



LAND USE AND WATER RESOURCES IN THE CONTEXT OF CLIMATE CHANGE

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Abstract: *Climate change has been identified as a major challenge in the effective management of sus-tainable land use and water resources. The Republic of Uzbekistan is a country located in Central Asia that has been identified as prone to the adverse effects associated with climate change, primarily due to rising temperature levels, increased levels of water scarcity, land degradation, as well as their high dependence on transboundary water resources. Over the last century, the average annual tem-perature rise in Uzbekistan has been identified as 1.6°C, an increase from the global average, coupled with a decline in water resources in Amu Darya and Syr Darya River basins by 10-40% by 2050. At the same time, more than 70% of land in Uzbekistan has been identified as degraded, with a number of regions featuring increased levels of secondary salinization. The aim of this study is to systematize and analyze the current tools, methods, and mechanisms used in the context of sustainable land use and rational water resources management under the impact of changes in the climate, with Uzbekistan used as the case study. The scientific research is based on an analysis of international experience, scientific literature, statistical information, and national policy documents. Particular emphasis is placed on the concept of land-water nexus, integrated management of water resources, as well as climate change effects on land and water resources availability and quality. From the study, it may be inferred that Uzbekistan is dealing with persistent problems, such as outdated infrastructure, frag-mented governance, limited access to finance, and resource users' lack of awareness and knowledge about the management of the available resources, despite the reforms that are being implemented. The study has formulated recommendations to be applied for the policymakers and practitioners to improve institutional coordination, expand financial support mechanisms, and promote innovative agricultural practices. The results achieved in this research contribute to the development of strategies for sustainable development and supporting the implementation of the “Uzbekistan 2030” Strategy, particularly with a focus upon the importance of integrated land and water resource management for attaining climate resilience and sustainable development.*

Keywords: *Climate change, land use, water resources, sustainable land management, inte-grated water resources management, water scarcity, land degradation, irrigation, Uzbekistan*



Introduction:

Relevance of the Problem. Climate change is one of the most serious global threats of the 21st century, significantly impacting land and water resources worldwide. The Republic of Uzbekistan, located in the arid zone of Central Asia, is among the countries most vulnerable to

climate change. According to the National Statistics Committee of the Republic of Uzbekistan, the average annual temperature in the country has increased by 1.6 degrees Celsius since 1880 (from 13.2 to 14.8 de-grees), exceeding the global average.

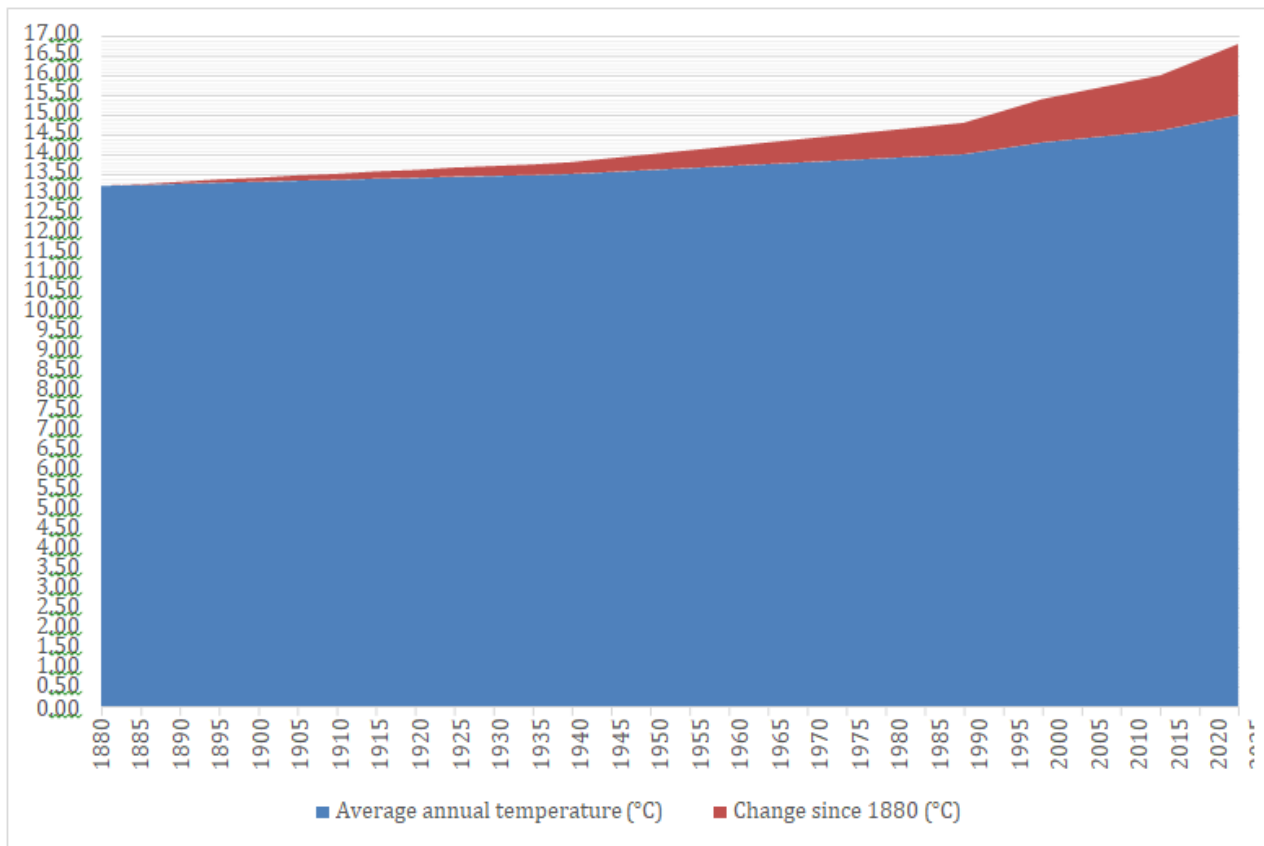


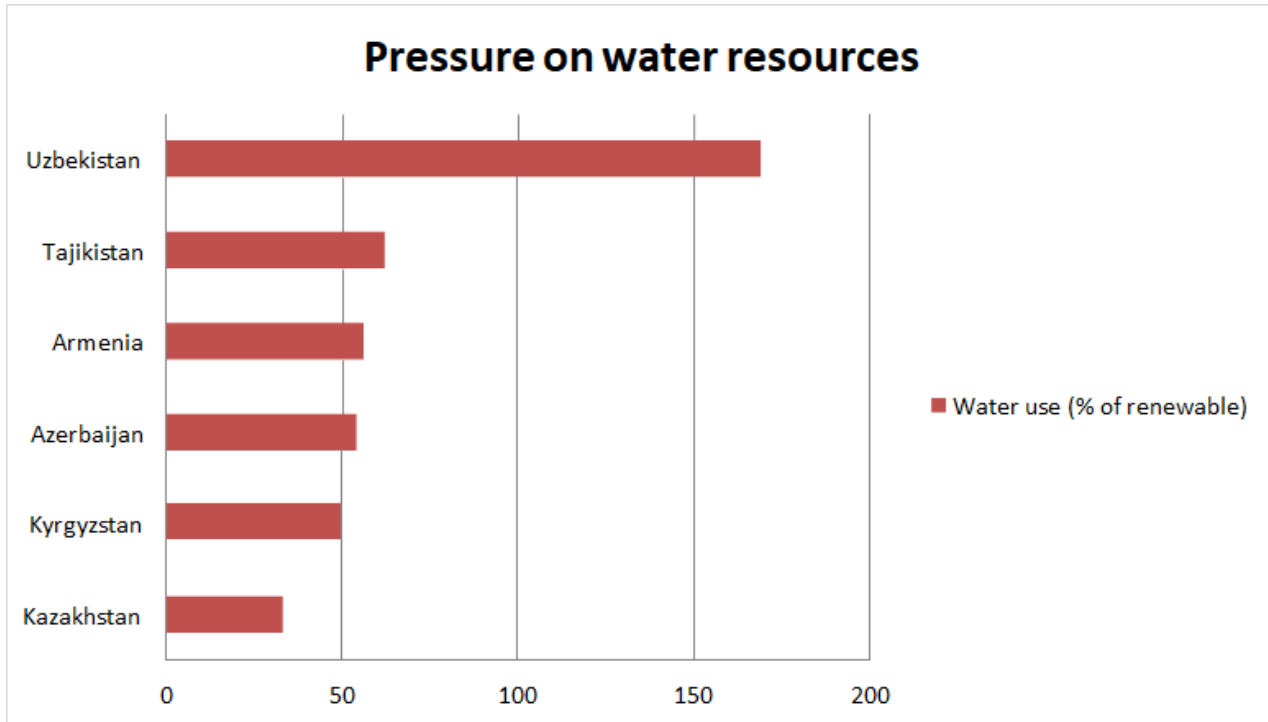
Figure 1: Dynamics of growth of average annual temperature in Uzbekistan (1880–2025)

For Uzbekistan, the relationship between land use and water resources is critical. According to the Institute for Strategic and Interregional Studies under the President of the Republic of

Uzbekistan, water resources in the Syr Darya basin are expected to decrease by 5% by 2050, and in the Amu Darya basin by up to 15%.



Figure 2: Pressure on water resources in Central Asia countries

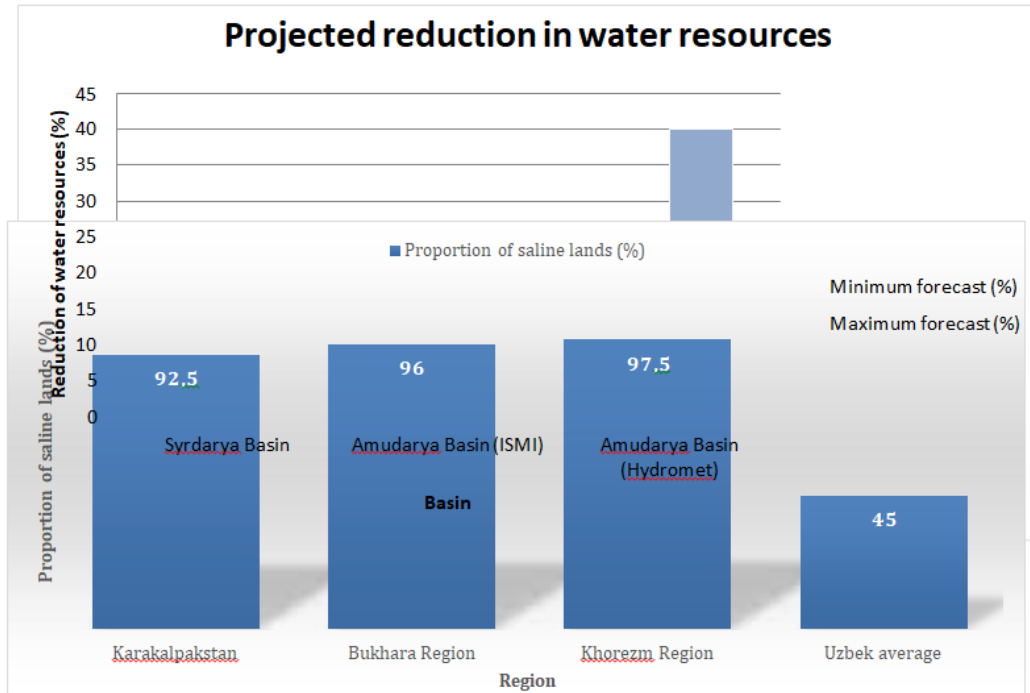


Experts from the Center for Hydrometeorological Service of Uzbekistan predict an even more significant reduction in water resources in the Amu Darya and Syr Darya basins by 25-40% by 2050. According to forecasts from the Food and Agriculture Organization of the United Nations (FAO), the level of stress on water resources in Uzbekistan and Turkmenistan has reached a critical level, exceeding 100%—the volume of water used amounts to 169% of the country's water reserves. Land degradation exacerbates the water crisis. According to

UN experts, more than 70% of Uzbekistan's territory is desert, and more than 70% of its land is degraded, resulting in annual economic losses of \$830 million. The territory of Uzbekistan requiring measures to combat desertification exceeds 20 million hectares. Approximately 2 million hectares (45%) of irrigated land have been subject to secondary salinization. The most critical situation is observed in Karakalpakstan (90-95% of saline land), the Bukhara region (96%), and the Khorezm oasis (95-100%).



Figure 3: Forecast of water resource reduction in river basins by 2050



Agriculture in Uzbekistan, a key sector of the national economy, relies heavily on irrigation and consumes approximately 90% of the country's water. Shavkat Khamrayev, Minister of Water Resources of the Republic of

Uzbekistan, notes that only 20% of the country's water resources are generated domestically, with the majority coming from neighboring countries. Furthermore, the water deficit could reach 15 billion cubic meters by 2030.

Figure 4: Salinization of irrigated lands by region of Uzbekistan

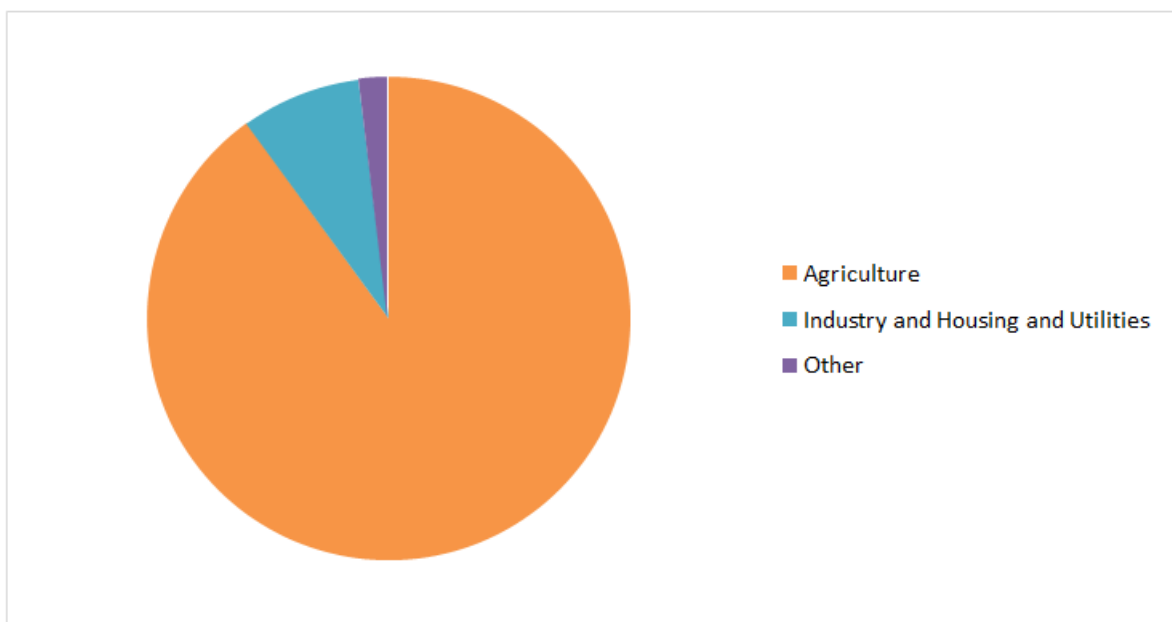


Figure 5: Structure of water consumption in Uzbekistan



Climate change is manifested by longer periods of dry heat, reduced snow accumulation and glacier degradation, increased evaporation on plains and in the foothills, and an increased frequency of droughts and extreme low-water events. Over the past 50-60 years, the area of

glaciers in Central Asia has shrunk by approximately 30%. It is predicted that between 2030 and 2050, air temperatures in the region could rise by another 1.5-3 degrees Celsius, with the greatest increase expected in the Aral Sea region due to the drying up of the Aral Sea.

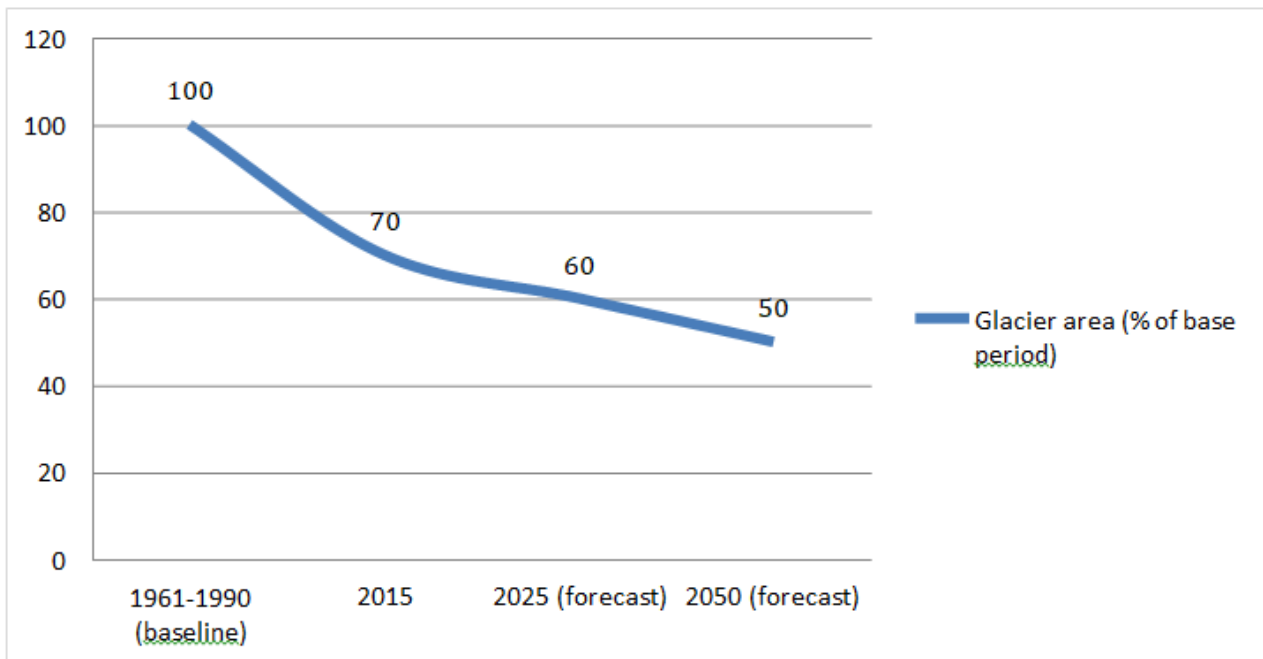


Figure 6: Reduction of glacier area in Central Asia

This situation requires the urgent implementation of modern tools and methods for land and water resource management to ensure the country's sustainable development. President of the Republic of Uzbekistan Shavkat Mirziyoyev has repeatedly emphasized the importance of addressing water issues at international forums, including the UN General Assembly and the Climate Change Conference (COP29).

The objective of the study is to systematize and analyze modern tools and methods for ensuring sustainable land use and rational water resource management

in the context of climate change, using the Republic of Uzbekistan as an example.

To achieve this goal, the following objectives were formulated:

1. To analyze the theoretical foundations and international experience of sustainable land and water resource management in the context of climate change;
2. To evaluate modern approaches to monitoring and forecasting the impact of climate change on land and water resources;



3. To explore innovative tools and technologies for adapting land and water use to climate change;

4. To study the legal, institutional, and economic mechanisms for land and water resource management in Uzbekistan;

5. To identify the main challenges and limitations to the implementation of modern resource management methods in Uzbekistan;

6. To develop recommendations for improving the land and water resource management system to achieve sustainable development goals.

The scientific novelty of the study lies in its comprehensive analysis of the relationship between land use and water resources in the context of climate change, taking into account the specific features of the arid zone of Central Asia, as well as in its systematization of modern tools and methods for adaptation to climate change applicable in Uzbekistan.

The practical significance of this study lies in its potential use in developing sustainable development strategies and programs, improving the legal framework for land and water resource management, and implementing the "Uzbekistan 2030" Strategy, which aims to create favorable environmental conditions for the population and conserve water resources as one of the country's five development priorities.

The study is based on an analysis of official documents, statistical data, scientific publications, and regulatory

legal acts of the Republic of Uzbekistan, including the Environmental Protection Concept until 2030, the Water Resources Development Concept of Uzbekistan for 2020-2030, the Water

Resources Management and Irrigation Sector Development Strategy in the Republic of Uzbekistan for 2021-2023, and the "Uzbekistan 2030" Strategy.

Theoretical Foundations of Sustainable Land and Water Resources Management

1.1. The Concept of Sustainable Development as Applied to Land Use

The concept of sustainable development is the fundamental basis of the modern approach to natural resource management. According to the definition of the UN World Commission on Environment and Development (Brundtland Commission), presented in the report "Our Common Future" (1987), sustainable development is development in which meeting the needs of the present does not undermine the ability of future generations to meet their own needs.

This formulation enshrined the principle of intergenerational equity as the foundation of sustainable development and received widespread recognition following the UN Conference on Environment and Development (Rio de Janeiro, 1992), which adopted Agenda 21—a comprehensive program of action to ensure sustainable development at the global, national, and local levels. The concept of sustainable development is



based on a three-pronged approach that balances three interrelated components:

1) The economic component—the rational use of resources to ensure economic prosperity and improve societal well-being;

2) The social component—achieving a high standard of living, a fair distribution of benefits, and ensuring social stability;

3) The environmental component—preserving the environment, biodiversity, and natural resources for future generations.

Academician T.S. Khachaturov, the founder of the science of environmental economics, wrote about the need for "sustainable socio-ecological-economic development of the country" back in 1979—long before the adoption of fundamental UN decisions in this area. The modern interpretation adds a fourth component to the traditional three—the management component, responsible for effective management and coordination of actions.

Sustainable development theory distinguishes two main approaches: the concept of strong sustainability and the concept of weak sustainability. Strong sustainability presupposes preserving natural capital for future generations without altering it. For example, according to UNESCO, "each generation should leave the world's water, air, and soil resources in the same condition as they found them when it first appeared on Earth." Weak sustainability, developed by Obel Laureate in Economics Robert

Solow, allows for the substitution of physical or human capital for natural capital, provided that the overall well-being of the next generation is not diminished.

With regard to land use, the concept of sustainable development means the use of land resources that ensures: (1) meeting the needs of the population for food, raw materials, and other products of land use; (2) maintaining and restoring soil fertility; (3) preventing land degradation, erosion, and desertification; (4) preserving biodiversity and the ecological functions of landscapes; (5) ensuring the economic efficiency of land use. According to Agenda 21 (Chapter 7), the goal of sustainable land management is to meet land resource needs through environmentally sound spatial planning. This requires the development of national legislation, the creation of effective land markets, a system of tax incentives and land use controls, and partnerships between the public, private, and community sectors. Sustainable soil management involves practices such as no-tillage, the creation of shelter-belts to reduce erosion, salinity control, and composting. The ever-increasing global population makes land particularly valuable as a resource, so land use and planning must consider factors such as soil erosion, sustainability, and renewability.

1.2. The Water-Land Nexus: Linkages and Interdependencies



The nexus approach (from the English word nexus – connection, interdependence) is a conceptual framework for the comprehensive analysis of the interrelations between strategic resources. The most widely used is the water-energy-food nexus (WEF nexus), which examines the interdependence of water resources, energy, and food security. Since food production is inextricably linked to land use, an expanded version of the concept considers a four-component nexus: the climate-land-energy-water (CLEW nexus).

Water, energy, food, and land, as researchers note, form a single "hyperconnected" global network, the functioning of which is characterized by complexity and feedback loops. This system is under pressure from population growth, climate change, political decisions, and socioeconomic development. The efficient functioning and sustainability of the land-water nexus are essential for human well-being.

The key interrelationships in the land-water nexus are:

1) Water for land use: Agriculture consumes approximately 70% of global freshwater withdrawals for crop irrigation. The availability and quality of water resources directly determine land productivity and agricultural use.

2) Land for water: Land use patterns influence the hydrological cycle, precipitation infiltration, groundwater recharge, surface runoff, and water

quality. Wetlands, forests, and natural ecosystems perform critical water regulation functions.

3) Competition for resources: Increasing food demand requires the expansion of irrigated land, which increases water withdrawals and can lead to the depletion of water resources. At the same time, land degradation reduces their water-holding capacity. 4) Energy Nexus: More than a quarter of the energy used globally is spent on producing and supplying food. Energy is needed to pump water, operate irrigation systems, and cultivate land.

Population growth, regional socioeconomic development, and changing resource consumption patterns in the context of a changing climate are dramatically increasing the demand for water, energy, and food. Ensuring water, energy, and food security requires considering the interrelationships between these sectors, seeking compromises to meet the needs of different consumers, and developing intersectoral cooperation and planning.

In Central Asia, the nexus approach is actively promoted by international organizations, including the OECD, UNECE, and FAO. The "Water, Energy, and Land Nexus in Central Asia" project is implementing pilot projects, holding regional dialogues, and developing specialist capacities. The nexus approach is designed to promote integrated management, taking into account the importance of ecosystems as guarantors of resource security. The Food



and Agriculture Organization of the United Nations (FAO) emphasizes that, given the projected population growth to 9 billion by 2050, food production will need to increase by 60%, creating unprecedented pressure on water and land resources. Understanding and applying the nexus approach helps avoid the unintended consequences of sectoral decisions and unlocks the potential to achieve the UN Sustainable Development Goals.

1.3. Impact of Climate Change on Resource Availability and Quality

Climate change has profound and multifaceted impacts on land and water resources, becoming one of the main threats to sustainable development in the 21st century. According to the Intergovernmental Panel on Climate Change (IPCC) Special Report "Climate Change and Land" (2019), the increase in surface air temperature over land since the pre-industrial period is almost twice the global average temperature.

Impact on Water Resources. The United Nations calls water the central element of the climate crisis. Water is the cause of most of the impacts of climate change—from unpredictable precipitation patterns to shrinking ice sheets, rising sea levels, floods, and droughts. Currently, approximately 2 billion people worldwide lack access to safe drinking water, and approximately half the world's population experiences severe water shortages for at least part of the year. These figures are expected to increase due to climate change and

population growth. Available and usable freshwater accounts for only 0.5% of the Earth's water resources, and climate change threatens these reserves. Rising temperatures disrupt precipitation patterns and the entire hydrological cycle. Changes in precipitation directly impact groundwater recharge: in regions with reduced precipitation, groundwater levels decline, leading to drinking water shortages and problems in agriculture.

According to UNESCO, climate change will negatively impact the availability, quality, and quantity of water resources needed to meet basic human needs. Rising water temperatures and reduced dissolved oxygen concentrations reduce the self-purification capacity of freshwater basins. This creates increased risks of water pollution and pathogen infestations caused by floods or higher concentrations of pollutants during droughts.

In coastal areas, rising sea levels can lead to salinization of groundwater, degrading its quality. Accelerated evaporation with rising temperatures increases the concentration of pollutants in water bodies. Hotter water typically contains less dissolved oxygen, which negatively impacts ecosystems.

Impact on land resources. The IPCC notes that climate change, including increased frequency and intensity of extreme events, is negatively impacting food security and terrestrial ecosystems, contributing to desertification and land degradation in many regions. Desertification, land degradation, and



drought (DLDD) negatively impact the availability, quantity, and quality of water resources, leading to water shortages.

Climate change is altering water availability, making it a more scarce resource in a growing number of regions. Global warming is exacerbating water shortages in already water-stressed regions and increasing the risk of agricultural droughts, which impact crop yields, and environmental droughts, which increase the vulnerability of ecosystems. Droughts can trigger devastating sand and dust storms, capable of transporting billions of tons of sand across continents. Deserts are expanding, reducing the land available for growing food crops.

Changing land cover affects evaporation and transpiration, which affects the amount of water available to recharge aquifers. Deforestation and land cultivation lead to increased surface runoff and decreased water infiltration into the soil, reducing groundwater recharge.

Regional Features. Most of the impacts of climate change on water resources are manifested in the tropics, where most developing countries are located. Archipelagos, mountainous regions, tropical regions, and the far north are most vulnerable. Some small island states may face existential threats.

Arid regions, such as Central Asia, face particular risks. Water scarcity increases the risks to agricultural production as water supply, storage, and transportation systems reach their design

limits. In many areas with high water stress, farmers withdraw shallow groundwater for irrigation, in some cases using non-renewable resources.

The need for adaptation. Gilbert F. Hounbo, Chair of UN-Water and President of the International Fund for Agricultural Development, emphasizes: "If we are truly committed to limiting global temperature rise to below 2°C and achieving the Sustainable Development Goals by 2030, we must take urgent action. Improved water management can support climate change mitigation and adaptation efforts." Adaptation to climate change requires innovative approaches to water resource management and land use. It is necessary to implement advanced technologies to increase water efficiency, improve water collection and recycling systems, and develop new methods for managing water resources. Healthy aquatic ecosystems and more effective water resource management can reduce greenhouse gas emissions and provide protection from climate threats.

CONCLUSION:

This study systematizes modern tools and methods for ensuring sustainable land use and rational water resource management in the context of climate change, using the Republic of Uzbekistan as an example. The analysis shows that the country faces serious challenges due to the combination of climate change, its geographical location in an arid zone, and its dependence on transboundary water resources..

Summary of Key Findings



1. Scope of the Problem

Uzbekistan is among the countries most vulnerable to climate change. The average annual temperature in the country has increased by 1.6 degrees Celsius since 1880, exceeding the global average. Water resources in the Syr Darya and Amu Darya basins are projected to decline by 10-40% by 2050. Over 70% of the country's territory is degraded, and approximately 2 million hectares of irrigated land have been subjected to secondary salinization.

2. Theoretical Foundations of Management

The study showed that sustainable land and water resource management should be based on the principles of a land-water nexus, recognizing the inextricable relationship between these resources. The concept of integrated water resources management (IWRM), adapted to the conditions of Uzbekistan, envisions the coordination of water use, land use, and ecosystem protection at the basin level. 3. Innovative monitoring and analysis tools

Modern technologies significantly improve resource management efficiency. Remote sensing enables monitoring of crop conditions, land degradation, and water quality. Digital platforms such as Smart Water enable real-time water consumption monitoring. Mathematical models of water balance and erosion processes support informed decision-making.

4. Water-saving technologies

The introduction of modern irrigation technologies is a key area of adaptation. Drip irrigation systems can reduce water consumption by 40-50% while simultaneously increasing crop yields. The Government of Uzbekistan provides subsidies covering up to 40% of the cost of such systems and concessional loans through the suvkredit.uz platform.

5. Legal and Institutional Mechanisms

Uzbekistan has created an extensive legal and regulatory framework for water resources management, including the Water Resources Development Concept for 2020-2030 and the Water Resources Management Strategy for 2021-2023. Economic instruments, such as water tariffs and subsidies, have been introduced to encourage efficient resource use.

6. Key Challenges and Constraints

Despite progress, significant barriers remain: the high cost of modern technologies, limited access to financing, fragmented institutional governance, outdated infrastructure, lack of data and information, and low awareness of best practices among farmers.

Recommendations for Policymakers and Practitioners For policymakers and government agencies:

1. Strengthening financial support

- Expand subsidy programs for water-saving technologies, increasing subsidies from 40% to 50-60% for small farms



- Develop public-private partnership mechanisms to attract investment in water infrastructure modernization

- Create a special climate adaptation fund to finance pilot projects**

2. Institutional Reforms**

- Strengthen coordination between ministries and agencies by establishing an interdepartmental water resources council with clear powers

- Empower basin water management organizations with greater authority in water planning and allocation

- Develop the capacity of local water user organizations

3. Information Systems Development

- Create a unified digital platform for monitoring and managing water and land resources with open access to data

- Invest in modernizing the hydrometeorological network and early warning systems

- Develop the use of remote sensing technologies for operational monitoring

4. Legal Improvements

- Improve water use legislation to ensure transparency and fairness in water allocation

- Strengthen enforcement mechanisms for water legislation

- Harmonize national legislation with international standards

For practitioners (farmers, water user organizations, agribusiness):

1. Implementation of water-saving technologies

- Transition to drip and subsurface irrigation systems, especially for high-value crops

- Apply soil mulching to reduce evaporation

- Use water-saving agricultural practices, such as minimum tillage

2. Diversification of agricultural production

- Implement crop rotations with drought-resistant crops

- Develop horticulture and viticulture as an alternative to water-intensive crops

- Transition to the production of high-value-added products

3. Improvement of farm-level management

- Actively participate in the work of water user organizations

- Implement water metering and irrigation planning systems

- Invest in training and professional development

4. Use of Innovative Solutions

- Apply digital tools for irrigation planning

- Use meteorological data and forecasts to optimize water use

- Participate in pilot projects to introduce new technologies Areas of Further Research



1. Deepening the scientific understanding of climate change
 - Developing detailed climate models for various regions of Uzbekistan, taking into account local characteristics
 - Studying the impact of climate change on the hydrological cycle, including changes in precipitation, snowmelt, and glacial runoff
 - Assessing the cumulative impact of climate change on ecosystems and biodiversity
2. Optimizing water and land use
 - Developing integrated water-land balance models for various agroclimatic zones
 - Studying optimal crop rotations and cropping patterns, taking into account water resource limitations
 - Analyzing the effectiveness of various irrigation systems in Uzbekistan
3. Socioeconomic aspects of adaptation
 - Assessing the economic effectiveness of various adaptation measures at the level farms and regions
 - Study of the social consequences of climate change and adaptation strategies for vulnerable groups
 - Analysis of barriers to the implementation of innovative technologies and development of measures to overcome them
4. Transboundary cooperation and regional integration
 - Development of mechanisms for the equitable distribution of transboundary water resources in the context of climate change
 - Study of the possibilities of creating regional climate monitoring and early warning systems
 - Analysis of successful international experience in transboundary basin management
5. Technological innovations
 - Development and adaptation of new varieties of agricultural crops resistant to drought and salinity
 - Study of the potential for using renewable energy sources for water lifting and irrigation
 - Development of intelligent irrigation management systems based on artificial intelligence and big data
6. Institutional and legal mechanisms
 - Analysis of the effectiveness of existing institutional structures for water resources management
 - Development of models for successful public-private partnerships in the water sector
 - Study of mechanisms for financing adaptation to climate change
7. Monitoring and evaluation
 - Development of a system of indicators for sustainable water and land resource management
 - Creation of a methodology for a comprehensive assessment of the vulnerability of territories to climate change changes



- Improving methods for assessing the ecosystem services of wetlands and other natural systems

Conclusions

Sustainable land and water management in the face of climate change is critical for ensuring food security, economic development, and social stability in Uzbekistan. The country has significant potential to adapt to changing conditions through the adoption of modern technologies, improved institutional governance, and the development of regional cooperation.

The success of adaptation strategies depends on a comprehensive approach that combines technological innovation, institutional reforms, economic incentives, and awareness raising among all stakeholders. Particular attention should be paid to supporting smallholder farmers and vulnerable groups.

The World Bank estimates that the benefits of adaptation investments in Uzbekistan are two to three times greater than the costs, underscoring the economic feasibility of proactive action. However, time for action is limited—delay increases the risks and costs of adaptation.

The results of this study can serve as a basis for developing evidence-based sustainable development strategies and programs, improving the legal and regulatory framework, and providing practical guidelines for various stakeholders. The implementation of the proposed recommendations will contribute to the achievement of the goals of the Uzbekistan 2030 Strategy and national commitments within the framework of international climate agreements.

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