



ADVANCED USE OF LAND RESOURCES THROUGH INTEGRATED LAND-WATER MANAGEMENT AND DIGITAL AGROECOLOGICAL MONITORING IN IRRIGATED AGRICULTURE

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Abstract

The advanced use of land resources has become a decisive scientific and practical direction for countries where agricultural productivity, rural employment, food security and ecological stability depend directly on the condition of irrigated soils. In Uzbekistan, the problem is especially significant because crop production is strongly linked with irrigation, drainage, soil salinity control, land reclamation, crop rotation and the rational distribution of limited water resources under increasing climatic pressure. The aim of this article is to develop a scientifically grounded conceptual model for advanced land-resource use based on integrated land-water management, digital monitoring, soil-reclamation assessment and agroecological planning. The study applies an IMRAD-based analytical design and synthesizes land-use theory, sustainable soil management principles, irrigation-sector modernization priorities and Uzbekistan's strategic policy context. The article argues that advanced use of land resources should not be reduced to increasing crop output per hectare; rather, it must be understood as a system of long-term productivity, soil fertility preservation, water-use efficiency, salinity prevention, digital cadastral accuracy, ecological risk reduction and farmer-level decision support. The proposed model combines five interrelated blocks: cadastral and geospatial inventory, agroecological zoning,



irrigation and drainage optimization, soil-health restoration, and institutional-economic incentives. The results indicate that sustainable intensification is achievable only when land-use decisions are based on measurable indicators such as soil salinity, groundwater depth, irrigation efficiency, organic matter balance, erosion risk, crop suitability and economic return per cubic metre of water. The study concludes that the future of land-resource management in Uzbekistan depends on the transition from extensive land exploitation to precision-based, data-driven and ecology-sensitive land governance.

Keywords: Land resources; advanced land use; irrigated agriculture; soil salinity; land reclamation; digital monitoring; agroecological zoning; Uzbekistan; sustainable soil management; irrigation efficiency.

INTRODUCTION

Land resources are not merely a spatial basis for agriculture; they are a complex natural-economic system in which soil fertility, water availability, climatic conditions, topography, drainage regime, biological activity, ownership relations and technological culture interact with one another. In the conditions of Central Asia, and particularly Uzbekistan, land is a strategic resource because the productivity of agriculture is highly dependent on irrigation, and irrigation itself is directly connected with hydrotechnical infrastructure, canal efficiency, collector-drainage networks, groundwater regulation and the prevention of secondary salinization. The scientific problem of advanced land-resource use therefore requires an interdisciplinary approach: agronomy explains crop-soil interaction, hydrotechnics explains irrigation and drainage regimes, geography and GIS explain spatial differentiation, ecology explains degradation risks, and economics explains the rational allocation of limited production factors. International sources emphasize that soil health and land degradation neutrality have become national priorities in Uzbekistan, while international soil partnerships and national institutions increasingly support activities aimed at restoring soil health and strengthening sustainable soil management practices [1]. This policy and scientific background shows that the subject is not a narrow agricultural issue but a central direction of national development. The Water



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Sector Concept for 2020-2030 and related irrigation-sector reforms are directed toward improving land and water resource efficiency, improving reclamation of irrigated lands, introducing market mechanisms and expanding digital technologies in the water sector [2]. In this sense, advanced use of land resources should be defined as the scientifically organized use of each land parcel according to its ecological capacity, irrigation potential, soil condition, crop suitability, economic efficiency and long-term sustainability. The relevance of the topic is strengthened by climate change, population growth, growing demand for food, decreasing water availability in transboundary river basins, and the need to prevent the loss of productive agricultural land. Climate assessments for Uzbekistan note that water resources in the Amu Darya and Syr Darya basins may decrease under climate pressure, while land degradation processes such as salinization, erosion and salt-dust transfer from the Aral Sea region may intensify [3]. Such projections make it clear that conventional land-use practices based only on annual production targets are no longer sufficient. The modern scientific task is to design land-use systems that simultaneously increase productivity, reduce environmental pressure, save water, improve soil fertility and strengthen the resilience of rural areas. The purpose of this article is therefore to substantiate an integrated model for advanced use of land resources within the discipline Advanced Use and Management of Land Resources. The research objectives are: first, to clarify the theoretical essence of advanced land use; second, to identify the key degradation and inefficiency factors affecting irrigated lands; third, to formulate a methodological basis for evaluating land-use potential; fourth, to propose a practical model that combines digital monitoring, reclamation measures and agroecological zoning; and fifth, to justify the expected scientific and practical results of this model for Uzbekistan's irrigated agricultural regions. The article proceeds from the hypothesis that land-resource efficiency can be improved not by isolated measures, such as only introducing drip irrigation or only updating cadastral maps, but by a combined system in which land inventory, water accounting, soil diagnostics, crop planning and economic incentives work as one coordinated mechanism. The theoretical importance of the study lies in expanding the concept of land productivity from a narrow agronomic category to an integrated ecological-economic category. Its practical importance lies in the



possibility of using the proposed framework for regional land-use planning, farm-level consulting, reclamation design, teaching materials and digital cadastral modernization. The novelty of the research is expressed in the systematic linkage of land cadastre, irrigation management, soil-health indicators and digital monitoring into a single decision-making model. This linkage is particularly important for Uzbekistan because many land-use problems are cross-sectoral: salinity is not only a soil problem, water losses are not only an engineering problem, and low crop profitability is not only an economic problem. They are components of one landscape system, and therefore they require an integrated response [4].

MATERIALS AND METHODS

The methodological basis of the study is a qualitative-analytical and systems approach that treats land resources as a multifunctional object of management rather than as a simple production area. The study is based on the synthesis of scientific literature, international reports, policy documents, land-reclamation concepts, sustainable soil management principles and irrigation-management practices. The first methodological component is systems analysis, through which land-resource use is divided into natural, technical, economic and institutional subsystems. The natural subsystem includes soil texture, humus content, salinity, erosion susceptibility, groundwater depth, relief and climate; the technical subsystem includes irrigation canals, drainage collectors, water-lifting facilities, field-level irrigation technologies and monitoring devices; the economic subsystem includes crop profitability, input costs, water productivity, land taxes, subsidies and market access; the institutional subsystem includes cadastral registration, land-use rights, farmer responsibility, extension services and state monitoring. The second methodological component is agroecological zoning, which allows land parcels to be classified according to suitability for crops and reclamation needs. In this approach, one hectare of land cannot be evaluated only by its formal cadastral category; it must also be evaluated by its real productive capacity, salinity class, irrigation reliability, drainage condition and environmental risk. The third component is comparative analysis of national and international evidence. FAO materials on salinization, rangeland degradation and



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soil-health priorities were used to frame the problem of degradation and sustainable soil management [1]. Uzbekistan's agricultural and water-sector reform documents were used to connect the research problem with national strategy, especially the emphasis on rational natural-resource use, environmental protection, irrigation modernization and digitalization [2], [5]. The fourth component is indicator-based assessment. For practical application, the study proposes that advanced land-use planning should be based on a group of measurable indicators: soil electrical conductivity or salinity class; groundwater depth and mineralization; humus content; irrigation-water productivity; drainage density; field levelling quality; crop yield stability; erosion risk; vegetation index dynamics from remote sensing; and economic return per hectare and per cubic metre of irrigation water. The fifth component is model-building. A conceptual model was designed by linking five stages of land-resource management: data collection, diagnosis, zoning, intervention and feedback monitoring. Data collection includes cadastral maps, satellite imagery, drone surveys, soil sampling, irrigation records and farmer surveys. Diagnosis identifies limiting factors such as salinity, waterlogging, erosion, compaction or low organic matter. Zoning classifies land into highly productive, conditionally productive, reclamation-required and ecologically vulnerable categories. Intervention includes drainage cleaning, laser land levelling, crop rotation, organic amendments, water-saving irrigation, canal lining, controlled irrigation scheduling and biological reclamation. Feedback monitoring evaluates whether the measures reduce salinity, raise water productivity and stabilize yields. This methodological design is especially suitable for Uzbekistan because the country's irrigated agriculture requires the coordination of land and water decisions. The Agriculture Development Strategy for 2020-2030 highlights rational use of natural resources and environmental protection as one of its strategic priorities [5]. The methodology therefore corresponds to both academic logic and national development priorities. It should be noted that the article does not rely on one experimental field plot; rather, it develops a generalized scientific model applicable to irrigated landscapes, especially in regions with salinity, drainage and water-scarcity risks such as parts of the Fergana Valley, lower river basins and arid agricultural zones. This model can later be tested through field



experiments, GIS-based land evaluation and farm-level pilot projects. The analytical procedure followed several steps. At the first step, the concept of advanced land use was separated from the older concept of extensive land exploitation. At the second step, the main limiting factors of land productivity were grouped according to their origin: natural, technical, economic and organizational. At the third step, indicators were selected according to the principle of measurability, because a land-management system that cannot be measured cannot be improved. At the fourth step, the selected indicators were arranged into an integrated diagnostic matrix. At the fifth step, land-use interventions were matched to each diagnostic category. For example, saline and waterlogged lands require drainage and controlled leaching; eroded foothill lands require anti-erosion farming and vegetation cover; compacted irrigated fields require deep loosening and organic matter restoration; and water-deficit areas require crop structure optimization and deficit irrigation planning. This step-by-step methodological logic allows the research to move from abstract sustainability principles to concrete management recommendations [6].

RESULTS

The first major result of the study is the clarification that advanced use of land resources must be interpreted as a transition from area-based land exploitation to function-based land management. In traditional practice, land productivity is often assessed by the amount of crop harvested from a given area. However, this criterion alone is incomplete because it may hide soil exhaustion, excessive water use, salinity accumulation, nutrient imbalance and declining resilience. Advanced land use must therefore be evaluated through a more complex set of indicators: stable yield, low degradation risk, efficient irrigation, positive soil-fertility balance, economic profitability and ecological safety. For example, a cotton or wheat field that produces a high yield in one year but requires excessive irrigation and causes groundwater rise cannot be considered advanced; by contrast, a field with moderate but stable yield, lower water consumption, improved humus balance and controlled salinity is closer to sustainable efficiency. The second result is the identification of five dominant constraints that limit advanced land-resource use in irrigated agriculture. The first constraint is salinization, which



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remains one of the most important threats for irrigated cropland in Uzbekistan. International land-degradation reporting and national assessments repeatedly indicate that a substantial share of irrigated lands is affected by different degrees of salinity and that the risk of secondary salinization remains closely connected with irrigation and drainage conditions [1], [6]. The second constraint is inefficient irrigation and water losses, especially where canals, field channels and irrigation scheduling are not adapted to real crop-water demand. The third constraint is the insufficient integration of cadastral, hydrological and soil data. A land cadastre may show parcel boundaries and legal status, but without salinity, groundwater and productivity data it cannot guide advanced land-use decisions. The fourth constraint is the weak connection between scientific recommendations and farmer-level economic incentives. Farmers may know that crop rotation, organic amendments or drainage maintenance are useful, but if short-term economic pressure is high, long-term soil-restoration measures may be postponed. The fifth constraint is climate variability, which increases uncertainty in water availability, evapotranspiration and drought frequency. The third result of the article is the proposed integrated model of advanced land-resource use. The model consists of five blocks. The first block is digital land inventory, in which cadastral maps are combined with satellite imagery, drone surveys, soil-analysis databases and water-delivery records. This block creates an objective digital profile of each field. The second block is agroecological zoning, which divides land into zones according to crop suitability, salinity level, irrigation reliability and reclamation needs. The third block is land-water optimization, where crop placement and irrigation scheduling are planned according to water productivity rather than only gross yield. This means that crops should be evaluated by yield per cubic metre of water and by their effect on soil health. The fourth block is reclamation and soil-health restoration, including drainage improvement, gypsum application where chemically justified, organic matter enrichment, green manure, salt-tolerant crop phases, deep loosening in compacted soils and biological activity enhancement. The fifth block is institutional feedback, including farmer training, transparent monitoring, economic incentives and regular updating of land-quality data. The fourth result is the formulation of practical criteria for evaluating the success of advanced land use. These criteria include reduction of



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soil salinity class over a three-to-five-year cycle; lowering of groundwater level in waterlogged fields; increase in irrigation efficiency; stabilization of crop yields under dry years; increase of soil organic matter; reduction of unproductive water losses; improvement of vegetation index values during the growing season; and higher net income per unit of land and water. The fifth result is the conclusion that digitalization can significantly improve land-resource governance only when it is connected with field-level decision-making. Digital maps without soil sampling, farmer training and irrigation reform remain decorative; GIS is a microscope, not medicine. It helps to see the disease, but treatment requires agronomic, hydrotechnical and economic action. Uzbekistan has already emphasized digital technologies in water-sector reform and irrigation management [2]. Therefore, the scientific task is to connect these technologies with land-quality monitoring, crop planning and reclamation design. The sixth result is the recognition that advanced land use must include rangelands and non-irrigated lands as well. In many arid and semi-arid territories, pasture degradation, vegetation loss, wind erosion and desertification reduce ecosystem productivity and indirectly increase pressure on irrigated cropland. This means that land-resource policy cannot focus only on irrigated fields; pasture restoration, vegetation recovery, erosion prevention and desertification control must also be included in the broader system of land-resource management [7]. The seventh result is the construction of a practical diagnostic matrix for advanced land-use planning. The matrix links the observed land problem with its likely cause, measurable indicator and recommended intervention. It demonstrates that every land-use decision should be evidence-based. Where the problem is salinity, the key indicators are electrical conductivity, salt composition, groundwater depth and drainage condition; the recommended interventions are drainage improvement, scientifically controlled leaching and salt-tolerant crop phases. Where the problem is low water productivity, the indicators are irrigation norm, yield per cubic metre of water, canal losses and field levelling quality; the interventions are water accounting, land levelling, improved scheduling and crop adjustment. Where the problem is declining fertility, the indicators are humus, bulk density, nutrient balance and biological activity; the interventions are organic amendments, crop rotation, legumes, compost and minimum soil



disturbance. Thus, the result of the study is not a general slogan about sustainability but a structured technological logic for moving from diagnosis to action.

Table 1. Diagnostic matrix for advanced land-resource use

Diagnostic problem	Key indicator	Recommended intervention	Expected effect
Soil salinity	Electrical conductivity, salt composition, groundwater depth	Drainage rehabilitation, controlled leaching, salt-tolerant crop rotation	Lower salinity class and improved crop stability
Low irrigation efficiency	Water delivery losses, irrigation norm, yield per cubic metre	Canal lining, field levelling, irrigation scheduling, water accounting	Higher water productivity and lower water losses
Declining soil fertility	Humus content, nutrient balance, bulk density	Organic amendments, legumes, compost, green manure	Improved soil structure and biological activity
Erosion risk	Slope, vegetation cover, runoff intensity	Contour farming, protective vegetation, anti-erosion strips	Reduced soil loss and better infiltration
Weak cadastral accuracy	Outdated maps, missing soil-water data	Digital inventory, GIS database, remote sensing updates	Transparent land-use planning and monitoring

DISCUSSION

The discussion of the results shows that the advanced use of land resources is best understood through the principle of productive sustainability, which means that land must produce economic value today without losing its ecological capacity tomorrow. This principle is especially important in irrigated agriculture because irrigation can be both a source of productivity and a driver of degradation. If irrigation is well managed, it stabilizes yields, supports crop diversification and increases rural income. If irrigation is poorly managed, it raises groundwater levels, mobilizes salts, damages soil structure and reduces long-term land value. Therefore, the central scientific question is not whether land should be used intensively, but how intensification can be made ecologically intelligent. The proposed model answers this question by linking land evaluation with water management. In practice, this means that each land parcel should receive a land-use passport containing cadastral status, soil properties, salinity class, groundwater data, irrigation source, drainage condition, crop history, yield



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dynamics and recommended interventions. Such a passport would allow local authorities, water-consumer organizations, farmers and extension specialists to make decisions based on evidence rather than assumptions. The model also supports the national direction toward digital technologies in water management and improved reclamation of irrigated lands [2]. A second discussion point is the relationship between land degradation neutrality and agricultural modernization. FAO and UNCCD-related approaches emphasize that achieving land degradation neutrality and strengthening soil health are important priorities for countries with arid and semi-arid landscapes [1], [7]. However, land degradation neutrality should not be interpreted only as preventing visible erosion or desertification. In irrigated areas, degradation may occur slowly and invisibly through salt accumulation, declining humus, compaction, nutrient imbalance and inefficient water use. Thus, advanced land use requires early-warning indicators. Remote sensing can identify vegetation stress, but it must be validated by field measurements. Soil electrical conductivity, groundwater depth and crop-yield mapping are essential for distinguishing between drought stress, salinity stress and nutrient deficiency. A third discussion point concerns economic incentives. Sustainable practices are often recommended scientifically but not always adopted economically. For example, laser land levelling, drip irrigation, drainage rehabilitation and organic-matter restoration may require initial investment. If the farmer does not receive financial support, technical advice or market benefits, adoption may remain limited. Therefore, advanced land-resource use requires a policy mechanism that rewards long-term soil protection. Possible instruments include preferential credit for water-saving technologies, subsidies for drainage improvement, payments for soil-restoration measures, differentiated land taxes according to land quality, and support for crop diversification. The Agriculture Development Strategy for 2020-2030 includes rational natural-resource use and environmental protection among its priorities, which gives a policy basis for such instruments [5]. A fourth discussion point is the risk of the rebound effect in irrigation modernization. Research on irrigated agriculture in Uzbekistan has shown that water-saving technologies may not automatically reduce total water use if saved water is used to expand irrigation or grow more water-demanding crops [8]. This means that technological modernization must be accompanied by



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water accounting, crop planning and institutional regulation. Drip irrigation is not a magic wand; without water limits and agronomic discipline, even a smart system can behave like a leaky bucket wearing a tie. A fifth discussion point is the importance of regional differentiation. Uzbekistan's land resources are not homogeneous: the Fergana Valley, Zarafshan Valley, Khorezm, Karakalpakstan, Surkhandarya and Kashkadarya differ in climate, soil, water availability, salinity, groundwater and crop structure. Therefore, a universal land-use prescription is scientifically weak. The proposed model is universal in structure but flexible in content. For example, in saline and waterlogged areas, the priority should be drainage, salt leaching control and salt-tolerant crop rotations. In foothill zones, erosion control, contour farming and vegetation protection may be more important. In densely populated irrigated regions, high-value crops, greenhouse systems and water-saving irrigation may produce better land productivity. In rangeland areas, vegetation restoration and controlled grazing are more relevant. A sixth discussion point is the role of education and professional training. Advanced land use cannot be implemented only through decrees or technologies; it requires specialists who understand land cadastre, GIS, hydrology, soil science, irrigation engineering, economics and ecology. Therefore, the discipline Advanced Use and Management of Land Resources should train students to work with real maps, soil data, water-balance calculations, crop suitability matrices and digital monitoring platforms. From the point of view of hydrotechnical education, the strongest professional value of this topic is that it connects land quality with water infrastructure. A future engineer or land manager must understand that a collector-drainage network is not simply a construction object; it is a land-productivity regulator. A canal is not only a water-delivery line; it is a factor of soil regime. A field map is not merely a document; it is a decision platform. The scientific novelty of this article lies in presenting advanced land use not as a single technology but as an integrated land-water-soil-economy model. Its practical importance lies in the possibility of using the proposed framework for regional land-use planning, farm-level recommendations, student coursework, cadastral analysis, irrigation modernization and reclamation projects. The limitation of the study is that the proposed model is conceptual and requires further field validation. However, conceptual models are necessary because they provide the



logical architecture for future empirical research. Without such architecture, separate experiments remain scattered and cannot easily influence policy or practice [9].

CONCLUSION

The advanced use of land resources is one of the most urgent scientific and practical directions for Uzbekistan because the country's agricultural productivity, food security, rural welfare and ecological stability depend on the rational management of irrigated and non-irrigated lands. The study shows that advanced land use must be based on the integration of soil-health preservation, irrigation efficiency, drainage improvement, digital monitoring, agroecological zoning and economic incentives. The article substantiates that traditional area-based evaluation of land is insufficient; modern land-resource management must evaluate each parcel through a set of indicators including salinity, groundwater depth, humus content, irrigation efficiency, crop suitability, erosion risk, vegetation dynamics and economic return per unit of water. The proposed integrated model consists of five blocks: digital land inventory, agroecological zoning, land-water optimization, reclamation and soil-health restoration, and institutional feedback. This model corresponds to Uzbekistan's strategic priorities in rational natural-resource use, water-sector digitalization, improved reclamation of irrigated lands and sustainable soil management. The main scientific conclusion is that land productivity should no longer be understood as maximum yield at any cost, but as stable productivity under ecological limits. The main practical conclusion is that advanced land-resource use can be achieved only when GIS maps, cadastral records, soil diagnostics, irrigation schedules, drainage measures and farmer incentives are connected in a single management system. In Uzbekistan, where salinization affects a substantial share of irrigated cropland and climate change may reduce future water availability, the transition to integrated land-water management is not optional; it is an engineering, ecological and economic necessity. The proposed approach can be used in higher education, regional planning, farm consulting, land-cadastral modernization and hydrotechnical-reclamation projects. Future research should test this model through field-based case studies in different regions of Uzbekistan, develop a



numerical land-use efficiency index, and create digital decision-support tools for selecting the most suitable crop, irrigation method and reclamation measure for each land parcel. The expected practical effect of the model is the reduction of land degradation risks, the stabilization of yields, the improvement of water productivity, the strengthening of soil fertility and the creation of more transparent land-management decisions. The expected educational effect is the formation of a new professional mindset among students and young specialists: land must not be treated as an unlimited surface, but as a living production system with measurable capacity and strict ecological limits. The expected policy effect is the improvement of coordination between land cadastre, water management, agricultural planning and environmental monitoring. Thus, advanced use of land resources should become a core methodological direction for sustainable agricultural modernization in Uzbekistan.

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