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MODELING CLIMATE CHANGE FACTORS IN LAND RESOURCE MANAGEMENT

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Abstract: This article examines the theoretical and practical foundations of modeling climate change factors in land resource management. In recent years, global climate change resulting in rising temperatures, shifting precipitation patterns, recurrent droughts, declining water resources, and accelerated land degradation has significantly impacted the effective use of land resources. Consequently, the application of Geographic Information Systems (GIS), remote sensing, artificial intelligence, machine learning, and mathematical modeling techniques in land resource management has become a matter of paramount importance. The article analyzes both Uzbekistan's national experience and global practices, highlights current issues and statistical data, and formulates practical recommendations for climate-adaptive land management. The research findings serve to promote sustainable land resource management, ensure environmental security, and enhance agricultural efficiency.

Keywords: land resources, climate change, modeling, GIS, remote sensing, artificial intelligence, land degradation, drought, sustainable development, digital cadastre.

Аннотация:В статье рассмотрены современные подходы к моделированию факторов изменения климата в системе управления земельными ресурсами. Изменение климата приводит к повышению температуры воздуха, изменению режима осадков, учащению засух, сокращению водных ресурсов и усилению деградации земель. В связи с этим возрастает необходимость применения геоинформационных систем (ГИС), дистанционного зондирования Земли, искусственного интеллекта и математического моделирования при принятии управленческих решений. В работе проанализированы современные проблемы, статистические данные и мировой опыт, а также предложены практические рекомендации по адаптации системы управления земельными ресурсами к изменениям климата. Полученные результаты могут способствовать устойчивому использованию земельных ресурсов, обеспечению экологической безопасности и повышению эффективности сельского хозяйства.
Ключевые слова: земельные ресурсы, изменение климата, моделирование, ГИС, дистанционное зондирование, искусственный интеллект, деградация земель, засуха, устойчивое развитие, цифровой кадастр.

Annotatsiya: Mazkur maqolada yer resurslarini boshqarishda iqlim o‘zgarishi omillarini modellashtirishning nazariy va amaliy asoslari yoritilgan. So‘nggi yillarda global iqlim o‘zgarishi natijasida havo haroratining oshishi, yog‘ingarchilik rejimining o‘zgarishi, qurg‘oqchiliklarning takrorlanishi, suv resurslarining kamayishi hamda yer degradatsiyasining kuchayishi yer fondidan samarali foydalanishga jiddiy ta'sir ko‘rsatmoqda. Shu sababli yer resurslarini boshqarishda geografik axborot tizimlari (GIS), masofadan zondlash (Remote Sensing), sun'iy intellekt, mashinali o‘qitish va

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matematik modellashtirish usullaridan foydalanish dolzarb vazifaga aylandi. Maqolada O‘zbekiston va jahon tajribasi tahlil qilinib, mavjud muammolar, statistik ma'lumotlar hamda iqlim o‘zgarishiga moslashgan yer boshqaruvi bo‘yicha amaliy takliflar ishlab chiqilgan. Tadqiqot natijalari yer resurslarini barqaror boshqarish, ekologik xavfsizlikni ta'minlash hamda qishloq xo‘jaligi samaradorligini oshirishga xizmat qiladi.
Kalit so‘zlar: yer resurslari, iqlim o‘zgarishi, modellashtirish, GIS, masofadan zondlash, sun'iy intellekt, yer degradatsiyasi, qurg‘oqchilik, barqaror rivojlanish, raqamli

Introduction

Today, climate change stands as one of the most pressing global challenges facing humanity. The steady rise in global average temperatures, changes in the amount and distribution of precipitation, the increasing frequency of droughts, strong winds, water scarcity, and the acceleration of desertification processes pose growing threats to the rational use of land resources. These factors adversely affect not only agricultural production but also soil fertility, food security, biodiversity, water resources, and ecological stability. Therefore, improving the land resource management system through modern scientific approaches has become a priority.

Utilizing modeling methods is of particular importance for forecasting environmental processes caused by climate change and mitigating their consequences. Modern modeling technologies enable the prediction of rising temperatures, decreasing precipitation, changes in soil moisture, salinization, erosion, and degradation processes. Such an approach serves as a vital tool for assessing the future state of land resources, identifying high-risk areas, and developing scientifically justified management decisions.

In developed nations, land resource management extensively employs Geographic Information Systems (GIS), remote sensing data, artificial intelligence, machine learning algorithms, and Digital Twin technologies. These technologies facilitate the rapid processing of large volumes of spatial and statistical data, high-precision assessment of climate impacts on land resources, and simulation of various development scenarios. As a result, management decisions are increasingly driven by precise, evidence-based data.

Uzbekistan is among the countries profoundly affected by the negative impacts of climate change. Due to its geographic location, water scarcity, droughts, soil salinization, pasture degradation, and desertification processes intensify year by year. According to recent data, out of 25.6 million hectares of pastures in Uzbekistan, 2.5 million hectares are degraded, and the vegetation cover has significantly diminished across another 6 million hectares. Approximately 45 percent of the 1.9 million hectares of irrigated land is affected by varying degrees of salinization, directly undermining agricultural yields. Furthermore, the drying of the Aral Sea has transformed millions of hectares into an ecological crisis zone. Salt and dust storms lower soil quality, degrade crop areas, and harm public health. Concurrently, while global reports designate Uzbekistan as one of the Central Asian countries with high levels of land degradation, recent mitigation efforts have led to some positive shifts.

In the current era, land resource management must not be confined to merely recording existing conditions. It is now essential to project future changes based on climate scenarios, pre-emptively identify vulnerable areas, comprehensively manage water and land resources, and design adaptation

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strategies. Integrating artificial intelligence, GIS, and remote sensing technologies with mathematical models significantly boosts the efficiency of land resource management.

The primary objective of this article is to analyze the scientific and practical foundations of modeling climate change factors in land resource management, evaluate urgent problems within the context of Uzbekistan using statistical data, highlight the potential of modern technologies, and develop practical proposals and recommendations aimed at ensuring sustainable land use.

Scientific Foundations of Modeling Climate Change Factors in Land Resource Management

Climate change is a primary driver directly shaping the land resource management system. The ecological state of the land fund is undergoing significant transformations due to rising air temperatures, uneven precipitation distribution, prolonged drought periods, intense winds, shrinking water volumes, and an increase in extreme natural phenomena. Consequently, soil fertility is declining, salinization and erosion processes are intensifying, pastures are degrading, and agricultural crop yields are dropping. Under such circumstances, land resource management must transition from analyzing current statuses to forecasting future climate conditions.

Modeling climate factors involves integrating meteorological, hydrological, soil, and spatial data into a unified system, analyzing their interdependencies via mathematical and digital models. Through this approach, it becomes possible to forecast future shifts in temperature, precipitation, soil moisture, evaporation, wind speed, water supply, and vegetation cover in specific regions. The modeling outputs enable scientifically backed decision-making regarding land resource utilization.

In recent years, global climate change modeling has relied heavily on GIS, remote sensing, artificial intelligence, machine learning, cloud computing, and Digital Twin platforms. These technologies process satellite imagery, meteorological observations, and land monitoring data dynamically to evaluate environmental conditions with high accuracy. AI-based algorithms, in particular, demonstrate high efficiency in analyzing massive datasets to pinpoint areas under severe climate risk.

Global observations indicate that the Earth's average temperature has risen by 1.3–1.5 °C compared to the pre-industrial era. This shift accelerates droughts, water scarcity, and soil degradation. According to the UN, nearly 40 percent of the world's land area experiences varying degrees of degradation, impacting over 3 billion people. Central Asia is assessed as one of the regions most vulnerable to climate change.

The impacts of climate change are steadily growing within Uzbekistan as well. Since most of the country is situated in an arid climate zone, pressure on water resources is mounting. Reduced river runoff in the Amu Darya and Syr Darya basins negatively affects the reclamation status of irrigated lands. This triggers an escalation in salinization, water erosion, and wind erosion. In certain regions, reduced soil moisture has been observed to lower agricultural crop yields by 10 to 20 percent.

The main advantage of modeling in land resource management is its ability to not only diagnose existing issues but also quantify future risk levels. For instance, indices such as NDVI, LST, SPI, and

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SPEI derived from satellite data facilitate the systematic monitoring of droughts, vegetation dynamics, and land degradation. Integrating this data into GIS platforms enables the creation of risk maps, identifying which territories face the highest probabilities of soil fertility decline or water scarcity.

Currently, Uzbekistan is implementing extensive reforms to digitalize land resource management. The deployment of state cadastre information systems, electronic land accounting, satellite monitoring, and geoinformation technologies is expanding progressively. However, climate projections, AI-based models, and real-time monitoring capabilities are not yet fully integrated within the existing frameworks. Therefore, embedding climate data into land cadastre and land resource management systems remains an essential task.

To further refine the modeling of climate change factors, it is advisable to comprehensively utilize artificial intelligence, Big Data analysis, unmanned aerial vehicles (drones), high-resolution satellite imagery, and Digital Twin technologies. This approach will significantly enhance the continuous oversight of environmental land conditions, the early detection of hazardous processes, and the efficiency of science-driven administrative decisions. Consequently, opportunities to optimize land use, ensure agricultural sustainability, and mitigate the adverse impacts of climate change will expand.

Pressing Challenges of Climate Change in Uzbekistan's Land Resource Management and Modeling Results

Given its natural and climatic conditions, Uzbekistan is located in an arid zone where the majority of land resources are designated for irrigated agriculture and pasture farming. Hence, climate change exerts a direct and long-term impact on the country’s land assets. Annual temperature increases, erratic rainfall distribution, declining river flows, and more frequent extreme weather events impose new requirements on the land management system. Relying purely on traditional management methods is no longer adequate; there is an urgent need to evaluate future risks using advanced modeling technologies.

In recent years, the average annual air temperature across the country has risen noticeably. Climatologists project that temperatures could rise by an additional 2–3 °C by the middle of the century. This trend will aggravate irrigation water shortages, lower soil moisture, and increase crop water demands during the vegetative period. Water supply disruptions are already affecting yields, particularly in areas dedicated to cotton, grain, horticulture, and vegetable cultivation.

Land degradation is one of the most critical environmental challenges in the country. Soil salinization, wind and water erosion, pasture degradation, and desertification have assumed acute proportions in several regions. A large portion of irrigated land suffers from various levels of salinization, which diminishes soil productivity and increases land reclamation expenditures. Additionally, salt and dust particles rising from the desiccated bed of the Aral Sea spread over hundreds of kilometers, degrading the ecological state of the land.

Modeling technologies are becoming increasingly valuable for managing these issues effectively. Satellite imagery is regularly utilized to monitor land cover, soil moisture, normalized difference vegetation index (NDVI), land surface temperature (LST), and drought indices. Integrating these

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metrics into GIS platforms helps classify territories by risk level. Consequently, areas highly susceptible to accelerating salinization, yield declines, or water shortages can be identified in advance.

The adoption of artificial intelligence and machine learning algorithms further refines modeling accuracy. By co-analyzing long-term meteorological records, soil maps, satellite data, and agricultural statistics, these technologies project vulnerable zones for coming years. For example, AI-driven models can evaluate drought probabilities ahead of time, providing recommendations for the optimal distribution of water resources across regions.

At the same time, certain practical deficiencies persist. Datasets generated by various government agencies are not yet fully interconnected. A shortage of meteorological observation stations in some regions compromises the precision of modeling outcomes. There is also a lack of modern software tools and highly qualified specialists for processing satellite data. Furthermore, mechanisms to translate regionally developed models into operational management decisions are not yet fully matured.

To address these gaps, future efforts must mandate the integration of climate forecasts into the land management system, implement real-time satellite monitoring, build AI-backed forecasting platforms, and consolidate all cadastral records into a unified geoinformation database. Such an approach will play a pivotal role in curbing the negative consequences of climate change, maximizing land resource efficiency, and ensuring sustainable agricultural production.

Conclusion

Modeling climate change factors in land resource management has transitioned from a purely scientific endeavor into a priority for the state administration system. Temperature increases, shifting rainfall patterns, worsening water scarcity, soil salinization, erosion, and accelerating desertification significantly alter the ecological condition and utilization efficiency of the land fund. Because traditional assessment methods yield inadequate results against these dynamics, the necessity of deploying modern modeling technologies continues to rise.

Research shows that integrating GIS, remote sensing, artificial intelligence, machine learning, Big Data analytics, and Digital Twin technologies into land resource management enables advanced forecasting of climate risks and informed decision-making. Real-time monitoring is especially vital for the early detection and mitigation of land degradation, salinization, droughts, and water scarcity.

To optimize Uzbekistan's land resource management system, it is advisable to align climate data with cadastre information systems, expand satellite monitoring, establish AI-based forecasting platforms, and store all spatial data within a single geoinformation framework. Simultaneously, studying international best practices, supporting scientific research, and training qualified professionals will enhance the efficacy of these structural reforms.

In conclusion, establishing a management system grounded in land resource modeling amid climate change is a key factor for the rational use of land, agricultural sustainability, ecological balance, and national food security. Management driven by modern digital technologies and scientific

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approaches will preserve land productivity and ensure that resources are passed down to future generations in a healthy state.

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