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GEOGRAPHICAL AND ECONOMIC SCENARIOS FOR SUSTAINABLE DEVELOPMENT OF THE KHOREZM OASIS UNTIL 2050 UNDER CLIMATE UNCERTAINTY

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Abstract: The Khorezm oasis, located in the lower reaches of the Amu Darya river, represents one of the most ecologically vulnerable zones in Central Asia due to the Aral Sea crisis and accelerating climate change. This paper explores the long-term geographical and economic trajectories of the Khorezm region up to the year 2050. Utilizing a combination of predictive climate modeling, Geographic Information Systems (GIS) spatial analysis, and macroeconomic forecasting, we develop three distinct development scenarios: pessimistic (continued resource degradation), status quo (fragmented adaptation), and optimistic (systemic green transition). The findings indicate that under the pessimistic scenario, unmitigated water scarcity and soil salinization will trigger severe agricultural contraction, reducing the regional Gross Regional Product (GRP) by up to 22% and inducing massive out-migration. Conversely, the optimistic scenario demonstrates that integrating smart water management, transforming the crop structure (away from water-intensive monocultures), and diversifying into ecotourism and industrial manufacturing can preserve demographic stability and ensure economic resilience. The paper concludes with strategic policy recommendations for regional planners to mitigate climate-induced demographic and economic risks.

Keywords: Khorezm oasis, Sustainable development, Economic scenarios, Climate adaptation, Demographic resilience, Predictive modeling.

Introduction The intersection of global climate change and regional ecological vulnerability presents a profound challenge to contemporary sustainable development, particularly in arid and semi-arid zones. The Khorezm oasis, characterized by its ancient agricultural heritage and structural dependency on the Amu Darya river basin, stands at the forefront of this environmental crisis. Over the past several decades, the catastrophic desiccation of the Aral Sea has transformed the geographic reality of Western Uzbekistan, shifting local climatic baselines toward extreme continental instability, characterized by rising average annual temperatures, acute hydrological deficits, and frequent salt-dust storms.

Historically, the economic vitality and demographic carrying capacity of the Khorezm region have been intrinsically linked to its complex irrigation networks. However, the traditional intensive agricultural model—a legacy of the twentieth-century cotton monoculture—is no longer viable under current climate trajectories. According to recent hydrological and meteorological projections, water availability in the lower reaches of the Amu Darya is expected to decrease significantly by the mid-21st century due to glacier melt in the Pamir-Alay mountains and increased transboundary consumption upstream. This impending deficit threatens not only food security but the entire socio-economic fabric of the region.

Simultaneously, these environmental shifts act as powerful catalysts for demographic restructuring. Water scarcity and land degradation are systematically diminishing rural livelihoods, creating a push factor that accelerates internal urbanization toward administrative centers like Urgench and Khiva, while driving external labor migration. If left unaddressed, this ecological-economic imbalance risks hollowing out the region's productive labor force and crippling long-term economic growth.

While existing literature thoroughly documents the historical and current impacts of the Aral Sea disaster, there is a critical gap in forward-looking, integrated geographical-economic assessments. Strategic planning requires empirical, scenario-based frameworks that look beyond immediate crises to project long-term realities.

Therefore, this study aims to construct comprehensive, multi-variable development scenarios for the Khorezm oasis spanning the horizon from the present to 2050. By synthesizing spatial geographic data with macroeconomic indicators, this research addresses two fundamental questions: How will projected climate variations spatially alter the economic landscape of Khorezm over the next quarter-century? And what structural transformations are required to guarantee sustainable demographic and economic continuity? Through this analysis, we provide a scientific roadmap for regional resilience in one of Central Asia's most critical landscapes.

To construct robust geographical and economic trajectories for the Khorezm oasis up to the year 2050, this study utilizes an integrated analytical framework. Meteorological baselines are derived from historical data (1970–2025) provided by the Center of Hydrometeorological Service of Uzbekistan (Uzhydromet), combined with regional downscaling of the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCP 4.5 and RCP 8.5). Spatial analysis of soil degradation, salinization, and changing agricultural boundaries was conducted using multi-temporal Landsat-8 and Sentinel-2 satellite imagery processed via Geographic Information Systems (GIS).

Macroeconomic indicators, including Gross Regional Product (GRP), employment elasticity, and sectoral output ratios, were sourced from the State Committee of the Republic of Uzbekistan on Statistics. Demographic projections are generated using a cohort-component population forecasting model, incorporating climate-induced migration multipliers based on rural household vulnerability indexes.

3. Results and Discussion

3.1. Spatial and Hydrological Dynamics under Climate Projections

Geographical modeling reveals that under a high-emission scenario (RCP 8.5), the Khorezm oasis will experience an average temperature increase of 2.4°C to 3.1°C by 2050 compared to the 2000–2020 baseline. This warming trend accelerates evapotranspiration rates by an estimated 18–24%, significantly inflating the water requirements of traditional crops.

Concurrently, flow fluctuations of the Amu Darya River at the Tuyamuyun Hydro-Complex are projected to intensify. Glacier retreat in the upstream headwaters will trigger a temporary, deceptive increase in spring runoff volume until approximately 2035, followed by a sharp, structural decline of 25–30% in total annual flow volume by 2050.

GIS spatial mapping indicates that the northern and western periphery of the oasis—specifically the Yangibozor, Shovot, and Gurlan districts—will suffer the highest rates of topsoil desertification. The water table in these areas is projected to become increasingly saline, raising the soil mineralization index (EC_e) past critical thresholds ($\ge 16\text{ dS/m}$), rendering thousands of hectares of arable land structurally barren.

3.2. Comparative Analysis of Three Socio-Economic Scenarios

To visualize the future of the Khorezm oasis, three comprehensive scenarios have been modeled to capture the interplay between climate factors, economic policy, and demographic realities over the next quarter-century.

Indicator for Year 2050	Baseline (2025)	Scenario A: Pessimistic (Resource Attrition)	Scenario B: Status Quo (Fragmented Adaptation)	Scenario C: Optimistic (Systemic Green Transition)
Water Allocation Accuracy	100% (Standard)	-32% deficit vs. demand	-12% localized shortage	$+5\%$ efficiency surplus
Arable Land Degradation	22% of total area	48% highly salinized	35% moderately degraded	$<15\%$ stabilized/restored
Real GRP Growth Rate	$\approx 5.2\%$ annual	-1.8% to $+0.5\%$ (Stagnation)	$+2.5\%$ to $+3.2\%$ (Volatile)	$+6.5\%$ to $+7.8\%$ (Sustainable)
Agrarian Share of GDP	38.4%	18.2% (Collapse driven)	28.5% (Subsidized)	14.0% (Value-driven shift)
Net Migration Rate	-1.2% annually	-4.8% (Severe out-flux)	-1.5% (Steady out-flux)	$+0.4\%$ (Brain-gain/In-flux)
Urbanization Rate	34.1%	62.5% (Unplanned/Slums)	48.0% (Gradual transition)	55.0% (Smart-city model)

Scenario A: The Pessimistic Blueprint (Unmitigated Resource Attrition)

This pathway presumes a lack of regional consensus on transboundary water governance in Central Asia, coupled with a rigid retention of water-intensive agrarian practices within Khorezm. As the structural water deficit crosses the 30% threshold by 2040, the regional economic core fractures.

Cotton and rice production become completely non-viable in the outer districts. The agricultural sector sheds over 150,000 jobs within a decade. Because the local industrial fabric is heavily dependent on raw agricultural processing, manufacturing experiences a parallel contraction.

Demographically, this model triggers an unprecedented wave of climate refugees. Rural families abandon the northern buffer zones, causing rapid, chaotic, and un-engineered horizontal expansion of Urgench and Xiva. Municipal infrastructure fails to absorb this displacement, leading to heightened urban poverty, falling life expectancy, and severe regional economic stagnation where real GRP effectively contracts by more than one-fifth.

Scenario B: The Status Quo Blueprint (Fragmented Adaptation)

This intermediate scenario assumes that the government implements localized, reactive adjustments rather than systemic structural overhauls. Modern irrigation technologies, such as drip lines and concrete lining of primary canals (e.g., Shovot and Tashsaka systems), are deployed unevenly, primarily benefiting large-scale agricultural clusters while neglecting smallholder dehqon farms.

Economic growth remains erratic and highly sensitive to seasonal water volumes. While absolute collapse is averted, the widening socio-economic gap between modernized districts and water-starved peripheries deepens internal demographic inequality.

Young, skilled labor continues to migrate externally to Tashkent or international markets, leaving behind an aging rural population. This demographic drain limits the region's long-term capacity to innovate or transition to high-value service economies.

Scenario C: The Optimistic Blueprint (Systemic Green Transition)

The optimistic trajectory demonstrates the profound impact of proactive, highly coordinated geographical-economic re-engineering. In this scenario, Khorezm undergoes a rapid structural shift away from crop volume toward value-added agricultural efficiency and industrial diversification.

By 2035, flood irrigation is entirely outlawed and replaced by automated, closed-loop smart drip-and-mist irrigation systems, reducing aggregate agricultural water consumption by 45% while boosting crop yields per cubic meter.

Critically, the crop geography of the oasis is entirely rearranged: cotton acreage is systematically scaled back by 70%, replaced by drought-tolerant, high-income halophytes, organic horticulture, and advanced greenhouse networks powered by the region's high solar irradiation capacity.

The saved water volume is redirected to restore local deltaic ecosystems and small lakes, mitigating the impact of toxic dust storms. Concurrently, the economic weight pivots toward high-tech industrial manufacturing, textile processing hubs, and a world-class ecotourism and cultural heritage cluster centered around Xiva.

The transition to Scenario C hinges heavily on shifting human capital dynamics. The economic modeling indicates that creating industrial zones along the rail and transport corridors connecting Urgench, Xiva, and Pitnak can smoothly absorb the labor forces shifting away from traditional farming.

Diversifying the economy protects the regional GRP from extreme climate events and erratic river flows. When agricultural output is decoupled from survival metrics, the demographic framework stabilizes.

Instead of desperate out-migration, the region creates an internal talent pool focused on digital services, green engineering, and advanced water resource management. This transformation turns a high-risk ecological crisis into an organized, sustainable, and highly resilient modern regional economy.

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