The landscapes of the Turkestan region are complex systems that have evolved over millennia through adaptation to climatic changes. Studying these landscapes is significant not only for reconstructing historical geoecological conditions but also for predicting how current ecosystems might respond to changing climatic factors [2]. Paleoclimatic and paleobotanical research serve as essential tools for understanding the dynamics of landscape formation and assessing the impact of past climatic conditions. In particular, historical records of plant communities act as reliable indicators capable of accurately reflecting long-term climatic changes [3].

IRSTI 39.19.29 https://doi.org/10.54668/2789-6323-2025-116-1-100-115 UDC 433

The significance of this study lies in its ability to reconstruct the landscape structure of the Turkestan region by analyzing paleobotanical remains to investigate changes in vegetation cover during past geological epochs [4]. These studies aim to evaluate the landscape evolution of the region within the context of climatic fluctuations and to predict potential scenarios of future ecological changes. Establishing a scientific basis for ensuring the stability of natural systems in the desert and semi-desert areas of the Turkestan region represents the core scientific and practical relevance of this research [5].

The primary objective of this study is to scientifically substantiate the leading role of climatic factors in the formation and long-term evolution of landscapes in the Turkestan region.

To achieve this goal, the following scientific and methodological tasks were defined:

Conduct an in-depth analysis of the paleoclimatic conditions that influenced the formation of landscapes in the Turkestan region;

Determine the historical transformation of plant communities and their interrelation with climatic factors;

Perform a comprehensive analysis of the evolutionary changes in landscapes based on stratigraphic and paleobotanical data.

The chosen research object is the landscapes of the Turkestan region (Figure 1), as this area directly experiences the impact of climatic changes and serves as a critical zone for assessing geosystem stability.

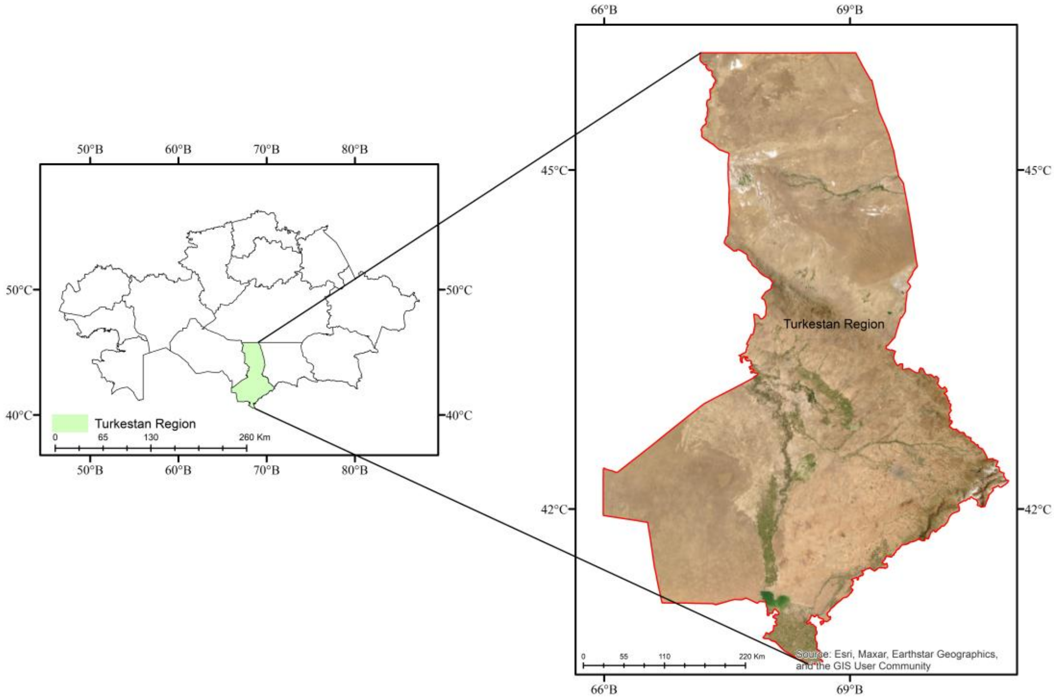

Figure 1. *Map of the Study Area*

The research focus is on the patterns and mechanisms by which climatic factors influence the composition, structure, and spatial distribution of vegetation in the Turkestan region. The selection of this area as the research subject is justified by the high sensitivity of its ecosystems to climatic fluctuations and the critical role of vegetation cover in determining the stability of regional ecosystems.

The results of the study demonstrated that climatic factors played a decisive role in the formation and long-term evolution of landscapes in the Turkestan region. A comprehensive analysis of paleobotanical and stratigraphic data revealed that changes in plant communities were closely linked to climatic fluctuations during past geological periods. Based on this data, the paleoclimatic dynamics of the region were reconstructed, allowing for an assessment of the long-term impacts of climate on regional landscapes.

The obtained data illustrate how the landscapes of the present-day Turkestan region have adapted to climatic fluctuations and highlight that these adaptation mechanisms are closely tied to long-term evolutionary processes. Within the scope of the study, the analysis of the historical evolutionary changes in the landscapes of the Turkestan region provided deeper insights into the impact of climate on regional ecosystems.

Overall, this research was aimed at scientifically evaluating the long-term effects of climatic factors on regional landscapes. The findings significantly contribute to understanding the historical changes in the landscapes of the Turkestan region and the patterns of their adaptation to climatic factors.

2. MATERIALS AND METHODS

The Turkestan region was selected as the study area due to its diverse landscape complexes formed under continental climatic conditions. The natural features of the region include various geomorphological structures such as plains, river valleys, and foothills. The climate in this area is characterized by aridity, with long, hot summers and mild winters, which directly influence the dynamics of its landscapes. The plant communities of the Turkestan region exhibit high sensitivity to climatic changes, providing a favorable context for studying their ecological adaptation mechanisms. The geographical and climatic characteristics of the area hold significant scientific value for exploring the long-term landscape evolution through paleoclimatic analysis.

Palynological analysis was utilized as the primary source of data for this study, as it enables a deeper understanding of the historical evolution of landscapes and the climatic changes in the region. During the research, pollen samples were collected from various ecosystems across the Turkestan region. These samples were used to examine the changes in plant communities and their adaptation to climatic factors [6].

Methods of Palynological Analysis: The palynological data employed in this study were sourced from previously published scientific works [7]. These data sets included processed pollen samples that were prepared for analysis, ensuring that the results obtained in this research were directly based on information validated by the scientific community. During the palynological studies, pollen grains were identified using microscopy to determine their species composition and quantitative proportions. This method enabled the reconstruction of climatic conditions and the distribution of vegetation in ancient geological periods, providing critical data for understanding the historical evolution of landscapes in the Turkestan region [8].

Statistical Modeling Based on Probability Theory: To evaluate the adaptation of plant communities in the Turkestan region to climatic factors (temperature and precipitation), a statistical model grounded in probability theory was applied [9]. A normal distribution function was employed to describe the survival probability of plants, modeling how variations in climatic parameters influence the survival rates of different plant species (Equation 1).

The model's formula is as follows:

$$P(T,R) = \exp\left(-\frac{(T-T_{opt})^2}{2\sigma_T^2} - \frac{(R-R_{opt})^2}{2\sigma_R^2}\right) \qquad (1)$$

Description of variables:

P(T,R) — probability of plant survival under given temperature (T) and precipitation (R) conditions;

T — actual temperature;

R — actual precipitation amount;

T_{opt} and $\boldsymbol{R_{opt}}$Ropt — optimal temperature and precipitation levels for the plant species;

$\boldsymbol{\sigma_T}$ және $\boldsymbol{\sigma_R}$ — mean deviations of temperature and precipitation.

Data Processing and Analysis Methods: The data collected in the study were processed and incorporated into the model. The effects of temperature and precipitation levels on the survival probabilities of plant species were quantitatively evaluated. The results obtained provided insights into the paleoclimatic evolution of the landscapes in the Turkestan region and the adaptation of current ecosystems to climatic changes.

Interpretation of Results: The model-derived data were analyzed to draw conclusions on how climate changes influence the structure of plant communities. The results established a scientific basis for predicting the long-term effects of climatic fluctuations on regional landscapes and for understanding mechanisms of ecological adaptation.

This study provided an understanding of how plant communities in the Turkestan region adapt to climate change and helped identify the long-term stability of ecosystems. By integrating palynological and statistical methods, it was possible to reconstruct the ecological history of the region and forecast the potential impacts of future climate changes.

3. RESULTS AND DISCUSSION

The study results revealed that climate changes during the Oligocene significantly impacted the vegetation cover in the Turkestan region. Drawing on data from various scholars [11], palynological research conducted in the Bosaga area of the Tamdytau region demonstrated that the climate during the Oligocene was characterized as dry and continental.

During this period, the uplift of the Himalayas, Tibet, and Tien Shan mountains, along with the recession of the Tethys Sea, restricted the spread of moisture-bearing air masses into the region, leading to a more continental and arid climate [12]. The annual precipitation was approximately 200…300 mm, decreasing to below 200 mm towards the end of the period. The average annual temperature was around 16,5°C, forcing the vegetation cover to adapt to these changes.

The probability of survival for various plant species was calculated using a probabilistic model during the study. The results enabled a quantitative assessment of the adaptability of plant species to changing climatic factors.

Juglans sp.: This species requires a temperate and humid climate. However, due to low precipitation levels during the Oligocene, its survival probability decreased to 0,37 %. These data indicate that walnut had a limited distribution in dry climates.

Quercus sp.: Oaks exhibited high drought tolerance, with a survival probability of 12,94 %, indicating their adaptability to the arid climate of the Turkestan region.

Betula sp.: The survival probability for birch was 7,19 %, suggesting that although birches were present in dry climatic conditions, they were limited to specific areas.

Palmae sp.: Being dependent on tropical and subtropical climates, palms had a survival probability of only 0,02 %. This indicates that palms were rare in the region during the Oligocene, surviving only in microclimatic niches.

Pinaceae: Pines were identified as species well-adapted to cold and dry climates, with a survival probability of 21,38 %. This reflects their ability to withstand seasonal droughts, allowing them to become widespread in the region.

According to data by I.S. Suleimanov (1967), the spore-pollen spectra collected from the Bosaga area revealed the composition of vegetation during the Oligocene period. The high proportion of angiosperm pollen (60…71 %) indicates their dominance during this time. Gymnosperms (9…24,5 %) and spores (0.5…6 %) accounted for lower shares. These findings highlight the degree of plant cover adaptation to the prevailing climate. The study results indicate that during the Oligocene, the climate of the Turkestan region was significantly drier and more continental than it is today. Low precipitation levels and high temperatures had a substantial impact on the structure of the vegetation cover. Drought-resistant species such as pines and oaks became widespread, while moisture-loving species like walnuts and palms were confined to limited microclimatic areas.

The climatic changes during the Oligocene had a profound effect on the landscapes of the Turkestan region. The reduction in precipitation and increase in temperatures contributed to the development of an arid climate, favoring the spread of only drought-adapted plant species. The uplift of mountain ranges and the recession of the Tethys Sea restricted the influx of moisture-bearing air masses, which further intensified the continental climate. These changes reshaped the vegetation structure, leading to the dominance of drought-tolerant species in the region's landscapes.

The assessment of climatic conditions in the Turkestan region during the Oligocene and their impact on vegetation using paleoclimatic and probabilistic modeling methods has provided deeper insights into the region's ecological history. Palynological data demonstrated how plant communities adapted to climatic changes. Literature sources and study findings confirm the increase in continentality of the climate due to the recession of the Tethys Sea and the uplift of mountain ranges [12].

Overall, this research has laid the foundation for a scientific re-evaluation of the historical development of landscapes in the Turkestan region and the climatic adaptation of its vegetation cover.

During the Early to Middle Miocene, the climatic conditions in the Turkestan region underwent significant changes, which also impacted the vegetation cover. The climate at that time was hotter and drier than it is today. The average annual temperature was estimated to be around +5°C, with annual precipitation levels at approximately 400 mm [13]. These climatic conditions significantly limited the survival of various plant species. The dominance of semi-desert and desert landscapes, along with the spread of drought-tolerant plants, led to the development of an ecosystem that was well-adapted to harsh, arid conditions.

The study results have revealed the adaptation mechanisms of plants in response to climatic changes. Drought-resistant species such as the Chenopodiaceae, as well as Labiatae and Geraniaceae common in semi-arid landscapes, demonstrated resilience to climatic fluctuations. The survival probability of the Chenopodiaceae was 1,81 %, indicating its limited distribution in cold and dry climates. Labiatae had a survival probability of 2,07 %, suggesting their presence only in regions closer to temperate climates.

The survival probabilities of temperate-climate-preferring trees, such as Juglans and Quercus, were notably low. The walnut's survival probability was merely 0,01%, while that of the oak was 1,83 %. This indicates their minimal distribution or confinement to small areas during the cold and arid Miocene climate.

The cold and dry climate of the Miocene exerted substantial ecological pressure on the vegetation cover in the Turkestan region. The distribution of forest plants was significantly restricted, while drought-resistant species became dominant. The predominance of semi-desert and desert plants during this period reflects the development of ecosystems adapted to the region's harsh climatic conditions.

The cold and dry climate of the Miocene had a profound impact on the landscapes of the Turkestan region. Decreasing precipitation and lower temperatures led to the expansion of semi-desert and desert ecosystems. Drought-resistant species dominated, while the distribution of temperate-climate trees became limited. During this period, forested landscapes were replaced by semi-desert and arid landscapes. Climate change significantly altered the structure of the region's ecosystems, favoring the survival of only drought-adapted species.

The cold and dry climatic conditions of the Miocene period significantly altered the structure of the vegetation cover in the Turkestan region. Drought-tolerant plants, particularly species such as Chenopodiaceae, Labiatae, and Geraniaceae, became dominant, while temperate-climate trees like Juglans and Quercus survived only in limited areas. These climatic changes provide insights into the ecological adaptation mechanisms of plants and the historical development of regional landscapes.

By the end of the Pliocene, climatic conditions in the Turkestan region underwent significant changes. The southward shift of the subtropical zone, along with a cooling trend, led to the establishment of a cold and dry climate in the region. The average annual temperature dropped to about 2…3°C, with precipitation levels around 300 mm [13]. These climatic shifts had a substantial impact on the vegetation cover, as the cold and arid conditions imposed limitations on plant adaptation during this period.

The study results indicate that the cold and dry climatic conditions during the Pliocene had a significant impact on the distribution of plant species. Coniferous trees such as Alnus and Pinus were relatively well-adapted, with survival probabilities of 10,54 % for alder and 15,97 % for pine. This suggests that these trees were well-suited to cold and arid climates and played an important role in the region's ecosystems.

However, the cold and dry climate restricted the distribution of some plants. For instance, Betula had a survival probability of only 0,17 %, indicating that despite its drought tolerance, it struggled to thrive in extremely cold conditions. Additionally, xerophytes like Chenopodiaceae and Artemisia were adapted to drought but were still limited by the cold climate. The survival probability for Chenopodiaceae was 0,86 %, and for Artemisia, it was 4,39 %.

The cooling climate of the Pliocene and the dominance of drought-resistant plants shaped the region's landscape structure. Drought-tolerant species such as Chenopodiaceae and Artemisia were widespread during this period, while temperate-climate-preferring species like Betula and Juglans had a much more restricted presence. Semi-desert and desert landscapes became dominant, with forested areas shrinking significantly.

The cold and arid climate of the Pliocene had a profound impact on the landscapes of the Turkestan region. The dominance of drought-tolerant species contributed to the expansion of semi-desert and desert landscapes. The distribution of forest plants was limited, with only temperate-adapted species persisting in small isolated areas. These climatic changes not only influenced the formation of desert landscapes but also shaped the structure of present-day ecosystems.

During the Pliocene period, the cooling climate in the Turkestan region significantly influenced the distribution of drought-adapted plants. Coniferous trees such as Pinus and Alnus demonstrated high adaptability, while drought-resistant species like Chenopodiaceae and Artemisia exhibited lower survival probabilities. This period was marked by the expansion of semi-desert landscapes and structural changes in the vegetation cover driven by climatic shifts.

In the mid-altitude zones of Central Asia, glacial periods intensified drought conditions, promoting the expansion of desert areas. The gradual enlargement of the Karakum and Kyzylkum deserts is evidenced by the increase in loess deposits. The frequent glacial-interglacial cycles during the Middle Pleistocene became a key factor driving overall aridification in Central Asia.

Climatic Changes During the Holocene: According to I. I. Borzenkova [14], during the warming phases of the Holocene, improved moisture conditions were observed in regions such as the Aral and Balkhash areas of Central Asia. In contrast, periods of global cooling led to increased aridification in the region. The study of Holocene climatic conditions in the Turkestan region revealed conflicting perspectives among researchers.

These studies provide deeper insights into how climatic changes influenced the development of the natural environment in the Turkestan region and highlight how human activities adapted to these changing conditions. The analysis of scientific research indicates that the climatic conditions of the Holocene underwent several phases: cooling, warming, increased moisture, and alternating cool-humid and warm-humid phases. Such fluctuating climatic conditions had a pronounced impact on relatively small areas like the Turkestan region.

During the pre-Holocene and its initial phases, a sharp increase in birch (Betula) pollen was observed in the spore-pollen spectra (SPS). This surge is associated with glaciation, abundant meltwater, and elevated soil moisture levels. Around 12,000 to 10,000 years ago, following the intensive degradation of glaciers, xerothermic conditions in the region were restored. Factors contributing to this included the absence of competition with other tree species and the substantial accumulation of morainic substrates enriched by glacial and meltwater.

According to K.S. Afanasyev [15], birch trees formed distinctive forest patches at elevations above 2700 meters near glaciers in the Aksu area. The spread of birch forests in the pre-Holocene period was driven not directly by climatic changes but by the abundant soil moisture resulting from glacier melt. Spruce (Picea) forests were located at higher elevations, primarily on north-facing slopes.

At the beginning of the Holocene, a decline in birch forests was observed. Xerophytic plants – such as Artemisia (wormwood), Chenopodium (goosefoot), and Ephedra – became dominant on southern slopes. Semi-deserts and dry steppes expanded across foothills and plains. In the high mountain zones, moist meadows and Kobresia grasslands were prevalent on north-facing slopes and in the lower sections of valleys.

The melting of glaciers in the Tien Shan Mountains was largely completed around 12,000 to 10,000 years ago, leading to the formation of the last morainic complexes. In the mountainous areas of southern Turkestan, glacier retreat coincided with the re-establishment of woodlands. Initially, these forests were dominated by birch and moisture-loving herbaceous plants. Spore-pollen data from the Kainar Bog indicate that birch pollen made up to 30 % of the samples during this period, reflecting abundant moisture in the region (see Figure 2).

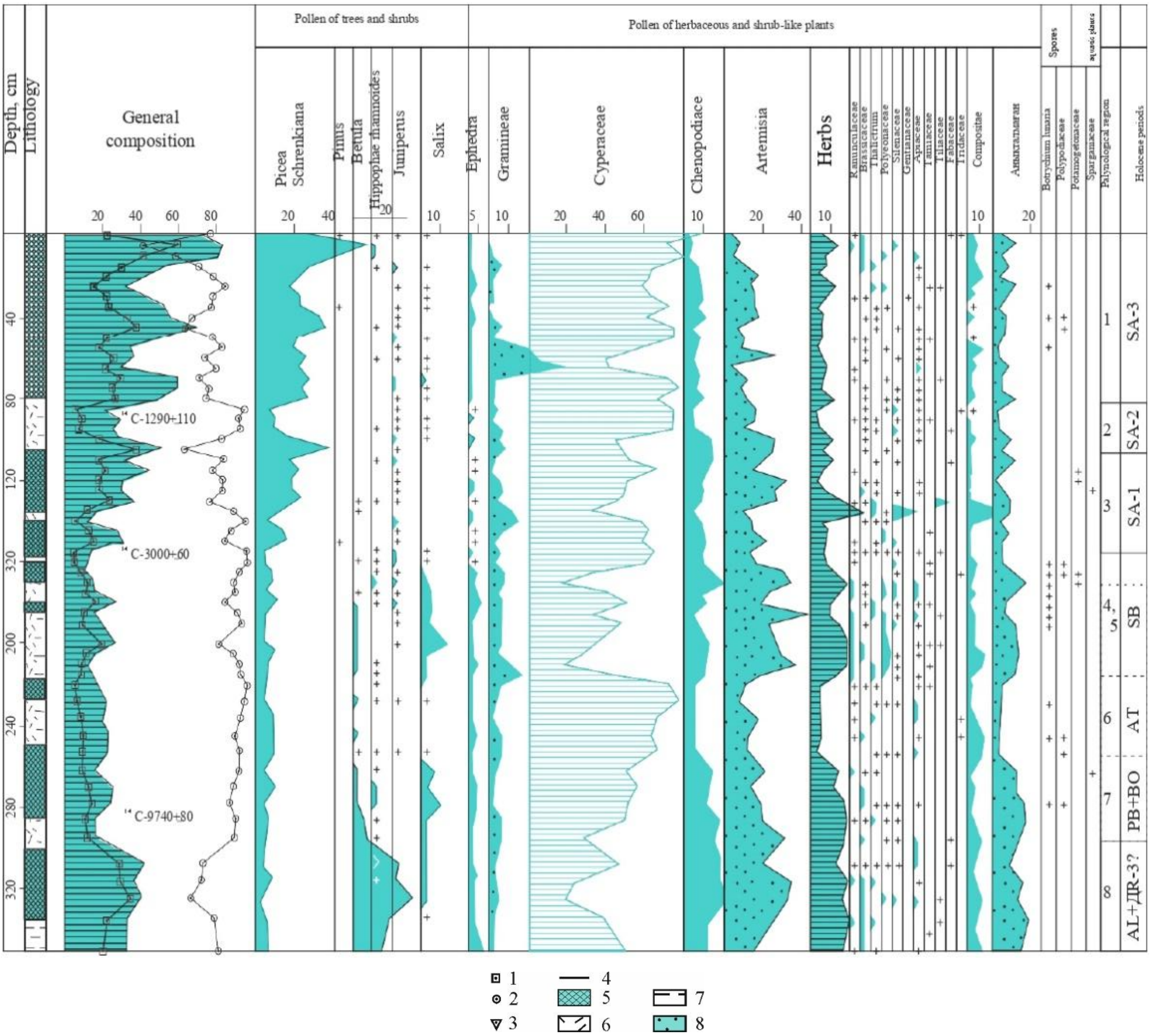

Figure 2. *Spore-pollen diagram of the Kainar Bog [16] (Northern slope of the Terskey Alatau Range, at an altitude of 2350 m above sea level)*

Legend: 1 – pollen of trees and shrub-like plants, 2 – pollen of herbaceous plants and subshrubs, 3 – spores, 4 – pollen of sedges (excluding tree pollen), 5 – peat, 6 – clays with plant remains, 7 – clays, 8 – sand and gravel

In the Middle Holocene (approximately 7,500 to 5,000 years ago), the climate became drier, leading to an increase in the xerophytization of vegetation (see Figure 3). Research conducted in the Aylama Bog indicates an increase in the prevalence of Ephedra (joint-pine), Artemisia (wormwood), and grasses. During this period, drought-resistant plants became dominant. In the foothills of the Turkestan region, Ephedra, Artemisia, and grasses also spread widely. In the lower zones, semi-desert and dry steppe landscapes became established.The current semi-deserts and steppes are considered a continuation of the climatic and vegetation patterns from this period. The widespread distribution of birch forests in the foothills of the Turkestan region during the Early Holocene suggests the occurrence of short-term humid phases. These conditions play a crucial role in understanding the climatic characteristics of the region, as the close relationship between plant communities and climate during the Early Holocene highlights their interdependence.

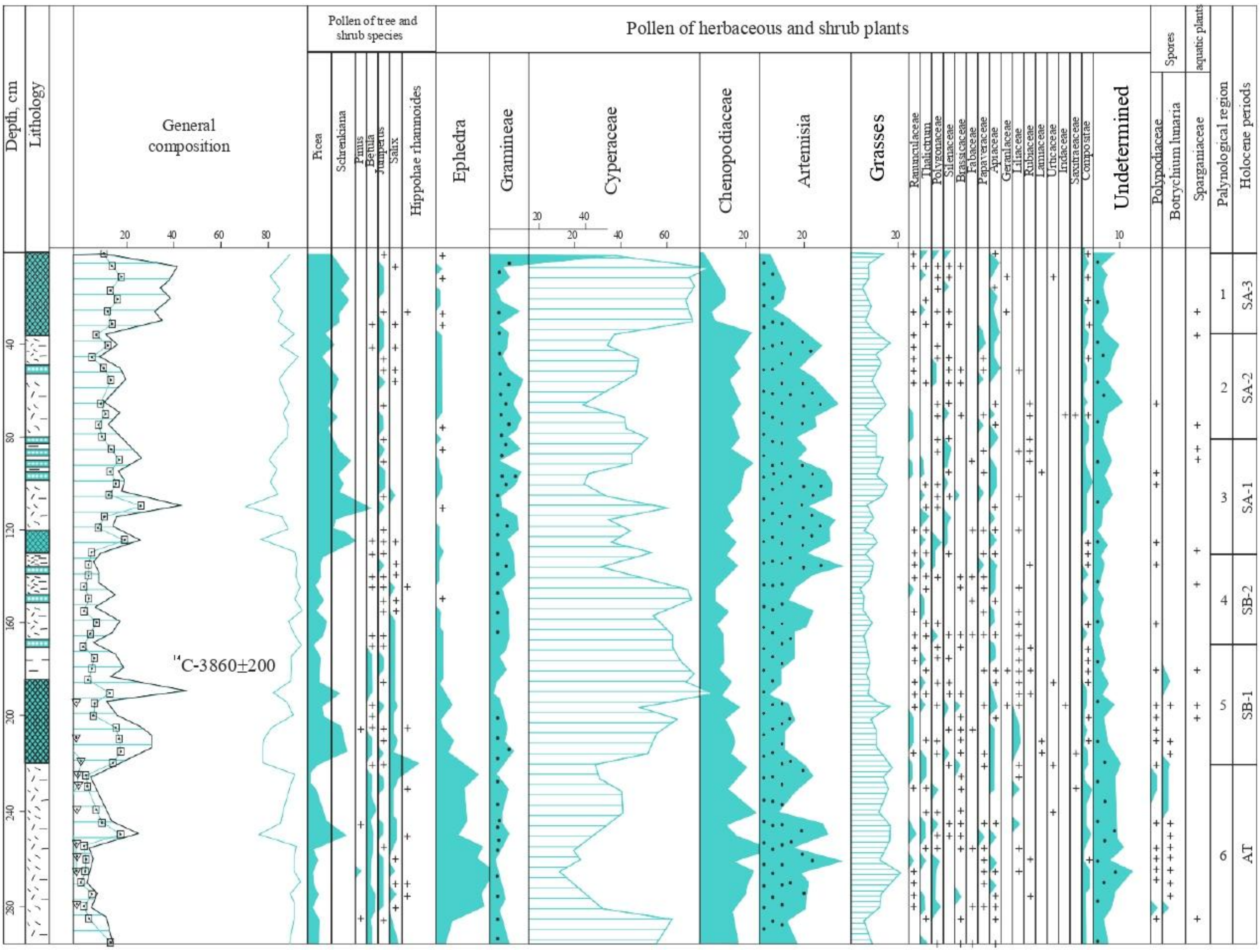

Figure 3. *Spore-pollen diagram of the Aylama Bog [16] (Northern slope of the Terskey Alatau Range, Chon-Kyzylsu River valley, at an altitude of 3250 m above sea level, subalpine belt) Legend: as in Figure 1.*

The Early Holocene Period (12…8 thousand years ago) was characterized by glacial melting, resulting in abundant meltwater, which significantly increased soil moisture. This created favorable conditions for the development of forest communities. Spore-pollen data indicate that during this period, the proportion of birch pollen was particularly high. For instance, studies at the Kainar Bog show that birch pollen accounted for up to 30 %, indicating a relatively moist climate. The soils nourished by meltwater supported the growth of forest stands.However, in subsequent periods, a trend toward drier climate conditions began, leading to a decline in birch forests and their replacement by xerophytic plants. This transition laid the foundation for the current desertification processes observed in the mountainous regions of the Turkestan area. The transformation of forest landscapes was directly linked to the degradation of glaciers and increasing aridification.

In the Middle Holocene, climatic changes had a significant impact on the region's landscape. According to paleoclimatic studies, glaciers receded substantially during this time, and new forests may have formed at elevations between 2,200…2,400 meters above sea level. These changes coincided with the retreat of glaciers in the Tien Shan ranges.

The initial composition of these forests included birch and moisture-loving herbaceous plants. However, around 6…5 thousand years ago, a drying trend became evident. This resulted in a decrease in the proportion of spruce and birch pollen, while xerophytic plants like Artemisia (wormwood), Ephedra, and grasses became more widespread. The formation of xerophytic communities in the foothills of the Turkestan region was a significant outcome of this period (see Figure 4).

During this phase, the increasing prevalence of Ephedra, Artemisia, and grasses indicates the dominance of drought-resistant species. This marks a gradual trend toward aridification in the region's climatic conditions.

In the Late Holocene (around 3,000 years ago), a significant increase in arid conditions was observed in the Turkestan region (see Figure 5). During this period, glaciers were restricted to higher elevations, situated significantly above their current levels. The decline of forested areas was accompanied by the establishment of xerophytic plant communities on south-facing slopes. This transition underscores the persistence of drier conditions and the adaptation of vegetation to increasingly harsh environments.

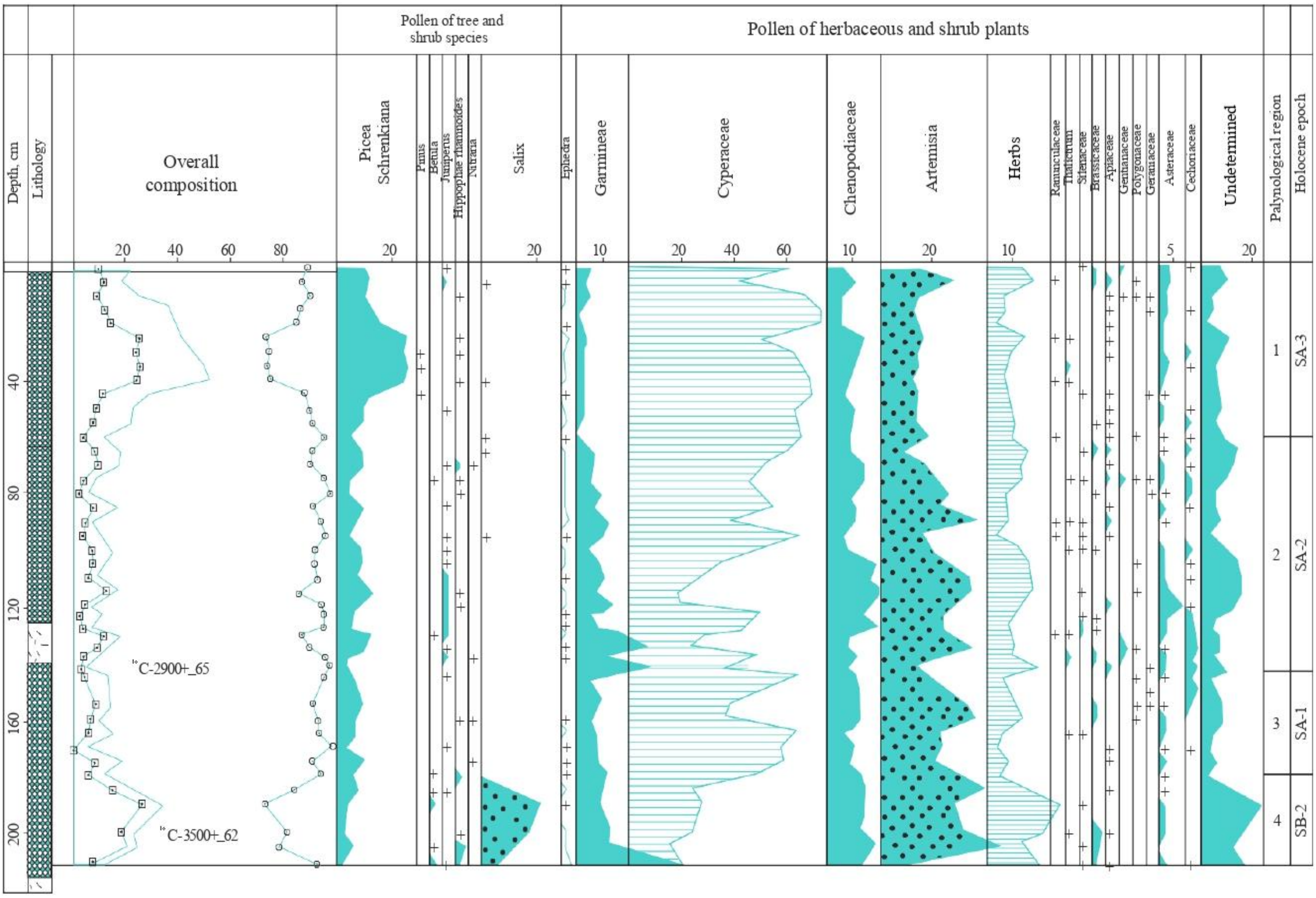

Figure 4. *Spore-pollen diagram of the Sharkratma Peat Bog [16] (Northern slope of the Terskey Alatau Range, at an altitude of 3560 m above sea level, alpine belt)*
Legend: as in Figure 1.

The loss of forested areas accelerated the adaptation of the region's natural environment to arid conditions. Only a few moist meadows remained on north-facing slopes, while semi-desert and dry steppe landscapes became established in the lower plains. The late Holocene sub-Atlantic phases (SA-1, SA-2, SA-3) reflect climatic variability and laid the foundation for the formation of the current natural landscapes in the Turkestan region.

Analysis of paleoclimatic and spore-pollen data demonstrates that climatic changes played a significant role in the landscape development of the Turkestan region. Climatic fluctuations during different phases of the Holocene influenced the shifts in vegetation cover and the formation of natural landscapes. These studies provide insights into the historical dynamics of the region's natural environment and offer a basis for predicting the effects of adaptation to ongoing climatic changes in the present day.

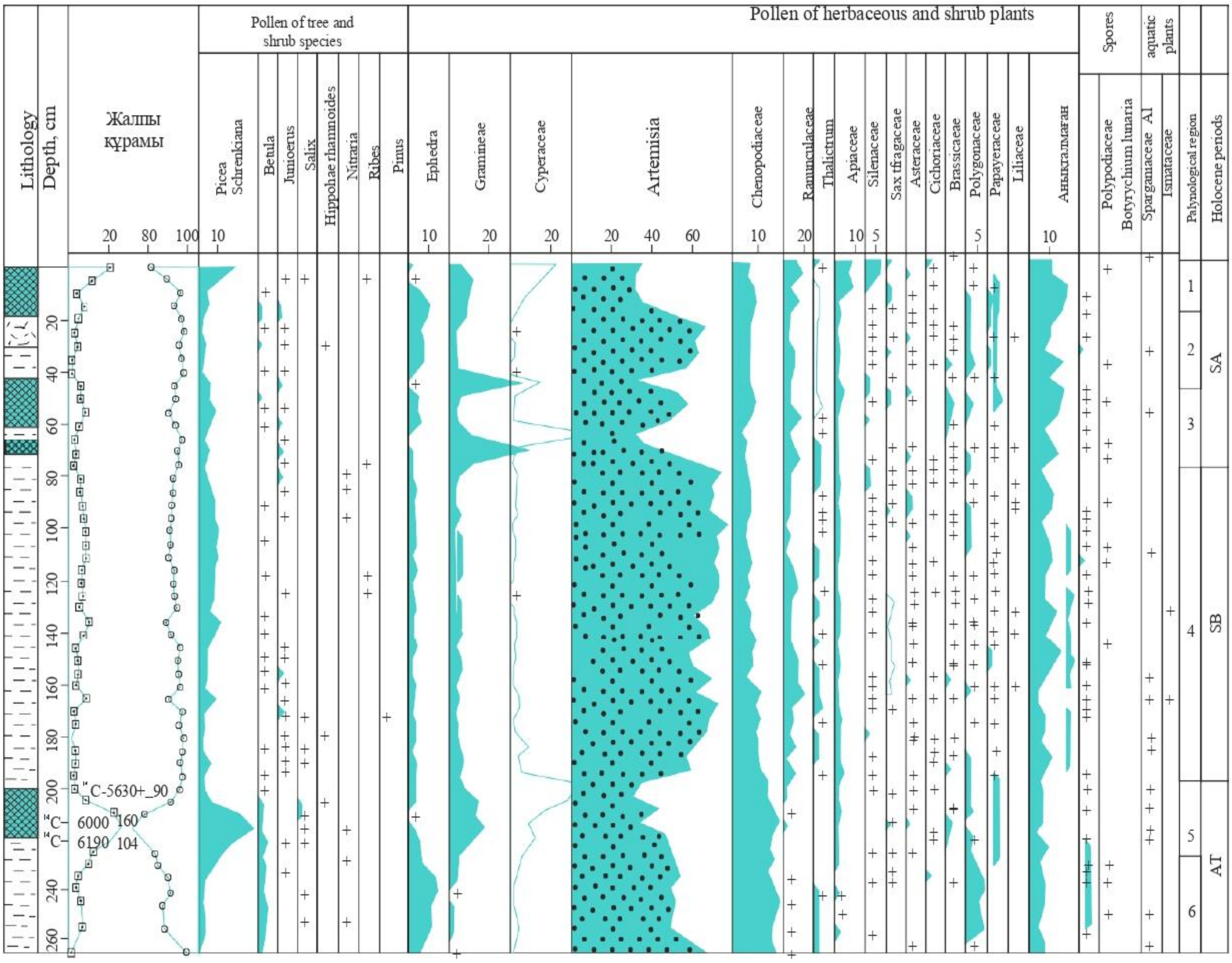

Figure 5. *Spore-pollen diagram of the Chichkan Peat Bog [16] (Northern slope of the Terskey Alatau Range, at an altitude of 2000 m above sea level, dry steppe belt)*
Legend: as in Figure 1.

In the foothills of the Turkestan region, a similar vegetation cover likely developed. Around the middle of the Mid-Subatlantic period (approximately 1,000 years ago), the climate became drier again, with rising summer temperatures. This led to the thinning of forests and the transition of meadows into steppe communities. However, in the past 1,000 years, the climate began to cool again, accompanied by glacier expansion. This glaciation phase corresponds to the "Little Ice Age."

During the warming period in Central Asia between the 7th and 12th centuries, annual precipitation increased to at least 150 mm, with most precipitation occurring in winter. The final significant cooling of the "Little Ice Age" led to the complete desertification of the Karakum and Kyzylkum regions.

According to E.V. Glushko, a prolonged dry phase lasting from 1750 BCE to 900 CE and a semi-arid phase ending around 600 CE were identified. During the first dry phase, average July temperatures rose from approximately 26 °C to 29 °C, and annual precipitation decreased from 170 mm to as low as 90 mm. These conditions led to the spread of desert and semi-desert landscapes. Subsequently, a period of increased moisture occurred in the mid-1st millennium BCE, with July temperatures dropping to 25…28°C and precipitation increasing to 140…250 mm/year. During this period, forest and woodland communities developed on alluvial plains, while fertile chestnut soils with shallow groundwater supported meadow and steppe communities.

In the later phases, as July temperatures once again increased to 26…29 °C and precipitation dropped to 100…200 mm/year, the landscape underwent significant restructuring.

The region between the Karatau Mountains and the Syr Darya River is notable for its close association between archaeological sites from various eras and the valleys of these geographic features. The Karatau mountain formations began to be utilized during the Neolithic period, coinciding with the early stages of human cultural development. As tools advanced, the expansive alluvial plains between Karatau and the Syr Darya became increasingly exploited. These plains consist of various layers of gravel, sand, and sandy loam, with elevations ranging from 200 to 300 meters above sea level. The accumulation plains are intersected by the valleys of small rivers flowing down from the Karatau Mountains.

A significant example of studies in the northern foothills of Karatau is the research conducted at the Bronze Age site of Arpauzen (Figure 6) [17].

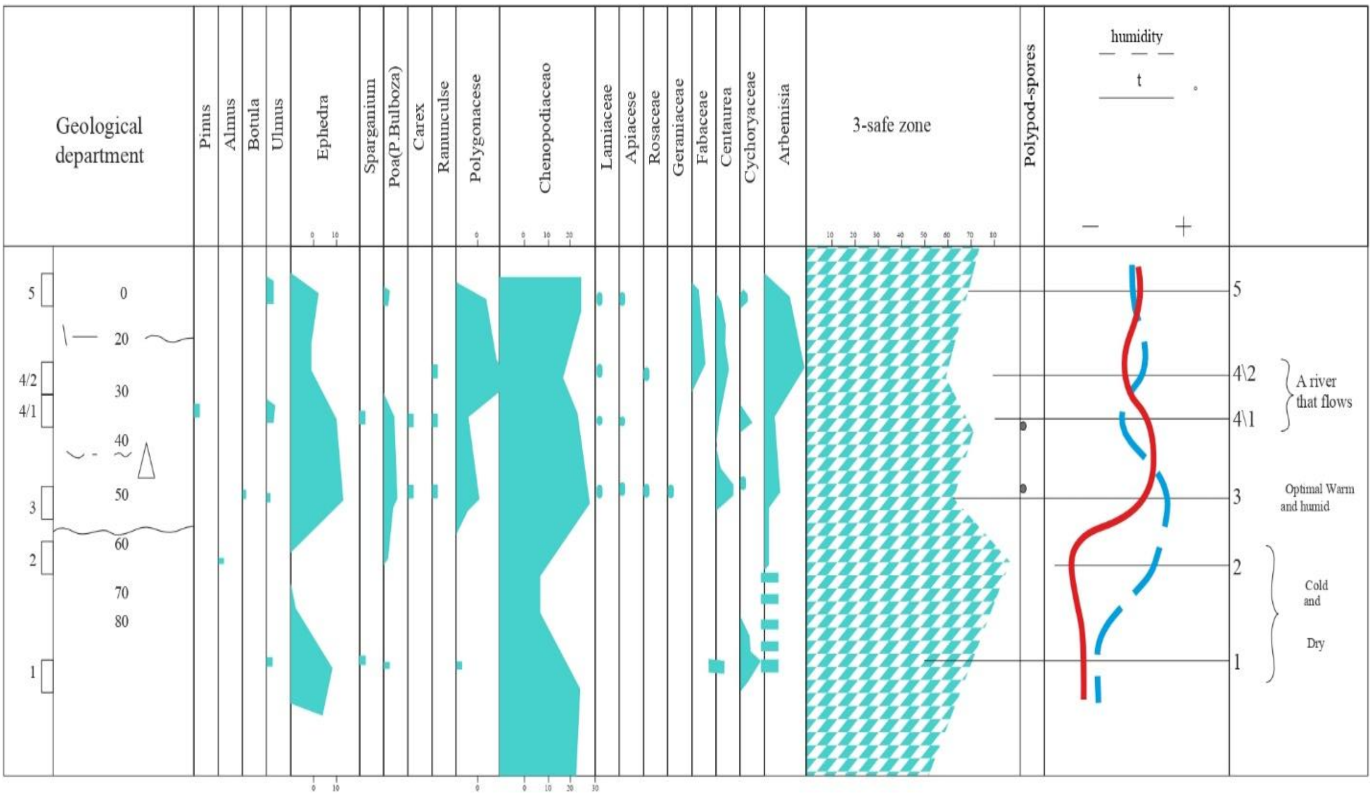

Figure 6. *Palynological diagram of Holocene deposits in the Karatau Mountains at the Arpauzen site [17]*

The Arpauzen site is located on the northeastern slopes of the Karatau Range. These slopes are generally convex or straight, with exposed rock formations visible in certain areas. To the northeast, steep slopes descend into valleys, where tectonically uplifted blocks featuring Devonian red sandstones are prominent.

Palynological data indicate that cold deserts dominated this area at the beginning of the Holocene. The Syr Darya River, spanning over 3,000 km, forms an extensive delta at its entry into the Aral Sea (see Figure 7) [18].

These findings suggest that the early Holocene landscape in the Karatau region was significantly different from today, with colder and more arid conditions prevailing. The study of the Arpauzen site provides insights into how tectonic activity and climatic changes shaped the region's topography and vegetation cover over time.

The development of the Syr Darya Valley is closely linked to the gradual shift of the river channel toward the right bank. The river's flow depended heavily on the glacial reserves in the mountains, as well as the year-round precipitation in the form of rain and snow.

Spore-pollen spectra from the Otyrar Oasis have revealed pollen from plants typical of a humid and temperate climate, which are no longer found in the region today. These include trees such as linden (Tilia sp.), birch (Betula sp.), and alder (Alnus sp.). In comparison to Holocene sediments, ancient deposits are evident in samples 1 and 2 (see Figure 8) [17].

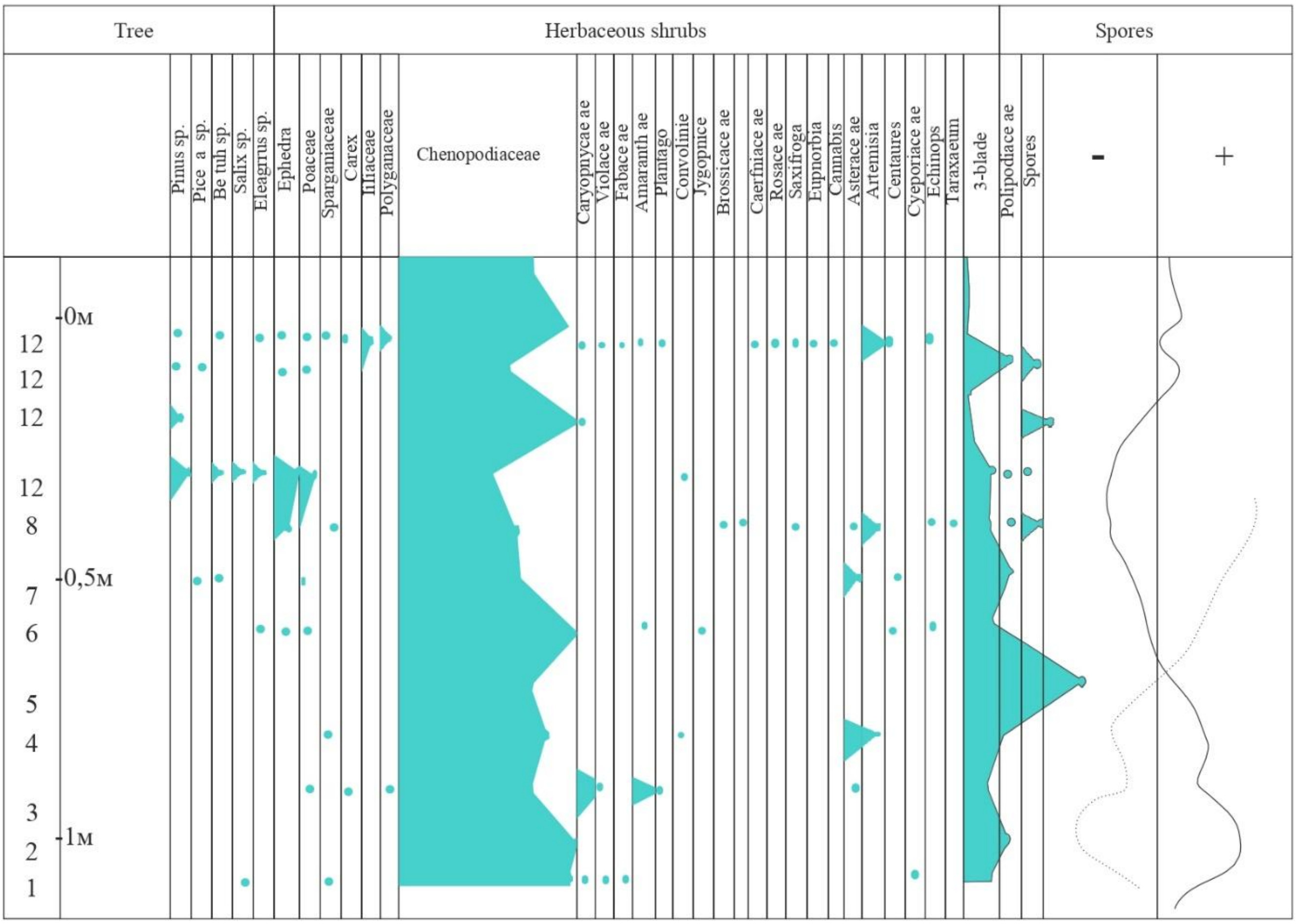

Figure 7. *Palynological diagram of Holocene deposits along the Syr Darya River [18]*

Palynological research was conducted using trench materials, which demonstrated significant climatic changes during the medieval period. Over the past 6,000 years, there have been alternating phases of optimal, moderate, and sharply dry ecological conditions. Moreover, the occurrence of dry and pluvial periods was consistent across different areas of this region [17].

Studying the evolution of the vegetation cover and climate in the Turkestan region has provided insights into the adaptation of natural systems to climate change and their long-term instability.

The results of paleoclimatic reconstruction have led to several key conclusions. During the periods studied (Oligocene, Miocene, Pliocene, Pleistocene, and Holocene), climatic changes had a direct impact on the structure and distribution of plant communities. These findings underscore the crucial role of climate in shaping the region's ecological history and provide a foundation for understanding how current and future climatic shifts may continue to influence the natural environment.

Glacial fluctuations and changes in sea levels intensified climatic instability, contributing to the formation of semi-desert and desert landscapes (see Figure 6) [18]. During the Middle Miocene and Pliocene epochs, the climatic conditions in the Turkestan region became significantly drier, leading to the expansion of deserts and semi-desert areas. In the Middle Miocene, the drying up of water bodies and the intensification of wind activity contributed to the formation of desert landscapes. In the Pliocene, the further drying of the climate resulted in the development of desert ecosystems and the adaptation of new species of flora and fauna. The natural changes during these periods laid the foundation for the formation of the current desert landscapes and ecosystems.

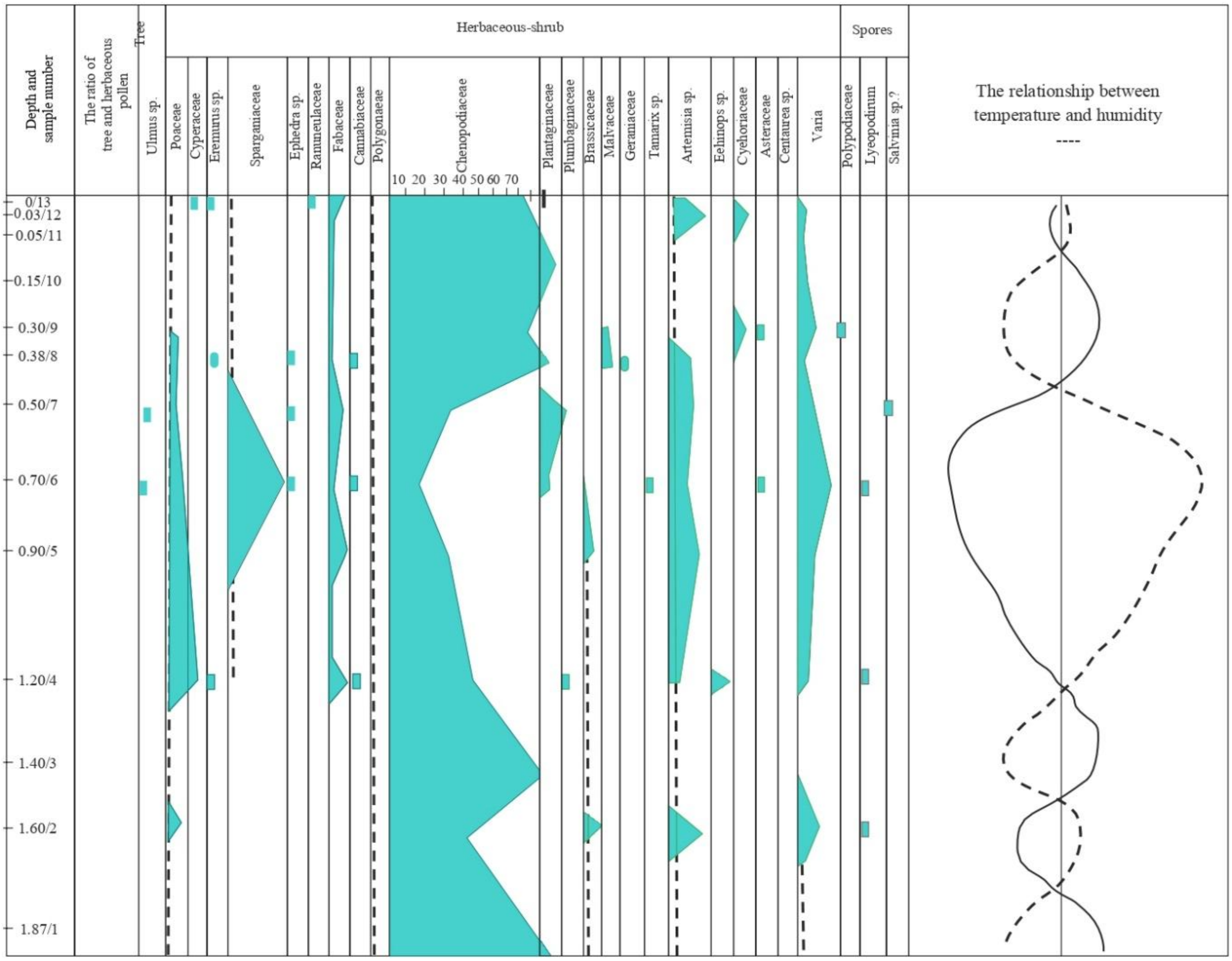

Figure 8. *Palynological diagram of Holocene deposits from Otyrar, trench 181 (upper section) [17]*

Additionally, in the Middle to Late Holocene, the melting of glaciers led to an increase in river water levels and the re-expansion of forest and woodland areas (see Figure 7) [17]. Drought-resistant species like Pinus and members of the Chenopodiaceae family became widespread, contributing to the stability of plant communities. In contrast, species like Juglans and Palmae had weak adaptability and survived only in favorable microclimatic niches.

The current natural conditions of the Turkestan region are the result of historical climatic fluctuations. The forests, woodlands, and river systems not only shaped the region's ecological landscape but also influenced early human activities and economic development. The existing semi-deserts and steppes are a continuation of the long-term paleo-climatic changes that have shaped the region over millennia. The geographical and climatic conditions of the region provided the early inhabitants with the opportunity to efficiently utilize natural resources such as forests and rivers. These resources significantly influenced their survival strategies, especially in agriculture, animal husbandry, and handicrafts. Forests provided timber, firewood, and construction materials, while rivers were crucial for water supply and irrigation. Such conditions played a decisive role in the economic development of early societies, as well as in shaping their culture and way of life.

In contrast, the current deserts and steppe areas are the result of long-term paleoclimatic changes that shaped the landscapes of the Turkestan region. These changes occurred over millions of years through various climatic periods and fluctuations, leading to the present state of the region's natural environment and landscapes. As a result of paleoclimatic changes, deserts and steppes emerged, plants and animals adapted to these conditions, and a dry climate became prominent.

4. CONCLUSION

The conducted research has provided a comprehensive assessment of the long-term evolution of landscapes in the Turkestan region and the impact of climatic changes on regional ecosystems. Through the integrated analysis of palynological and stratigraphic data, the study has elucidated the influence of climatic fluctuations on plant communities and landscape structures from the Oligocene to the Holocene periods. Specifically, the dominance of drought-resistant plants during dry and cold phases, and the spread of forest vegetation during more humid phases, was clearly identified.

The results demonstrate that the current natural conditions of the Turkestan region are a direct consequence of prolonged historical climatic changes. For instance, the intensification of arid conditions during the Pliocene and Pleistocene led to desertification, whereas increased precipitation during the Holocene facilitated the recovery of plant communities and boosted biodiversity. Thus, the natural systems of the Turkestan region have demonstrated adaptive resilience to climatic changes, establishing a complex ecological equilibrium.

The data obtained through this study provide a foundation for understanding long-term adaptation mechanisms to climatic factors, allowing for an evaluation of the region's resilience to future climatic shifts. These findings contribute to the development of strategic measures aimed at enhancing the stability of desert and semi-desert areas. Additionally, the results hold significant scientific and practical value for predicting the landscape development of the region and the adaptation of its current ecosystems to climate change.

In summary, studying the historical evolution of landscapes in the Turkestan region is not only theoretically significant but also crucial for developing strategies for the protection of regional ecosystems and sustainable development.

AUTHORS' CONTRIBUTION

Conceptualization – DA; resources - RK ; formal analysis – AYe ; methodology - ZhO; software - NR.; supervision – DA, ZhO ; visualization – AYe, RK; writing—review and editing - AYe, RK .

REFERENCES

1. Jackson J., Sunshine J. (2007). Public confidence in policing: A neo-Durkheimian perspective. The British Journal of Criminology, Vol. 47. No. 2, pp. 214–233. URL: https://doi.org/10.1093/bjc/azl031
2. Seddon A. W. R. Mackay, A. W. Baker, A. G. Birks, H. J. B. Breman, E., Willis K. J. (2014). Climate change and the future of biodiversity in the 21st century. Nature, Vol. 512, No.7515, pp. 412-415. URL: https://doi.org/10.1038/nature13440
3. Berg, L. S. Climate and life. Moscow: State Publishing House (Gosizdat/GIZ), 1922.
4. Mykleby P. M., Snyder P. K., Twine T. E. (2017). Quantifying the trade-off between carbon sequestration and albedo in midlatitude and high-latitude North American forests. Geophysical Research Letters, Vol. 44, No. 5, pp. 2493–2501. URL: https://doi.org/10.1002/2016gl071459
5. Zhou W., Yu S., Burr G. S., Kukla G. J., Jull A. J. T., Xian F., Xiao J., Colman S. M., Yu H., Liu H., Liu Z., Kong X. (2010). Postglacial changes in the Asian summer monsoon system: A pollen record from the eastern margin of the Tibetan Plateau. Boreas, Vol. 39, No. 3, pp. 528–539. URL: https://doi.org/10.1111/j.1502-3885.2010.00150.x
6. Muratova M. V., Boyarskaya T. D., Liberman A. A. Application of probability theory to reconstruct paleoclimatic conditions based on palynological analysis. In: Recent tectonics, modern deposits, and humans. Moscow: Moscow University Press, 1972, pp. 239–246.
7. Kurganskiy A., Skjøth C. A., Baklanov A., Sofiev M., Saarto A., Severova E., Smyshlyaev S., Kaas E. (2020). Incorporation of pollen data in source maps is vital for pollen dispersion models. Atmospheric Chemistry and Physics, Vol. 20, No. 4, pp. 2099–2119. URL: https://doi.org/10.5194/acp-20-2099-2020
8. Halbritter H., Ulrich S., Grímsson F., Weber M., Zetter R., Hesse M., Buchner R., Svojtka M., Frosch-Radivo A. (2018). Illustrated Pollen Terminology. In: Methods in Palynology, Springer, pp. 97–127. URL: https://doi.org/10.1007/978-3-319-77315-5_5
9. Alshanbari H.M., Odhah O.H., Ahmad Z., Khan F., El-Bagoury A.A.-A.H. (2023). A New Probability Distribution: Model, Theory and Analyzing the Recovery Time Data. Axioms, 12, 477. URL: https://doi.org/10.3390/axioms12050477
10. Geology of the USSR. Volume XL. Southern Kazakhstan. Geological description. Volume 1. Collective authors. Moscow: Nedra Publishing House, 1971, 536 p.
11. Sinitsyn V. M. Paleogeography of Asia. Moscow-Leningrad: Publishing House of the USSR Academy of Sciences, 1962.
12. Bayshashov B. U., Kazenas V. L. Geological history and faunogenesis of Kazakhstan and adjacent territories during the development of mammals and anthophilous insects. Almaty, 1999.
13. Caves J. K., Bayshashov B. U., Zhamangara A., Ritch A. J., Ibarra D. E., Sjostrom D. J., Mix H. T., Winnick M. J., Chamberlain C. P. (2016). Late Miocene uplift of the Tian Shan and Altai and reorganization of Central Asia climate. GSA Today, Vol. 27, No. 2. URL: https://doi.org/10.1130/GSATG305A.1
14. Borzenkova I. I. (1990). Moistening of arid regions of the Northern Hemisphere during the Late Glacial-Holocene period. Izvestiya of the USSR Academy of Sciences. Geographical Series, (2), pp. 28-38.
15. Afanasyev K. S. Vegetation of the Turkestan Range. Moscow-Leningrad: Botanical Institute named after V.L. Komarov, 1956, 278 p.
16. Melnikova A. P. (2015). Evolution of natural systems, climate change in the Tien Shan during the Holocene, and the use of spore-pollen spectra in the mountains of Central Asia. Izvestiya RAN, Geographical Series, (5), pp. 83–98.
17. Nigmatova S. A. Stratigraphy, paleogeography, and climates of the Quaternary period in the arid regions of Central Asia (based on palynological data): doctoral dissertation. Almaty: Institute of Geological Sciences named after K.I. Satpayev, 2010, 271 p.

18. Borovsky V. M., Pogrebinsky M. A. (1958). The ancient delta of the Syr Darya and the Northern Kyzylkum. Proceedings of the Soil Science Institute of the Kazakh SSR Academy of Sciences, Vol. 1, pp. 395–425.

КЛИМАТТЫҚ ӨЗГЕРІСТЕРДІҢ ТҮРКІСТАН ОБЛЫСЫНЫҢ ЛАНДШАФТТЫҚ ДИНАМИКАСЫНА ӘСЕРІ: КЕҢІСТІКТІК-УАҚЫТТЫҚ ТАЛДАУ

Дана С. Ахметова [1*], Жанар О. Озгелдинова [1] PhD, Нургуль Е. Рамазанова [1] PhD, Айгуль Е. Егінбаева [1] PhD, Рабига Н. Кенжебай [2] п.ғ.к.

[1]Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан; akhmetovadanaaa@mail.ru, ozgeldinova@mail.ru, nurgulram@gmail.com, aeginbaeva@mail.ru
[2]Мұхтар Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан; mega.rabiga@list.ru
Автор корреспондент: Дана С. Ахметова, akhmetovadanaaa@mail.ru

ТҮЙІН СӨЗДЕР

климаттық өзгерістер
кеңістіктік-уақыттық талдау
палинологиялық талдау
өсімдік қауымдастығы
климаттық бейімделу
палеоклиматтық зерттеу
стратиграфиялық деректер
өсімдіктердің тарихи трансформациясы
Түркістан облысы

Мақала жайында:
Жіберілді: 10.11.2024
Қайта қаралды: 21.03.2025
Қабылданды: 28.03.2025
Жарияланды: 01.04.2025

АБСТРАКТ

Бұл зерттеу Түркістан облысының ландшафттарының ұзақ мерзімді дамуы мен климаттық өзгерістердің аймақтық ландшафтарға әсерін талдауға бағытталған. Палинологиялық және стратиграфиялық талдаулар арқылы олигоценнен голоценге дейінгі аралықта климаттық ауытқулардың өсімдік қауымдастықтарына және ландшафт құрылымына ықпал ету заңдылықтары анықталды. Түркістан облысы ландшафттарының өсімдік жамылғысының климаттық өзгерістерге икемделу механизмдерінің дамығанын көрсетті. Түркістан облысының қазіргі ландшафттардың тарихи климаттық тұрақсыздықтарға бейімделу нәтижесінде қалыптасқаны анықталды, бұл аймақтың өсімдік жамылғысынның тұрақтылығын сақтаудың негізін құрайды. Алынған мәліметтер аймақтық ландшафттардың эволюциясын түсінуге және климаттық өзгерістерге тұрақты бейімделу стратегияларын әзірлеуге мүмкіндік береді. Түркістан облысының қазіргі ландшафттар тарихи климаттық өзгерістерге икемделу нәтижесінде қалыптасқаны белгілі болды. Бұл деректер аймақтық өсімдік жамылғысының сақтау және климаттық өзгерістерге тұрақты бейімделу стратегияларын әзірлеу үшін маңызды. Алынған нәтижелер Түркістан облысының ландшафттық эволюциясын және климаттық өзгерістерге төзімділік механизмдерін тереңірек түсінуге мүмкіндік беріп, аймақтың болашақтағы экологиялық тұрақтылығын бағалауға негіз болады.

ВЛИЯНИЕ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ НА ДИНАМИКУ ЛАНДШАФТОВ ТУРКЕСТАНСКОЙ ОБЛАСТИ: ПРОСТРАНСТВЕННО-ВРЕМЕННОЙ АНАЛИЗ

Дана С. Ахметова [1*], Жанар О. Озгелдинова [1] PhD, Нургуль Е. Рамазанова [1] PhD, Айгуль Е. Егінбаева [1] PhD, Рабига Н. Кенжебай [2] к.п.н.

[1]Евразийский национальный университет имени Л.Н.Гумилева, Астана, Казахстан; akhmetovadanaaa@mail.ru, ozgeldinova@mail.ru, nurgulram@gmail.com, aeginbaeva@mail.ru
[2] Южно-Казахстанский университет имени Мухтара Ауэзова, Шымкент, Казахстан; mega.rabiga@list.ru
Автор корреспондент: Дана С. Ахметова, akhmetovadanaaa@mail.ru

КЛЮЧЕВЫЕ СЛОВА

климатические изменения
пространственно-временной анализ
палинологический анализ
растительные сообщества
климатическая адаптация
палеоклиматическое исследование
стратиграфические данные

АБСТРАКТ

Это исследование направлено на анализ долгосрочного развития ландшафтов Туркестанской области и влияния климатических изменений на региональные ландшафты. Палинологический и стратиграфический анализ позволил выявить закономерности воздействия климатических колебаний на растительные сообщества и структуру ландшафтов в период от олигоцена до голоцена. Было показано, что ландшафты Туркестанской области развили механизмы адаптации растительного покрова к климатическим изменениям. Установлено, что современные ландшафты Туркестанской области сформировались в результате

историческая трансформация растительности
Туркестанская область

По статье:
Получено: 10.11.2024
Пересмотрено: 21.03.2025
Принято: 28.03.2025
Опубликовано: 01.04.2025

приспособления к исторической климатической нестабильности, что составляет основу для сохранения стабильности растительного покрова региона. Полученные данные позволяют лучше понять эволюцию региональных ландшафтов и разработать стратегии устойчивой адаптации к климатическим изменениям. Современные ландшафты Туркестанской области, как было выяснено, являются результатом адаптации к историческим климатическим изменениям. Эти данные имеют важное значение для разработки стратегий по сохранению регионального растительного покрова и его устойчивой адаптации к климатическим изменениям. Полученные результаты позволяют глубже понять эволюцию ландшафтов Туркестанской области и механизмы устойчивости к изменениям климата, что станет основой для оценки экологической стабильности региона в будущем.