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Assessment of Socio-Economic and Environmental Potential in Natural Vulnerable Areas of the Southern Aral Sea Region (Based on the Example of the Takhtakupyr District of the Republic of Karakalpakstan)

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Abstract
This study aims to comprehensively assess the environmental and socio-economic situation in Takhtakupyr District of the Republic of Karakalpakstan, determine the influence of environmental factors on the region's economy, and identify priority directions for the district's development ("growth points"). The study relies on a mixed-methods design combining qualitative and quantitative methods. Data were collected from 12 representatives of government administration bodies (average work experience — 14.5 years) using two types of structured questionnaires (Type A — ecological-economic; Type B — demographic-economic) based on Likert scales of 1–5 and 1–10 points, and analyzed using descriptive statistics. **Results**: experts rated the impact of environmental factors (drought, water scarcity) over the past three years at 4.4 out of 5 points, and the expected risk over the next five years at 4.7 out of 5 points. Agriculture and animal husbandry were identified as the most affected sector (4.9/5). Under conditions of water scarcity, camel breeding (9.2/10) and sheep breeding (8.7/10) were identified as the most promising sectors, while water-saving technologies (9.5/10) and alternative energy (8.8/10) were identified as the highest-priority innovations. 91.7% of experts supported an optimistic (sustainable) development scenario.
Practical significance: the results serve as a practical basis for local and regional administrative bodies in identifying livestock farming, renewable energy, and ecotourism as priority "growth points," as well as in designing short-, medium-, and long-term development programs.
Scientific novelty: the study empirically tests François Perroux's "growth poles" theory at the district level in a territory affected by the ecological crisis of the Aral Sea basin, using an expert-assessment methodology — a direction that is relatively understudied in this regional context.

Keyword: Takhtakupyr District, ecological-economic potential, growth points, expert assessment, Aral Sea basin, Karakalpakstan, sustainable development.

Introduction

The ecological crisis of the Aral Sea basin has, over the past half-century, caused serious damage to living conditions, economic activity, and the health of the region's population (Micklin, 2020). Takhtakupyr District, located in the northern part of the Republic of Karakalpakstan, is one of the territories most affected by this ecological crisis.

The district faces problems such as water scarcity, soil degradation, air pollution, and loss of biological diversity. These factors hinder the population's economic activity — in particular, the potential of agriculture, animal husbandry, and tourism — as well as socio-economic development in general (Alibekov & Alibekov, 2008; Shibuo, Jarsjö & Destouni, 2007). In recent years, the relationship between environmental factors and processes of socio-economic development and adaptation at the regional level, as well as the formation of sustainable development strategies for such territories, has become particularly relevant (Aimbetov & Niyazimbetov, 2025; Aimbetov, 2025).

1.1. Characteristics of the study area

Takhtakupyr District is located in the northern part of the Republic of Karakalpakstan and borders Kungrad District to the west, the city of Nukus and Kegeyli District to the south, and the Republic of Kazakhstan to the north. The district's area is 16,656 km^2; the territory is represented predominantly by desert and semi-desert landscapes, and the climate is sharply continental and arid.

According to official and estimated statistical data, the district's population in 2022 was about 40,600 people, and in 2025 — about 38,900–39,000 people (population density — 2.34 people/km^2; annual change for 2023–2025 — −0.08%). 43.2% of the population lives in rural areas, and 56.8% — in urban-type settlements (City Population, 2025).

In accordance with the Decree of the President of the Republic of Uzbekistan "On Programs for the Socio-Economic Development of the Republic of Karakalpakstan in 2026" (PP-70 of 21 February 2026), it is envisaged that by the end of 2026 the gross regional product will increase by 8.1%, the unemployment rate will fall to 4.2%, and by 2030 the gross regional product will reach 102.4 trillion soums.

Serious obstacles to achieving these goals are the district's peripheral location, insufficient infrastructure development, and water scarcity. In this connection, the purpose of this study is to assess the impact of the environmental situation on the district's economy and to scientifically substantiate priority growth points for the district by analyzing the results of an expert survey of 12 highly qualified specialists from the Takhtakupyr District khokimiyat.

2. Literature review

2.1. Theoretical foundations of regional potential

The assessment of the socio-economic and environmental potential of territories has been widely studied in the world scientific literature. Walter Isard, one of the founders of regional economics and regional science, characterized a region as an interconnected unity of economic, social, and spatial systems, arguing that a regional system cannot be viewed merely as an economic base — it represents an organic synthesis of economic structure, the social organization of society, and a spatial substrate (Isard, 1966, p. 45; Isard, 1972, p. 89).

The classics of regional-economics theory — J. H. von Thünen, A. Weber, and W. Christaller — showed that regional development is determined by distance, transport costs, and population needs. Von Thünen substantiated the location of agriculture in concentric zones based on transport costs and land rent; Weber examined the location of industrial enterprises with regard to transport costs, labor costs, and agglomeration factors; Christaller developed the hierarchical placement of settlements ("central place theory").

According to Harry Richardson, regional growth potential is determined not by the simple sum of available factors of production, but by the efficiency of their spatial combination and the ability to minimize spatial contradictions (Richardson, 1977, p. 84). Michael Porter later explained regional competitiveness through local clusters — sets of interconnected industries, suppliers, and institutions (Porter, 1993, p. 182); Paul Romer and Robert Lucas, in endogenous-growth models, emphasized the role of human capital and innovation (Romer, 2011, p. 93); and Paul Krugman, within the framework of new economic geography, analyzed agglomeration effects (Krugman, 2014, p. 39). As Aimbetov (2025) notes, addressing the problems of a region's sustainable socio-economic development requires comprehensively accounting for the relationship among the territory's natural-resource potential, its institutional environment, and the population's standard of living.

2.2. Growth pole theory

The theoretical basis of this study is the concept of "growth poles" put forward by the French economist François Perroux (Perroux, 1955). According to this theory, economic development spreads unevenly across a territory, arising instead in "points" concentrated around leading industries or enterprises, and stimulates the development of other sectors through direct and indirect linkage effects. Jacques Boudeville further developed this theory from a geographical perspective, defining a growth point as a set of expanding industries concentrated around a particular territorial center (Boudeville, 1966).

Gunnar Myrdal's theory of cumulative causation emphasizes the self-reinforcing nature of the development process, while Joseph Schumpeter emphasized that innovation is the primary source of economic growth — indicating the need to also rely on innovative activity when identifying "growth poles." As Kurmasheva (2024, p. 26) notes, applying growth-pole theory in a region's development strategy means directing the vector of development toward territories that could become growth poles in the future.

In regions affected by ecological crisis, such as the Aral Sea basin, this concept acquires special significance: under conditions of limited resources, when it is impossible to develop all sectors equally, it is advisable to select sectors with relative advantages — for example, sustainable types of animal husbandry or renewable energy — as priority "points" and concentrate investment on them. Under such conditions, the question of how the region's natural and socio-economic systems respond to external shocks (drought, water scarcity) — that is, the mechanisms of adaptation and synergistic interaction — acquires particular importance (Aimbetov & Niyazimbetov, 2025), since these mechanisms determine the resilience of "growth points."

Research on the methodology for the practical assessment of this theory has also continued in recent years. In particular, Novikova and Leontieva (2021) proposed methodological foundations for assessing the effectiveness of growth points in a region's economic space, emphasizing the need to revise regional development policy in the post-pandemic period, as well as the advantages of using spatial resources and polarized development. This methodological approach theoretically complements the expert-assessment method applied in the case of Takhtakupyr District (Novikova & Leontieva, 2021).

2.3. Potential-assessment methodologies

The indicator-based approach is widely used in assessing territorial potential. The OECD methodology proposes evaluating regional development in terms of economic productivity, the labor market, demographic trends, and infrastructure development. Baklanov and Moshkov (2002a, p. 35; 2002b, p. 12) proposed a methodology for the integrated assessment of territorial systems, dividing it into resource-economic, socio-demographic, and environmental capacity blocks, and developed an algorithm for calculating an integrated index through the normalization of indicators.

Among multi-criteria decision-making methods, the Analytic Hierarchy Process (AHP), proposed by Saaty (1980), and the TOPSIS method, developed by Hwang and Yoon (1981), are effectively applied to systematize expert assessments in regional studies.

The concept of environmental potential, based on Odum's (1971) ecosystem-ecology theory, includes the state of natural resources, ecosystem services, the environment's capacity for self-restoration, and its degree of resilience to anthropogenic load. Costanza and co-authors (1997) developed a methodology for assessing the economic value of ecosystem services, while Daly (1996) developed a theory of balance between economic growth and environmental constraints. The concept of "planetary boundaries," put forward by Rockström and co-authors (2009), created a methodological basis for defining regional development strategies within environmental limits.

The Human Development Index (HDI) and its environmentally adjusted variant (UNDP, 2021), as well as the Genuine Progress Indicator (GPI; Kubiszewski et al., 2013), are recognized as modern tools for comprehensively assessing regional development.

2.4. Literature review on the natural-resource potential of Takhtakupyr District

The territory of Karakalpakstan, of which Takhtakupyr District is part, has long attracted researchers' attention in terms of natural resources; however, the available data remain scattered across various scientific fields — mineralogy, hydrology, and hydrobiology.

Mineral resources. One of the main sources on this subject is the monographic study by Kurbaniyazov and Zakirov (1979). The authors established that bentonite clays in the subsoil of Karakalpakia are widely distributed and are not inferior in quality to the best bentonites of Georgia, Ukraine, the Tatar ASSR, Azerbaijan, Western Turkmenistan, and adjacent districts of Uzbekistan (Kurbaniyazov, Zakirov, 1979). This finding provides an important basis for assessing the region's industrial raw-material potential, since bentonite clay is widely used in oil and gas extraction (drilling fluids), metallurgy, construction, and agriculture (as a soil ameliorant). Borshi-tau (Borshitog') is a hill/elevation at the foot and on the slope of which the complex is located. A reinforced-concrete staircase of 272 steps leads up the slope of Borshi-tau hill to an observation platform offering a view of the natural landscape and the lake. It is located near the settlement of Daukara.

Water and biological resources: the Sudochye lake system and Lake Karateren. A special place in the study of the territory's water and biological resources is occupied by the Sudochye lake system, which includes Lake Karateren — an important natural body of water located in the immediate vicinity of Takhtakupyr District.

According to the "Aral Encyclopedia" (2008), four bodies of water currently exist on the site of the former large Lake Sudochye: Akushpa, Big Sudochye, Karateren, and Begdulla-Aydin.

Origin and history. East Karateren is one of six isolated lakes in the lower right-bank delta of the Amu Darya and is a relic of the Daukara lake system. This system stretched from the Beltau elevation in the east to the mouth of the river in the west, was previously connected to the Aral Sea, and was fed by the waters of the Amu Darya through the Karabayli and Kosuzyak (Kuanyshzharma) channels (Matmuratov, 2016).

Hydrological dynamics (degree of mineralization). The lake has gone through four consecutive phases in its history:

- in 1911, the water body had free flow and the water was fresh;
- by 1931, the lake had become isolated from the sea and the river;
- by 1946, the water had become bitter-salty, and the water surface had shrunk from 90 to 4 km^2;
- since the late 1950s, owing to the inflow of fresh (discharge) water, the water surface increased again and mineralization decreased — today the lake is a slightly brackish water body (Matmuratov, 2016).

Fish resources. In 2010, six fish species from the carp and catfish families were recorded in East Karateren — Turkestan dace, roach, asp, silver carp, catfish, and common carp. Researchers emphasize the richness of the lake's

food and fish resources and note the need for serious attention to it from fishery organizations (Matmuratov, 2016).

Thus, Lake Karateren, formed as a result of the desiccation of the Aral Sea, is one of the relic water bodies of the Amu Darya delta and constitutes an important natural resource of Takhtakupyr District in terms of biodiversity and fishery potential — a circumstance that led to the creation of an ethno-tourism complex on its shore.

Review conclusion. Analysis of the available literature shows that Takhtakupyr District and the adjacent territory of Karakalpakstan possess natural-resource potential in two main areas — mineral raw materials (bentonite clays) and water-biological resources (Lake Karateren and the Sudochye system). At the same time, there remains a need for additional, up-to-date research aimed at a modern cadastral assessment and a comprehensive ecological-economic analysis of these resources.

2.5. Research gap

Analysis of the available literature made it possible to identify the following research gaps: (1) a lack of methodologies adapted to the local context — most methods are based on conditions in developed countries; (2) a limited statistical data base; (3) the predominant orientation of existing methods toward static assessment; (4) insufficient development of methodologies that integrate environmental and economic components within a single system.

Comprehensive assessment studies in the context of Takhtakupyr District have been conducted relatively rarely (Bekova & Musayev, 2020; Qosimov & Ergashev, 2022), which underscores the scientific significance of this work. Moreover, in the field of ecotourism, Saidmamatov and co-authors (2020), having studied the supply side of tourism in the Aral Sea basin (at the level of tour operators and travel agencies), established that, despite high awareness among local stakeholders of ecotourism potential, the main obstacle remains a lack of experience, competencies, and international connections (Saidmamatov et al., 2020).

There is also insufficient research on the role of tourism in the economy of the Aral Sea region's districts: Niyazimbetov (2025), analyzing the socio-economic aspects of tourism using the example of Muynak District, shows that ecotourism can serve as an alternative growth direction for neighboring territories of the Aral Sea region as well — a finding of methodological significance for Takhtakupyr District too. This study aims to fill the identified gap by adapting existing theoretical foundations (primarily the "growth poles" concept of Perroux and Boudeville) to the specific features of Uzbekistan's districts.

3. Research methodology

3.1. Research method

The study relies on a mixed-methods design combining qualitative and quantitative methods. Two types of structured questionnaires served as the main data-collection instrument: Questionnaire Type A covered ecological and economic aspects (the impact of environmental risk on the economy, income sources, labor productivity, and the need for innovation and infrastructure), while Questionnaire Type B covered demographic and economic potential (the territory's economic potential, prospects for livestock-farming directions, and the alignment of tourism and investment). Responses were assessed using Likert scales of 1–5 and 1–10 points.

3.2. Sample and composition of experts

Using purposive sampling, 12 experts — representatives of government administration bodies — took part in the study. They were selected as individuals possessing complete information about the ecological and economic situation of Takhtakupyr District and having at least 5 years of work experience in the relevant field. The experts' average work experience in their field was 14.5 years (under 5 years — 2 people; 5–15 years — 6 people; over 15 years — 4 people), which increases the reliability (validity) of the survey results.

3.3. Data analysis method

The collected data were analyzed using descriptive-statistics methods (mean value, degree of dispersion, percentage indicators). Results were visualized using bar charts, radar (spider) charts, and pie charts. Owing to the limited sample size (n = 12), inferential statistical methods (e.g., hypothesis testing) were not applied — this limitation is separately noted in Section 6.3 (Limitations).

4. Research results

4.1. Expert profile

A total of 12 experts took part in the survey. All were representatives of government administration bodies, with an average work experience in this field of 14.5 years.

Table 1. Distribution of experts by work experience

Experience group	Number of experts	Share
Under 5 years	2	16.7%
5–15 years	6	50.0%
Over 15 years	4	33.3%
Total	12	100%

4.2. General assessment of the environmental situation

Experts were asked to assess the impact of the Aral Sea catastrophe, drought, and water scarcity on socio-economic development on a scale of 1–5 (1 — no impact at all, 5 — very strong negative impact).

Table 2. Dynamics of environmental risk over time

Indicator	Average score (1–5)	Risk level
Impact over the past 3 years	4.4	High / negative
Expected impact over the next 5 years	4.7	Critical / very strongly negative

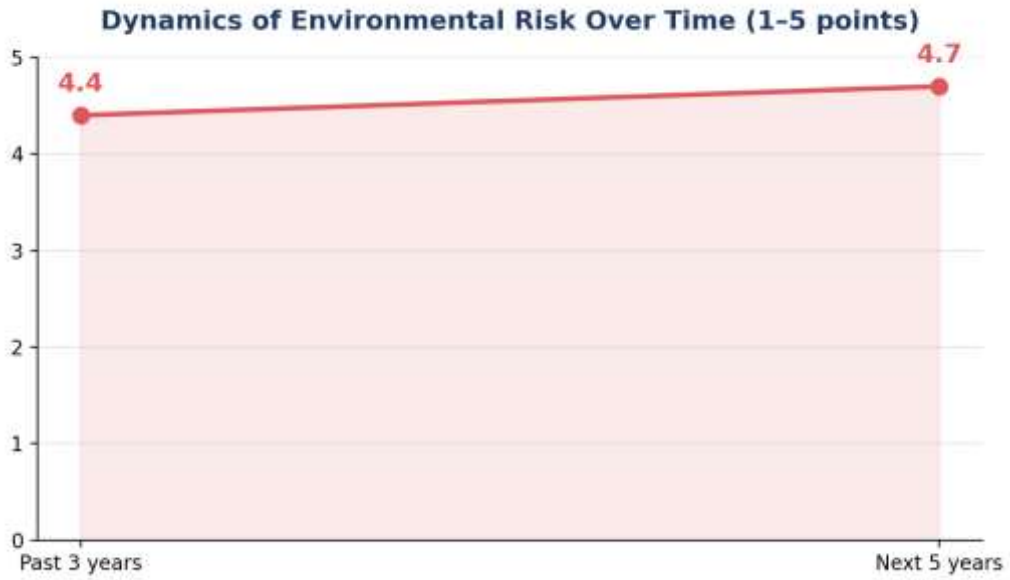

Figure 1. Dynamics of environmental risk over time

All experts rated the current situation as a "strong" or "very strong" negative impact; 75% of them (9 people) are concerned about a further intensification of water scarcity over the next five years and gave the maximum score — 5.

The sectors most affected by the ecological crisis were identified according to the following ranking (in decreasing order of damage):

Table 3. Level of environmental damage by sector

No.	Sector	Damage index (average score)
1	Agriculture and animal husbandry	4.9
2	Drinking water supply	4.6
3	Public health	4.5
4	Population income and living standards	4.2
5	Education and social infrastructure	3.1

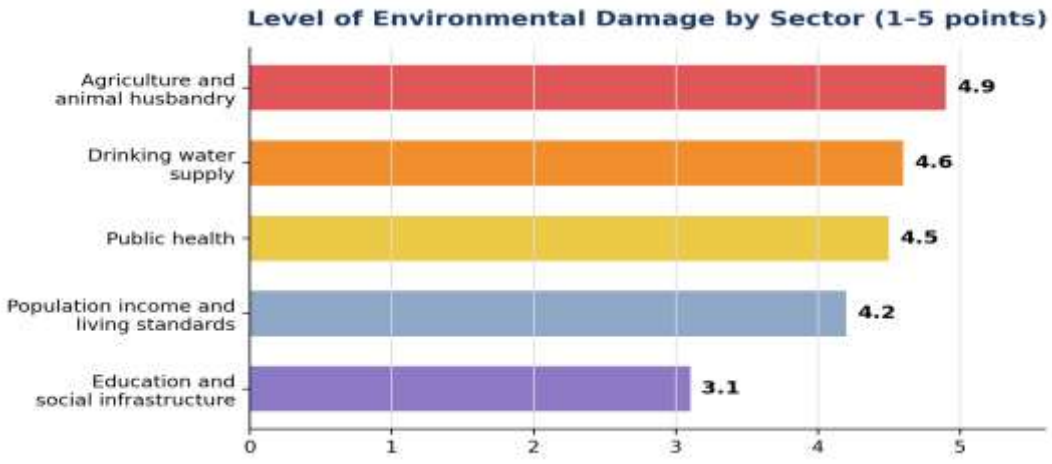

Figure 2. Level of environmental damage by sector

The results show that the ecological crisis has, above all, a strong direct negative impact on the sphere of material production (agriculture — 4.9) and on vital human needs (drinking water and health), whereas education and social infrastructure are subject to relatively indirect effects.

4.3. Sources of population income and labor productivity

Experts assessed, in percentages, the sources from which the district population's overall income is formed. Based on the aggregation of 12 responses, the following average figures were obtained:

Table 4. Average distribution of population income sources

Income source	Share (%)
Salaries of budget-funded organizations (education, healthcare, etc.)	32
Social payments (pensions, benefits, subsidies)	24
Sale of livestock and agricultural produce	18
Entrepreneurship and small business	14
External and internal labor migration (remittances)	12

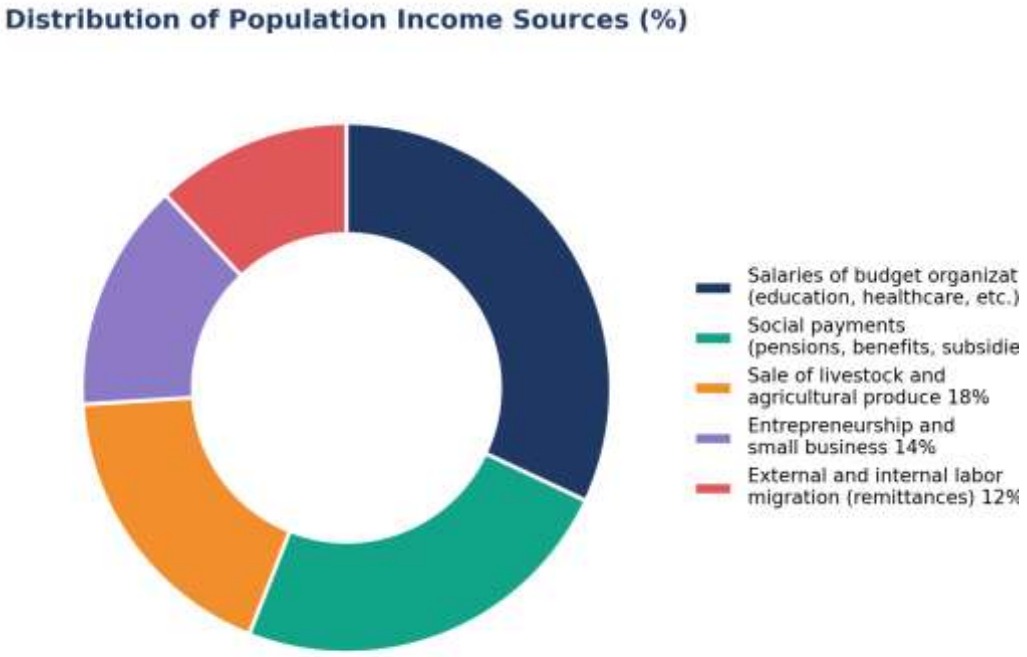

Figure 3. Distribution of population income sources

The results show that the public sector (32%) remains the most stable source of income in the district, while animal husbandry and agriculture, owing to water scarcity, have fallen from their former leading position to third place (18%). The share of remittances from labor migration (12%) indicates the need to create local jobs in the district.

According to experts, worsening climate conditions (extreme heat, salt-dust storms) seriously reduce labor productivity: during the unfavorable summer period, labor productivity falls by 25–35%, and a worker loses on average 15 to 22 working days per year.

Indicator	Range
Decline in labor productivity (%)	25–35
Lost working days (days/year)	15–22

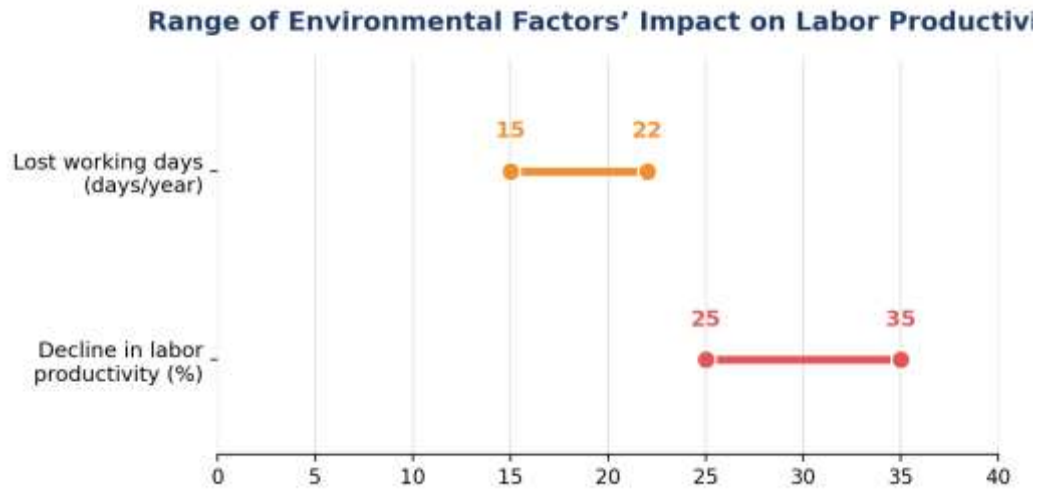

Figure 4. Range of environmental factors' impact on labor productivity

4.4. Economic prospects under conditions of water scarcity

Experts were asked to assess which directions of agricultural development are promising under conditions of water scarcity in the district, on a scale of 1–10 (1 — completely unpromising, 10 — very promising).

Table 5. Ranking of livestock-farming and crop-farming directions under water scarcity

No.	Agricultural direction	Promise index (1–10)
1	Camel breeding	9.2
2	Sheep and goat breeding	8.7
3	Poultry and rabbit breeding	7.4
4	Cattle breeding (meat and dairy)	4.5
5	Traditional farming (rice/cotton)	2.1

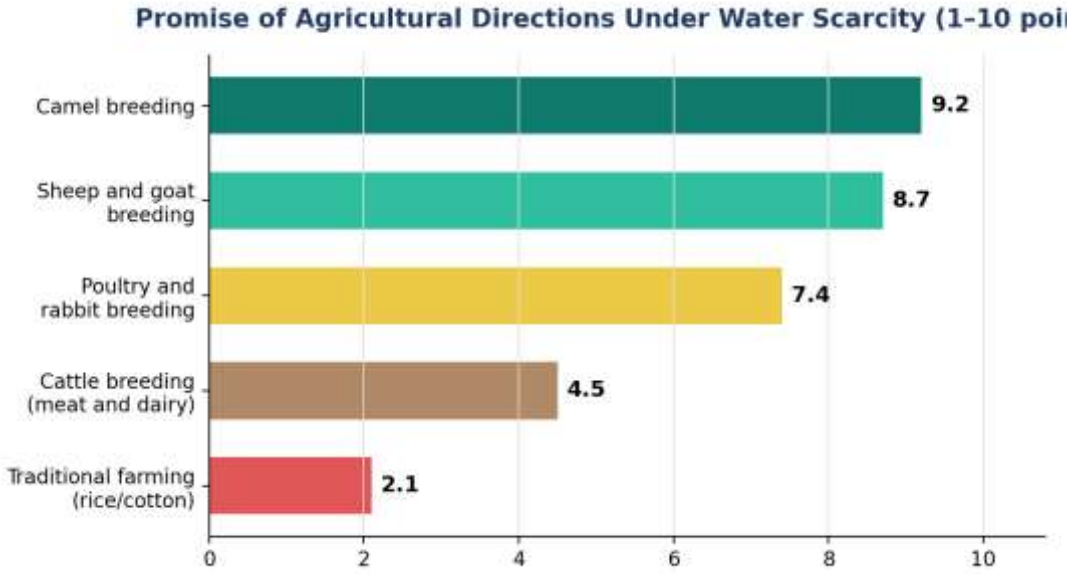

Figure 5. Promise of agricultural directions under water scarcity

Camel breeding (9.2) was recognized as the sector best suited to arid, desert conditions, while sheep and goat breeding (8.7) was recognized as a priority direction owing to its resilience to pasture salinization. In contrast, traditional farming (rice, cotton), which requires large amounts of water, received the lowest promise rating (2.1), leading to a recommendation for its sharp reduction or complete abandonment.

To strengthen the potential of livestock-farming directions related to water consumption, the following recent source can be drawn upon: a study conducted in Southern Kazakhstan, based on an analysis of water-consumption norms for various types of livestock (including an average of 35 liters/day for camels and 6 liters/day for sheep and goats), used geographic information systems to propose a practical model for planning pasture water supply in arid regions. These results quantitatively confirm the advantage of camel and sheep breeding over cattle

breeding in terms of water conservation and are consistent with the promise ratings given by Takhtakupyr's experts (camel breeding — 9.2/10; sheep breeding — 8.7/10) (Water journal, 2025, vol. 17, No. 9).

4.5. Current state of infrastructure systems

Experts assessed the state of existing infrastructure networks on a scale of 1–10 (1 — completely unsatisfactory, 10 — excellent).

Table 6. Current state of infrastructure systems

Infrastructure area	Condition score (1–10)	Problem level
Drinking water supply	3.2	Critical / very low
Internal road network	3.8	Severe / low
Healthcare (medicine)	4.5	Unsatisfactory
Electricity and gas supply	4.8	Unsatisfactory
Internet and communications quality	6.2	Average

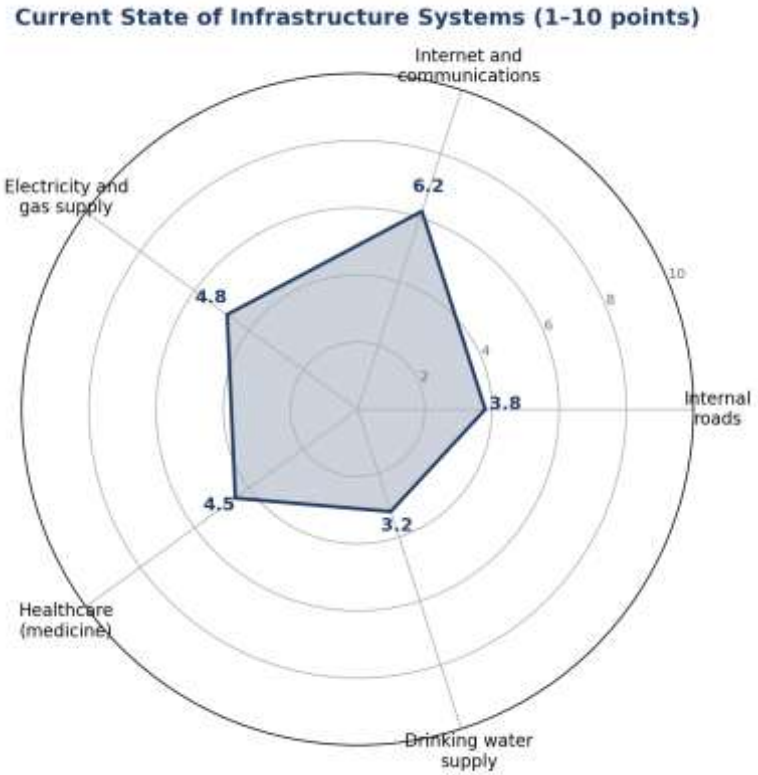

Figure 6. Current state of infrastructure systems — radar chart

The results show that drinking water supply (3.2) and road infrastructure (3.8) are the most critical areas, while the quality of internet and communications (6.2) is in a relatively satisfactory state — although the level of digitalization in remote villages remains low.

4.6. Opportunities for introducing innovative technologies

To preserve and develop the district's economy under conditions of water scarcity, experts rated the following innovations as the highest priority (1–10 scale):

Table 7. Priority level of innovative directions

Rank	Innovative direction	Priority (1–10)
1	Water-saving technologies (drip irrigation)	9.5
2	Alternative (solar and wind) energy	8.8
3	Drought- and salt-resistant crop varieties	8.4

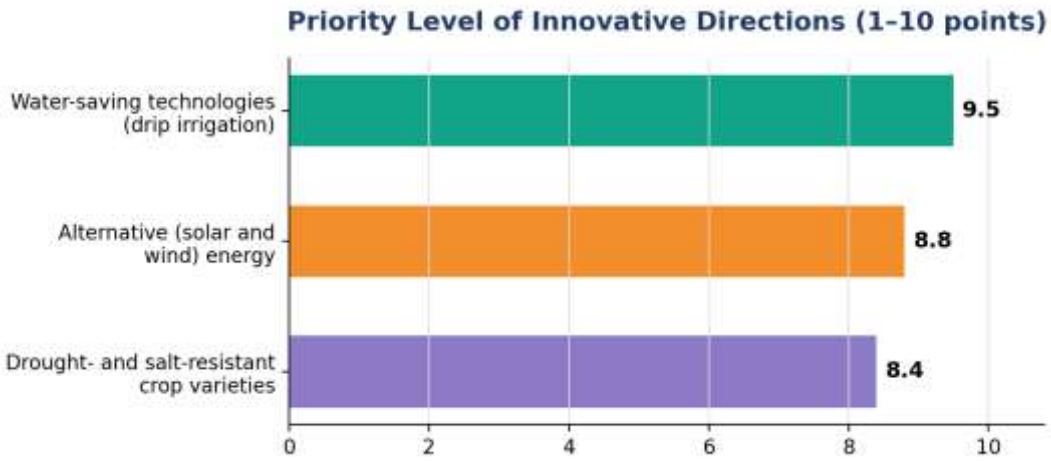

Figure 7. Priority level of innovative directions

Water-saving technologies (9.5) were rated as a decisive factor for the future of agriculture. According to experts, the district's hot, windy climate expands opportunities for using alternative energy sources (sun and wind) (8.8), and new drought- and salt-resistant crop varieties were identified as an important direction for preserving soil fertility (8.4).

4.7. Tourism potential and ecotourism prospects

Experts rated the tourism potential of the Aral Sea region and Takhtakupyr District relatively highly: the potential for ecotourism and extreme tourism was rated at 7.8 out of 10 points — the dried bed of the Aral Sea, desert landscapes, and local culture were recognized as having great potential for attracting foreign tourists. At the same time, the main obstacles cited were a shortage of hotels (campsites), road infrastructure, and catering establishments. In Takhtakupyr District of the Republic of Karakalpakstan, on the shore of Lake Karateren, the "Karateren" ethno-tourism complex opened on 16 October 2024, including a yurt camp, a campsite, and venues for cultural events, oriented toward ecotourism enthusiasts.

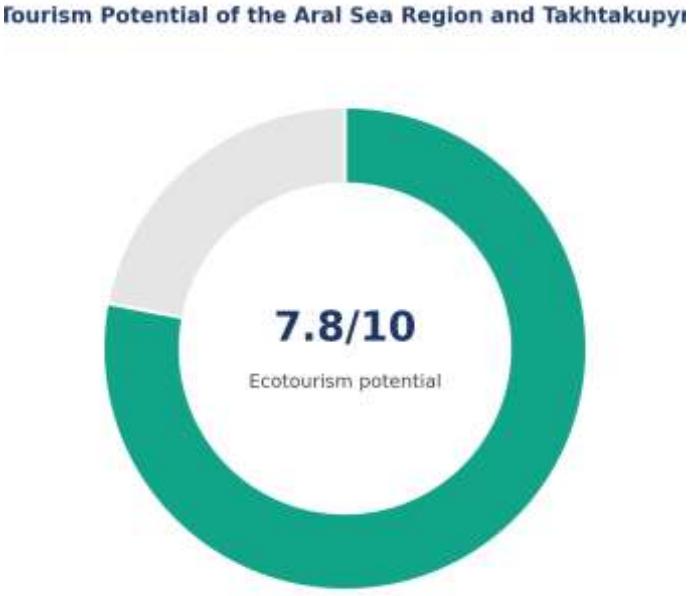

Figure 8. Tourism potential of the Aral Sea region and Takhtakupyr

A large-scale study conducted by Saidmamatov, Matyakubov, Rudenko, Filimonau, Day, and Luthe (2020) (based on a survey of 86 representatives of tour operators and travel agencies) was the first to empirically examine the supply side of ecotourism in the Aral Sea basin. The study's results show that local stakeholders are well aware of the socio-ecological significance of ecotourism and view it positively, but the main constraining factors are infrastructure (roads, hotels, catering) and access to microfinancing. This finding directly aligns with the opinion of Takhtakupyr District's experts regarding high tourism potential (7.8/10) amid infrastructure shortcomings (Saidmamatov, Matyakubov, Rudenko, Filimonau, Day & Luthe, 2020). This result is also consistent with

Niyazimbetov's (2025) study on the example of Muynak District: the author, analyzing the socio-economic aspects of tourism in the districts of the Aral Sea region, particularly emphasizes ecotourism's potential for diversifying local population income and creating jobs — a finding that further substantiates the need to regard tourism as a third strategic "growth point" for Takhtakupyr District as well.

5. Discussion

Final indicator	Score (1–10)
Economic potential	5.7
Impact of ecology on the economy	6.3
Migration: employment	5.2
Migration: environmental factor	5.5
Renewable energy	8.9

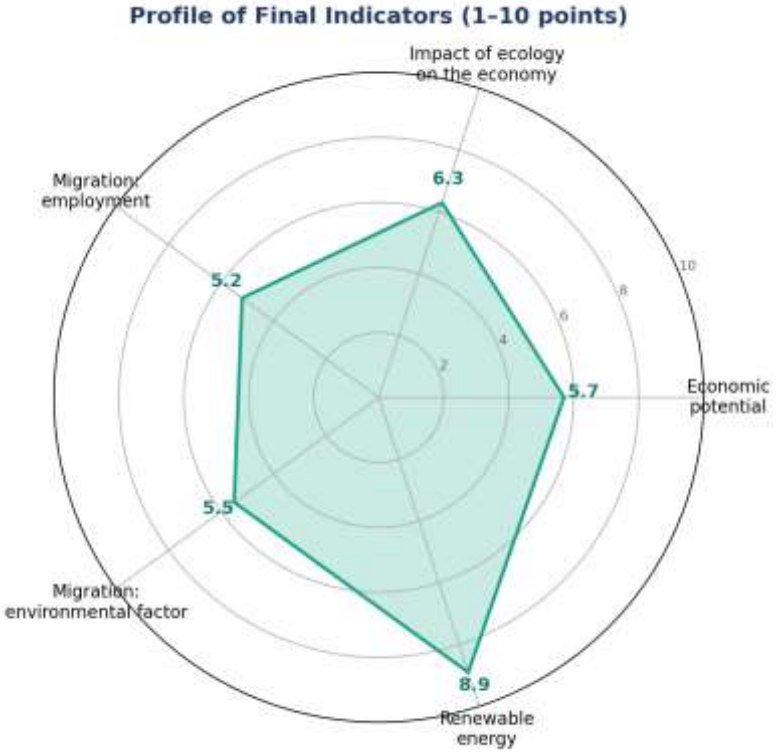

Figure 9. Profile of final indicators — radar chart

The study's results confirm a number of important conclusions. First, in Takhtakupyr District the relationship between environmental problems and the economic situation is strong: the overall level of impact was rated as medium-strong (6.3/10), which is consistent with the general trend in the Aral basin noted by Micklin (2016) and Alibekov & Alibekova (2008).

This conclusion is also confirmed by recent research: Wang and co-authors (2023), analyzing the Aral Sea from a hydro-eco-social perspective, show a close relationship between environmental and socio-economic factors in the region and propose the possibility of bringing the socio-ecological system into balance by raising the sea level by +40 m (Wang et al., 2023). In addition, Wang, Chen, Fang, Li, and Liu (2022), analyzing the socio-political and environmental factors behind the growing water crisis in Central Asia, note that the shrinking of the Aral Sea basin is one of the most severe manifestations of this crisis — indicating a close connection between the water scarcity recorded in Takhtakupyr District and the general regional trend (Wang, Chen, Fang, Li & Liu, 2022).

Second, under conditions of water scarcity, animal husbandry — particularly camel breeding (9.2/10) and sheep breeding (8.7/10) — has been identified as the most resilient and promising direction. This result is of particular significance from the standpoint of Perroux's "growth poles" theory: under conditions of limited resources, instead of developing all sectors evenly, it is advisable to select livestock-farming directions with relative advantages as a priority "point" and concentrate investment on them (Perroux, 1955; Boudeville, 1966).

This conclusion is reinforced by quantitative research on the water consumption of livestock-farming sectors in arid regions: for example, a geoinformation analysis conducted on pastures in Southern Kazakhstan shows that the water requirements of camel and sheep/goat breeding are significantly lower than those of cattle breeding, strengthening the scientific justification for choosing these sectors as a priority "growth point" under conditions of limited water resources (Water, 2025, vol. 17, No. 9).

Third, renewable energy, especially solar energy (innovation priority — 8.8/10), can be regarded as a second strategic "growth point" for the district. This finding is consistent with Schumpeter's idea of innovation-driven development and Romer's endogenous growth theory (Romer, 2011) — innovation and knowledge, through "spillover" effects, can have a positive impact on the economy of the entire region.

In this connection, Rakhimov and co-authors (2025), having assessed wind-energy potential across the regions of Uzbekistan using data from 77 meteorological stations (2000–2022), established that relatively high wind speeds and energy density occur in the north-western districts around Nukus (including Karakalpakstan) — which technically substantiates experts' high priority rating for alternative energy (8.8/10) in Takhtakupyr District (Rakhimov et al., 2025, Renewable Energy Research and Application, 6(2), 191–211).
Fourth, the share of migrant remittances (12%) sharply indicates the need to create local jobs in the district — from the standpoint of Myrdal's theory of cumulative causation, if appropriate measures are not taken, the outflow of qualified young personnel from the district could reinforce a negative cumulative chain.
Fifth, the fact that 91.7% of experts supported the optimistic scenario confirms confidence in the district's potential for sustainable development, despite the serious existing problems. Thus, based on growth-pole theory, three strategic clusters of the district were identified — sustainable animal husbandry, renewable energy, and ecotourism; it is expected that targeted investment in these clusters will produce a positive spillover effect extending to other sectors as well.

5.1. Study limitations

- The sample size is limited (n = 12), so the results should be viewed not as a statistical generalization but as a qualitative indicator of expert opinion; this precludes the application of inferential statistical tests.
- Since all experts were representatives of government administration bodies, the direct opinions of farmers, entrepreneurs, and the local population were not fully incorporated into the study — it is recommended that this be addressed in future research through triangulation.
- The cross-sectional design does not fully capture dynamic changes occurring over time; longitudinal studies are needed in the future.
- Supplementing the subjective Likert-scale assessments with objective statistical data (e.g., hydrological measurements, official economic indicators) would increase the reliability of the results.

6. Conclusions and recommendations

Scenario	Share of experts
Optimistic scenario	91.7%
Other scenarios	8.3%

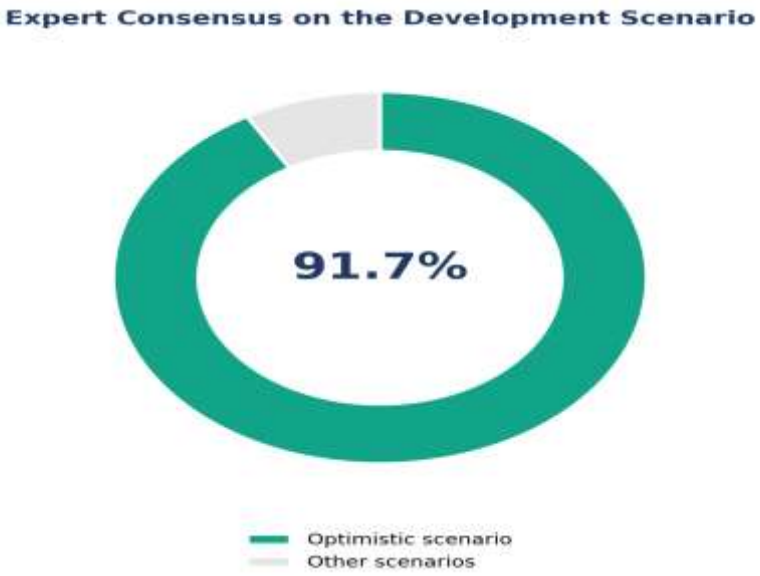

Figure 10. Expert consensus on the development scenario

6.1. Conclusions

1. Environmental problems in Takhtakupyr District have a medium-to-strong impact on population health, standard of living, and economic activity (6.3/10).
2. The district's economic potential is rated at a medium level (5.7/10); there is potential for development through directions resilient to water scarcity.
3. Renewable energy (8.9/10) has been identified as a strategic investment priority for the district.
4. In the process of population migration, environmental factors (5.5/10) and the employment level (5.2/10) play the primary role.
5. 91.7% of experts consider the path of sustainable development to be optimal.
6. Based on growth-pole theory, three strategic clusters of the district have been identified — animal husbandry, renewable energy, and ecotourism; investment directed at them is expected to produce a spillover effect across the district's entire economy.

6.2. Practical recommendations

Short-term (1–3 years): expanding the supply of clean drinking water; introducing drip-irrigation technologies; implementing programs to create local jobs.

Medium-term (3–5 years): implementing solar and wind energy projects; developing ecological and historical tourism infrastructure; introducing salt-resistant crop varieties.

Long-term (5–10 years): developing regional environmental-safety programs; implementing public–private partnership mechanisms; strengthening economic integration with neighboring countries.

6.3. Directions for future research

Future research is recommended to expand the sample to include farmers, entrepreneurs, and the local population, to track dynamic changes through a longitudinal design, and to triangulate expert assessments with hydrological and official statistical data.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The survey data collected during the study can be provided by the corresponding author upon reasonable request.

Ethics Statement

Survey participants were informed of the study's purpose, and participation was voluntary.

References

1. Alibekov, L., & Alibekova, D. (2008). Causes and Socio-Economic Consequences of Desertification in Central Asia. NATO Security through Science Series C: Environmental Security. DOI:10.1007/978-1-4020-8544-4_3.
2. Boudeville, J. R. (1966). Problems of Regional Economic Planning. Edinburgh University Press.
3. City Population. (2025). Taxtakopir District, Uzbekistan — population statistics. https://www.citypopulation.de/en/uzbekistan/admin/qoraqalpogston/UZ35230__taxtakopir/
4. Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature, 387, 253–260.
5. Daly, H. E. (1996). Beyond Growth: The Economics of Sustainable Development. Beacon Press.
6. Hwang, C. L., & Yoon, K. (1981). Multiple Attribute Decision Making: Methods and Applications. Springer-Verlag.
7. Kubiszewski, I., Costanza, R., Franco, C., Lawn, P., Talberth, J., Jackson, T., & Aylmer, C. (2013). Beyond GDP: Measuring and achieving global genuine progress. Ecological Economics, 93, 57–68.
8. Micklin, P. (2020). The Aral Sea: A story of devastation and partial recovery. In P. Micklin, N. V. Aladin, & I. Plotnikov (Eds.), The Aral Sea (pp. 1–33). Springer Geography.
9. Novikova, N., & Leontieva, A. (2021). Methodological approaches to assessing the efficiency of growth poles in the economic space of the region. E3S Web of Conferences, 296, 06038.
10. Odum, H. T. (1971). Environment, Power, and Society. Wiley-Interscience.
11. Perroux, F. (1955). Note sur la notion de pôle de croissance. Economie Appliquée, 8, 307–320.
12. Rakhimov, Yu., et al. (2025). Evaluation of wind energy potential of Uzbekistan. Part I: Gross potential assessment. Renewable Energy Research and Application, 6(2), 191–211.
13. Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S.,

Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. A. (2009). A safe operating space for humanity. Nature, 461, 472–475.
14. Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill.
15. Shibuo, Y., Jarsjö, J., & Destouni, G. (2007). Hydrological responses to climate change in the Aral Sea drainage basin. Geophysical Research Letters, 34, L21406.
16. UNDP. (2021). Human Development Report for Central Asia. United Nations Development Programme.
17. World Bank. (2020). Revitalizing the Aral Sea Basin: A Regional Framework for Action. World Bank.
18. Decree of the President of the Republic of Uzbekistan No. PP-70 of 21 February 2026, "On Approval of the Programs for the Socio-Economic Development of the Republic of Karakalpakstan in 2026 and Subsequent Years."
19. Aimbetov, N. (2025). Problems of Regional Sustainable Social and Economic Development. Monograph. Farma Print, Nukus.
20. Aimbetov, N., & Niyazimbetov, M. (2025). Adaptation and Synergetics. Monograph. Farma Print, Nukus.
21. Niyazimbetov, M. K. (2025). Institutional aspects of socio-economic sustainable development of the region. Bulletin of the Karakalpak Branch of the Academy of Sciences of the Republic of Uzbekistan, No. 3.
22. Baklanov, P. Ya., & Moshkov, A. V. (2002a). Spatial economic structures and methods for their comprehensive analysis. Bulletin of the Far Eastern Branch of the Russian Academy of Sciences, (4), 30–40.
23. Baklanov, P. Ya., & Moshkov, A. V. (2002b). Integral assessments of the natural-resource and socio-economic potential of territories. Geography and Natural Resources, (1), 10–16.
24. Bekova, R., & Musayev, A. (2020). Ecological and economic problems in the Aral Sea basin. Economics and Innovative Technologies, (3), 45–58.
25. Isard, W. (1966). Methods of Regional Analysis: An Introduction to the Science of Regions (Russian translation). Progress.
26. Isard, W. (1972). Development of Regional Science (Russian translation). Ekonomika.
27. Krugman, P. (2014). Space and economic theory (Russian translation by S. Kireev). Bulletin of the Association of Russian Sociologists. Economic School.
28. Kurmasheva, V. A. (2024). Poles of growth and development of a territory's economy. NSUE Scientific Notes, (3), 20–30.
29. Porter, M. (1993). International Competition: Competitive Advantages of Countries (Russian translation, ed. V. D. Shchetinin). Mezhdunarodnye Otnosheniya.
30. Richardson, G. (1977). Theory of Regional Growth (Russian translation). Progress.
31. Romer, P. (2011). Endogenous technological progress. In Economic Policy: Selected Articles (Russian translation, pp. 85–100).
32. State Committee of the Republic of Uzbekistan on Statistics. (2023). Republic of Karakalpakstan: Statistical Collection. Tashkent.
33. Qosimov, F., & Ergashev, A. (2022). Ecological crisis and population migration. Bulletin of the Geographical Society of Uzbekistan, 51, 112–120.
34. Elkanov, R. Kh. (n.d.). Development poles and growth points of an innovative economy: Russian and foreign experience.
35. Saidmamatov, O., Matyakubov, U., Rudenko, I., Filimonau, V., Day, J., & Luthe, T. (2020). Employing ecotourism opportunities for sustainability in the Aral Sea region: Prospects and challenges. Sustainability, 12(21), 9249.
36. Wang, X., Chen, Y., Fang, G., Li, Z., & Liu, Y. (2022). The growing water crisis in Central Asia and the driving forces behind it. Journal of Cleaner Production, 378, 134574.
37. Wang, Y., et al. (2023). Reviving the Aral Sea: A hydro-eco-social perspective. Earth's Future, 11(11), e2023EF003657.
38. Tazhiyev, S., Murtazin, Y., Sotnikov, Y., Rakhimova, V., Adenova, D., Abdizhalel, M., & Yerezhep, D. (2025). Geoinformation and analytical support for the development of promising aquifers for pasture water supply in Southern Kazakhstan. Water, 17(9), 1297.
39. Kurbaniyazov, K. K., & Zakirov, M. Z. (1979). Bentonites of Karakalpakstan. Tashkent: Fan.
40. Eshimbaev, D. (1968). On the chemical composition of the water of the lakes of the Karakalpak ASSR. Bulletin of the Karakalpak Branch of the Academy of Sciences of the UzSSR, (1).
41. Mirabdullayev, I. M., Talskikh, V. N., & Gromyko, K. V. (2001). Sudochye Lake as a refuge of the Aral hydrofauna. Reports of the Academy of Sciences of the Republic of Uzbekistan, (5–6).
42. Matmuratov, M. A. (2016). On the zoobenthos of the East Karateren Lake. Theory and Practice of Modern Science, (6-1) (12), 860–864.
43. Zonn, I. S., & Glants, M. G. (authors); Kosarev, A. N., & Kostyanoy, A. G. (eds.). (2008). Aral Encyclopedia. Moscow: International Relations.