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Research paper

Utilization of The Natural Resource Potential of The Kara-Suu District of Kyrgyzstan in The Context of Central Asia: An Updated Review

Shaimkulova Roza Raimberdievna [1] *, Matikeev Kurmanali [1], Obdunov Elmurat Abduvapovich [1], Shermatova Zharkynai Tashpolotovna [1], Turgunova Venera Jumabaevna [1], Artykbaeva Sonunbu Zhumabekovna [2]

[1] Affiliation: Institute of Natural Science, Physical Culture, Tourism, and Agriculture Technologies, Osh State University, Osh city, Kyrgyzstan
[2] Affiliation: Osh Technological University, Institute of Innovation and Information Technologies, Osh State University, Osh city, Kyrgyzstan
**Corresponding author E-mail: roshaimkulova@oshsu.kg*

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Abstract

This article examines the utilization of the natural resource potential of the Kara-Suu district within the broader context of Central Asia. Particular attention is paid to the historical stages of forest landscape use from antiquity to the present. The study analyzes key factors contributing to forest reduction, including economic activities, armed conflicts, and climate change. The ecological consequences of deforestation and its effects on land and pasture resources are discussed. The authors propose a range of measures for the sustainable use of natural resources and forest restoration as part of the region's sustainable development strategy. The urgent need to understand historical and contemporary natural resource utilization patterns in Central Asia has increased because of worsening environmental conditions and declining resources. The research investigates the natural resource capabilities of the Kara-Suu district in Kyrgyzstan, which stands as a vital ecological and geopolitical area while connecting to Central Asian environmental transformations and sustainability. The research examines forest landscape utilization in Kara-Suu from ancient times until the present day while analyzing its historical development. The research focuses on how economic instability and military conflicts, together with growing populations and climate shifts, have transformed forest areas and land use patterns. The article presents a complete sustainable natural resource management system that suits the Kara-Suu area based on its research findings. The research presents evidence-based strategies for forest restoration and policy interventions and community-led stewardship practices. The study demonstrates how Kara-Suu can function as a model for Central Asian sustainable development through its alignment of measures with regional sustainability targets.

Keywords: *Kara-Suu District; Natural Resources; Forest Landscapes; Environmental Change; Sustainable Development; Central Asia.*

1. Introduction

The sustainable management of natural resources stands as a fundamental element for worldwide environmental conservation work, especially in areas where ecological deterioration endangers both biodiversity and human survival [1]. The Food and Agriculture Organization (FAO) documented a 10 million-hectare annual forest loss across the world during the period from 2015 to 2020, according to their 2022 report [2]. The combination of unsustainable agricultural methods and excessive grazing, and climate change impacts has severely harmed Central Asia, including the Kara-Suu district of Kyrgyzstan. The forest area of Kara-Suu decreased from 12,450 ha in 2000 to 10,580 ha in 2020, according to Landsat and Sentinel imagery analysis, which indicates a 15% decrease in forest cover [3]. The environmental transformations threaten both ecosystem stability and local economic security because more than 60% of regional residents maintain their livelihood through agro-pastoral activities [4]. The identification of historical and present-day resource depletion factors in these areas becomes essential for creating sustainable mitigation plans that support United Nations Sustainable Development Goals 15 (Life on Land) and 13 (Climate Action) [5].

The recognition of land degradation in Central Asia has increased, yet researchers have not thoroughly studied how historical land-use practices combine with socio-economic changes and climatic stressors in Kyrgyzstan's Kara-Suu district [6]. The Kyrgyz Ecology Agency (2020) reports that research about environmental change in Kyrgyzstan mainly investigates large-scale deforestation patterns and general climate effects. The current research focuses on broad environmental changes and fails to address essential human-made factors, which include agricultural reform effects and uncontrolled logging activities. The absence of thorough empirical research about these historical and regional practices has resulted in a major information deficit. The absence of evidence-based knowledge about human activities that

altered ecosystems during the past decades prevents regional policymakers and conservation stakeholders from creating successful targeted strategies for forest management and environmental protection [7]. The district's walnut-fruit forests, which hold global genetic diversity importance, face little scientific investigation despite their high risk of overexploitation. The current degradation rates will surpass irreversible thresholds unless we obtain actionable insights because this situation will force rural communities to relocate and create more resource conflicts [8]. Our study addresses the critical need by studying natural resource utilization phases in Kara-Suu to establish degradation origins, which will guide adaptive management approaches.

The research establishes new knowledge through its combination of historical ecology with modern geospatial methods to analyze land-use changes in Kara-Suu during fifty years. The research methodology differs from previous studies because it combines archival records with remote sensing imagery and community surveys to develop a comprehensive story about resource exploitation and its effects in the central Asian region. The study uses participatory GIS (PGIS) to merge local indigenous knowledge with ecological viability for developing culturally appropriate conservation recommendations. The research shows that Soviet collectivization and post-independence land privatization created separate phases of forest fragmentation, which have not been studied in Central Asian scholarship before. The study outcomes will enable policymakers to develop a sustainable framework that balances economic growth with environmental recovery in areas that experience similar post-socialist changes.

2. Research Methods

This study uses a multidisciplinary methodological framework to assess natural resource utilization and conservation in the Kara-Suu district of Kyrgyzstan through qualitative and quantitative analytical methods. The research design follows a structured approach to collect data systematically from research databases while performing rigorous analysis to establish evidence-based conclusions.

2.1. Systematic literature and policy review

A thorough examination of peer-reviewed literature, together with governmental and NGO reports and historical records and legal documents, was carried out to determine the theoretical and regulatory framework of natural resource management in the Kara-Suu district of Kyrgyzstan. The academic databases Scopus and PubMed were used to execute a keyword-based search with relevant terms mentioned in Table 1, about natural resources and forest degradation, and sustainable land use. The review will combine existing knowledge about exploitation patterns and conservation regulations, and social-environmental effects to reveal essential research gaps, which will guide sustainable development approaches for the region. The research focuses on specific drivers of land degradation in Kara-Suu instead of studying general trends throughout Central Asia. The existing research examines regional patterns of forest loss during 2000–2020 but fails to identify the post-Soviet factors that drive forest loss through fuelwood substitution and informal logging, and pasture intensification at the district level. Our study narrows this gap by integrating participatory GIS and stakeholder interviews to connect specific policies and community practices to observed forest fragmentation. We also extend insights from walnut-fruit forest perception studies by showing how local valuation of forest services aligns (or conflicts) with observed land-use choices in Kara-Suu. The previous research focuses on extensive regional environmental deterioration patterns, but our study investigates specific human-made factors in Kara-Suu through informal logging and pasture expansion and post-Soviet land policy changes. Also, recent studies examine local community views about walnut-fruit forests but fail to link these views to actual land-use transformation data. Our research combines participatory GIS with historical analysis to establish a connection between human activities in specific areas and their effects on ecological systems.

Table 1: List of Keywords Used in Search Strategy

Database	Keywords Used
Scopus	"Natural Resource Management", "Forest Degradation", "Kara-Suu District", "Sustainable Land Use", "Central Asia", "Environmental Policy"
PubMed	"Natural Resources", "Deforestation", "Environmental Impact", "Conservation Policy", "Pasture Degradation", "Land Use", "Central Asia"

2.2. Longitudinal comparative analysis

The assessment of natural resource conditions through time requires analyzing environmental and socio-economic data from 2000 to 2020. The evaluation method assesses how human activities, together with climate changes and policy measures, affect ecosystem health throughout extended periods. The research also analyzes past patterns of land use and water availability and biodiversity, and soil quality to determine environmental degradation and evaluate previous conservation methods.

2.3. Geospatial and predictive modeling

The analysis used Landsat 5 TM / 7 ETM+ / 8 OLI (30 m) and Sentinel-2 MSI (10 m) imagery to create forest cover maps for 2000, 2010, and 2020. The Random Forest model (n = 500 trees) in QGIS (v3.x) with Orfeo Toolbox processed annual median composites after cloud/shadow removal to produce classifications that were validated through high-resolution imagery interpretation of stratified random samples. The evaluation of accuracy included overall accuracy and the user's/producer's accuracy, and Cohen's κ. The analysis produced change maps and percent change statistics for the Kara-Suu administrative area, while Theil–Sen slopes calculated the trends. The analysis of drivers used generalized linear models to study forest-to-non-forest transitions based on road/settlement distance and slope, and protected area status, while the RF model permutation importance measured variable influence.

Data from Global Forest Watch shows that from 2001 to 2024, Kara-Suu lost 34 ha of tree cover, equivalent to 0.24% of the 2000 tree cover area. This does not account for gains in tree cover over the same period (Figure 1).

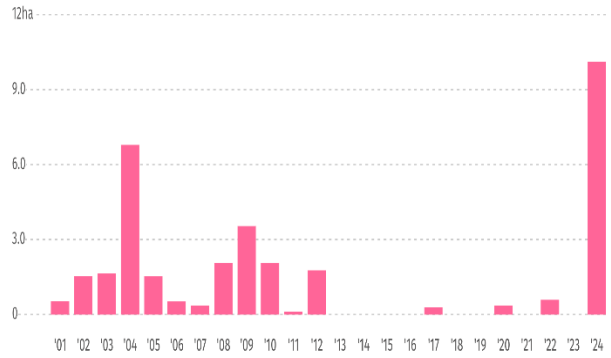

Fig. 1: Tree Cover Loss in Kara-Suu, Osh, Kyrgyzstan from 2001 To 2024.

2.4. Field-based data collection and stakeholder engagement

The research uses empirical data collected through fieldwork that combines environmental sampling of soil and water and vegetation analysis with remote sensing applications. The study uses surveys and semi-structured interviews to gather qualitative data from local communities and policymakers, and industry stakeholders about resource use practices and socio-economic dependencies, and conservation challenges. The research will use statistical methods, including regression models and principal component analysis (PCA), to identify relationships between environmental variables and human-made factors.

3. Historical Overview of Forest Use in Central Asia

Central Asia's forest landscapes have constituted a fundamental ecological and economic resource since antiquity, serving as critical enablers of cultural development and technological innovation throughout the region's history. The earliest pottery and metallurgical traditions that originated in Central Asia enabled their cultures to develop complex forest management systems, which created lasting impacts on both environmental systems and cultural artifacts [9]. The archaeological record shows timber resources functioned as essential building components for both everyday buildings and monumental structures during different historical time periods. Dendro architectural studies show that different species were chosen for construction depending on the ecological regions where they were available, since turanga (Populus diversifolia) from lowlands and juniper (Juniperus spp.) and spruce (Picea spp.) from mountainous areas were selected [10]. The advanced woodworking techniques developed over millennia become visible through the intricately carved wooden structural elements of 12th-15th century Islamic architecture [11].

The material discoveries from major archaeological sites show that forest exploitation occurred without interruption throughout history. Archaeological investigations at Pshakshi-Tepe and Altyn-Tepe, along with other key sites, have discovered wood construction elements which date from the Scytho-Sarmatian period (4th c. BCE - 3rd c. CE) through the Kangju-Khorezmian period (3rd-1st c. BCE) and the Kushan period (1st-5th c. CE) [12]. Wood-based construction technology demonstrates continuous development throughout the occupational layers spanning from the 6th-9th centuries to the Timurid era (11th-16th centuries) and subsequent periods. Chinese archaeologists conducting Silk Road excavations at Aktan-Khoto and Khara-Khoto sites have produced important dendrochronological data. The analysis of preserved turanga specimens shows that ancient urban centers originally surrounded extensive riparian forests, which people systematically harvested for construction materials and fuelwood. Radiocarbon dating of structural timbers reveals patterns of sustained exploitation that correlate with periods of urban expansion and technological development [13].

The archaeological findings reveal an intricate connection between human settlements and forest ecosystems in Central Asia, where wood served as a vital resource for building construction and energy generation, and cultural development. The extended human interaction with this region has created multiple layers of material evidence that guide our comprehension of human survival methods and environmental transformations in this vulnerable ecosystem [14].

4. Phased Deforestation and Landscape Transformation in Central Asia: A Historical Analysis

The human-caused transformation of Central Asian forests has been a long process that has grown more severe throughout multiple millennia until it reached its peak after the Soviet era [15]. The environmental transformation of this region has unfolded through four distinct historical phases, which were shaped by different socio-economic factors and ecological effects.

4.1. Pastoral-fuel stage (Pre-1st century CE)

The early stage of Central Asia showed about 70-80% forest coverage based on toponymic remnants (Archaly, Kaiyngdy), relict forest islands, and archaeological features including buried pottery kilns and dendrochronological samples. The limited anthropogenic pressure during this epoch resulted primarily from low population density and rudimentary technological capacity [16] . The main forest use during this time involved collecting fuel for homes and early metalworking activities, while grazing practices caused little environmental damage because pastures were highly productive in the region. The deforestation patterns showed specific spatial patterns because lowland regions suffered more damage than mountainous refugia, which established an early human-made gradient that continued through later historical times [17].

4.2. Pastoral-fuel-military stage (1st-17th centuries CE)

During the medieval era, three simultaneous forces transformed forest management practices because urban growth occurred along rivers (Syr Darya, Amu Darya) and military operations reshaped landscapes, and trade routes expanded across Eurasia [18]. The threefold pressure system led to extensive deforestation in strategic areas, including the Samarkand, Tashkent, and Fergana oases, where archaeological

findings show that all forests were cleared within 15-20km of urban settlements. The military operations brought forth destructive methods, which included forced timber extraction for fortification construction and forest fires set by troops during their campaigns, as recorded in Dzungar invasion accounts [19].

4.3. Construction-fuel-pastoral stage (17th-19th centuries CE)

During this phase, the exploitation of resources reached its peak as city-states developed formal timber extraction systems to support their architectural growth. The dendroarchaeological evidence shows that urban areas completely cleared their riparian species, including turanga and sea buckthorn, which led to the development of advanced transportation systems for montane forest harvesting [20]. The forest boundaries shifted vertically by 300-500 meters during this time, which resulted in the current fragmented landscape patterns because only protected topographic areas maintained their natural state.

4.4. Pastoral stage (post-1960s)

The current era marks the peak of centuries-long exploitation, which Soviet agricultural policies and post-collapse institutional breakdown have intensified. Forest cover now occupies only 3-5% of its historical area according to modern remote sensing data, while the remaining forests show marked structural degradation and diminished biodiversity. The post-Soviet period led to increased forest fragmentation because of land privatization and decreased central authority control, and the shift from wood to alternative energy sources during price fluctuations. Population growth in the Kara-Suu district (23% increase between 1991–2020) further intensified pressure on grazing lands and irrigation systems as per the Kyrgyz Ministry data. The combination of agricultural development and settlement-based pasture activities near residential areas resulted in higher edge effects and land conversion threats. The local forest loss patterns in Kara-Suu match the productivity changes observed in other former Soviet republics, yet the area's specific topography and road development created unique low-lying hotspots of deforestation. The shift to intensive pastoralism has finished transforming forested areas into human-controlled steppe landscapes, which affects local water cycles and carbon storage abilities, and climate regulation patterns [21].

5. Urban Expansion and Ecological Transformation in Medieval Central Asia

Historical study by Dr. Heinrich Harke documents a pivotal period of urban growth across Central Asia between the 13th and 17th centuries, coinciding with intensified Dzungar invasions. This era witnessed unprecedented demand for timber resources, serving dual purposes as construction material for expanding cities and fuel for growing populations [22]. The military campaigns of this period proved particularly destructive, with invading armies employing scorched earth tactics that included deliberate forest fires during strategic retreats. Contemporary accounts and ecological reconstructions suggest these combined pressures resulted in the elimination of 40-45% of forest cover and degradation of an additional 20-25% of woodland areas during this timeframe [23].

The ecological consequences of this deforestation were profound and irreversible in many regions. Historical records from the Tarim Basin describe a continuous perimeter of poplar-tamarisk forests encircling the desert margins as recently as the mid-19th century, a verdant buffer that has since dwindled to scattered remnants due to compounded pressures of groundwater depletion and systematic logging [24] [25]. The transition from forest to steppe ecosystems was particularly evident in lowland areas, where decreased soil moisture created conditions favoring herbaceous meadows over woody regeneration. This landscape transformation fundamentally altered regional hydrology and microclimates, establishing ecological patterns that persist in modern Central Asia.

The 17th century marked a new phase of resource exploitation as urban centers demanded ever-greater quantities of construction timber. Lacking alternative building materials, cities turned to mountain forests, initiating large-scale logging operations that relied on caravan networks to transport timber to urban centers [26]. This systematic deforestation created a distinct elevational shift in remaining forest cover, with intact ecosystems retreating into inaccessible "refugia" at higher altitudes. Concurrently, human settlement patterns followed river valleys upstream, creating a spatial correlation between deforestation and migration routes that reshaped both the ecological and demographic landscapes of Central Asia during this transformative period [27].

6. Forest Restoration and Environmental Constraints in Central Asia

Due to the development of Siberia, the expansion of the coal and gas industry, and environmental preservation initiatives, the pace of deforestation decreased from the 1950s to the 1990s. This era witnessed the establishment of silver-leaf poplar plantations, which became viable for construction within 10 to 15 years [28]. In Central Asia, where construction materials are scarce, turanga (poplar) plantations have proliferated, as this species is extensively utilized for residential construction. The experiences of inhabitants in the plains and arid parts of Central Asia should be generally applied to mountainous places, where poplar and turanga are deemed inappropriate for construction and are utilized solely as fuel. The shift to a market economy and new governance structures requires the expansion of poplar and turanga plantations, as the current forests of Central Asia are insufficient to satisfy the demand for construction materials [29].

In the future, grazing in protected areas and overgrazing in extensive forest regions should be prohibited. A primary difficulty in forest landscape management is the removal of stumps, deadwood, and branches, which could otherwise be utilized as fuel to provide the heating requirements of villages and small cities for several years. Concurrently, soil leveling and tree planting should be executed, while selective sanitary felling would facilitate the rejuvenation of aged, unproductive trees [30].

Central Asia is wholly situated inside the inland desert region, distinguished by a wide array of distinct and contrasting physical-geographical circumstances owing to its extensive north-south and west-east span. Denudation processes exhibit variability across temporal and spatial dimensions. The specified region comprises three principal components—plains, mountains, and plateaus—that exhibit considerable variation in their natural characteristics and external processes [31]. In the highlands of Central Asia, forest ecosystems display strong vertical zonation, as do erosion processes. The prevalent notion among numerous geographers that landslides occur universally in mountainous regions is not totally correct. Landslides predominantly occur in areas like the Altai, Sayan, Tengir-Too, and Dzungaria, where annual precipitation varies between 350 and 1000 mm, and the soil layer exceeds one meter in depth [32]. Frost weathering causes rockfalls at mountain summits, obliterating not only solitary trees but occasionally entire forest areas. This phenomenon has been recorded in regions including Kel in the Isfayram-Sai valley, Jylyuu-Suu in the Sokh valley, and At-Jailoo in the Kyrgyz-Ata valley [33].

Observations in the Tengir-Too mountains indicate that the terrain exerts a minimal influence on impeding or decelerating descending rock masses. Consequently, the presumption that trees protect against rockfalls is frequently erroneous. Rockfalls and landslides generally occur

at elevations beyond 1,000 meters above the forest belt, where slope gradients seldom decrease below 50–60°. Even little rockfalls can severely impact forest stands, indicating that the survival of forests on steep slopes is significantly influenced by the degree of denudation. The present distribution of forest landscapes reveals that mountain forests predominantly thrive on moderate western inclines. The arid, steep, and dissected southern and eastern slopes typically exhibit a scarcity of dense woods, but scattered trees can be located in comparatively moderate and moist areas [34]. There are constant differences in the soil profile regarding thickness and rock composition. As slope steepness grows, soil formation diminishes, and dynamic geological processes like slumping and erosion dominate, resulting in conditions where forests cannot avert rock failures. On mild inclines and level terrains, the soil layer frequently surpasses 2–3 meters in depth. Landslides frequently occur in these regions, substantially disturbing forest ecosystems and creating phenomena referred to as "drunken forests." Temperature variations induce cracks that trigger landslides, commonly occurring near the higher boundaries of the forest belt and often obliterating these forest areas [35].

To resolve this, trees should be planted in the upper peripheries of the forest belt. Furthermore, the activities of mowing, uprooting bushes, and clearing shrubland should be forbidden. Engaging in such actions solely in the lower regions of the forest distribution zone will not produce the intended outcome. The severity of landslides is contingent upon the depth of the soil mantle, often ranging from 5 to 6 meters, and tree root systems alone are inadequate to avert them.

7. Problem Resolution and Future Recommendations

The Kara-Suu district exists at a vital point where extensive resource extraction meets the immediate necessity of environmental restoration. Our research shows that the area undergoes transformation because deforestation creates scars while pastures shrink and water patterns change and human activities intensify. The multiple environmental stressors require a complete change in how we understand and handle and value natural resources. The future demands permanent solutions which will guide human activities toward ecological limits while sustaining local economic activities. Key Recommendations for Sustainable Resource Management are as:

7.1. Reforestation and ecosystem rehabilitation

The implementation of large-scale afforestation programs using native species should be combined with community-based forest management initiatives to restore degraded landscapes and enhance biodiversity [36].

7.2. Sustainable water resource management

The implementation of modern irrigation techniques (e.g., drip irrigation) and watershed management strategies should be used to reduce hydrological imbalances and ensure fair water distribution [37].

7.3. Promotion of climate-smart agriculture

Agroforestry, rotational grazing and soil conservation practices should be promoted to reduce land degradation while maintaining agricultural productivity [38].

7.4. Economic incentives for conservation

Green financing mechanisms such as payments for ecosystem services (PES) and eco-tourism initiatives, should be developed to encourage sustainable land-use practices among local communities [39].

7.5. Strengthening policy and regulatory enforcement

The legal frameworks for natural resource protection should be enhanced to enforce stricter laws against illegal logging and overgrazing while promoting participatory governance models for inclusive decision-making [40].

8. Discussion and Conclusion

The ecological path of the Kara-Suu district reached a vital turning point because centuries of resource exploitation created a complex network of environmental problems. The region's natural capital has experienced a significant transformation because forest areas have decreased and land quality has deteriorated and water cycles have changed, and human activities have increased. The changes in this area result from multiple historical and present-day factors, including past land-use patterns and population changes and agricultural development and current climate patterns. The path to sustainability demands nothing short of a paradigm shift in resource governance. The proposed intervention framework consists of three essential components, which include targeted reforestation and landscape rehabilitation for ecological restoration and climate-smart water and land management practices, and adaptive policymaking for institutional strengthening. The implementation of circular economy principles in agriculture stands as a priority, along with payment for ecosystem services schemes and geospatial monitoring technologies for enforcement. These measures represent more than environmental remediation because they function as investments that build regional future resilience. Kara-Suu can establish a sustainable development model through economic activity alignment with ecological thresholds to achieve prosperity alongside environmental preservation. The success of this transformation depends on continuous multi-stakeholder participation, which unites traditional wisdom with scientific progress to develop solutions that maintain ecological integrity and social-economic stability. The existing research provides a foundation for multiple directions of future investigation and practical implementation. Scientists need to conduct experimental reforestation studies, which will determine the most suitable tree species pairings and planting arrangements for damaged riparian zones and lowland regions. The establishment of mixed walnut–fruit tree systems in longitudinal plots for 5–10 years will generate reliable information for expanding reforestation efforts. The integration of Sentinel-1 radar and LiDAR remote sensing technologies in future research will help researchers detect small changes in canopy structure through the reduction of cloud cover limitations. The combination of these tools with real-time monitoring systems enables the creation of warning systems for illegal logging activities and fast assessment of forest fires and pest infestations. The research on socio-economic aspects needs expansion through participatory action studies, which involve local institutions and households. The

research should assess PES schemes through effectiveness studies while identifying implementation challenges and testing various payment structures and management frameworks. The analysis of geospatial data with socio-economic survey results will reveal how family choices affect land management practices. Scientists need to establish numerical values for the hydrological and climate advantages that forest restoration brings to the environment. Research models that analyze forest restoration and rotational grazing effects on baseflow and soil erosion and microclimate control will create stronger evidence for uniting forest policies with climate adaptation initiatives throughout Kyrgyzstan. The partnership between regional authorities and NGOs should establish demonstration projects which unite ecological recovery with local community economic development. The proof-of-concept models developed through these pilots will demonstrate successful methods for implementing large-scale interventions in other forested districts throughout Central Asia. This initiative serves as both an environmental necessity and a complete transformation of how communities relate to their essential ecosystems.

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Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Statement

Not Applicable.

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Author Contribution

Conceptualization: Shaimkulova Roza Raimberdievna, Matikeev Kurmanali;

Methodology

Shaimkulova Roza Raimberdievna, Obdunov Elmurat Abduvapovich;

Data Curation and Analysis

Obdunov Elmurat Abduvapovich, Shermatova Zharkynai Tashpolotovna;

Writing – Original Draft Preparation

Shaimkulova Roza Raimberdievna, Shermatova Zharkynai Tashpolotovna; Writing – review and editing: Turgunova Venera Jumabaevna, Artykbaeva Sonunbu Zhumabekovna. All authors have read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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