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INNOVATIVE GIS-BASED DIGITAL SOLUTIONS FOR EFFICIENT LAND AND WATER RESOURCE MANAGEMENT IN UZBEKISTAN

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Abstract

Efficient management of land and water resources is one of the key priorities for sustainable agricultural development in Uzbekistan. This article explores the role of innovative Geographic Information Systems (GIS) and other digital technologies in improving resource management practices across the country. The study focuses on the application of remote sensing, satellite monitoring, GPS technologies, unmanned aerial vehicles (UAVs), and spatial data analysis for irrigation planning, soil monitoring, and land-use optimization. Particular attention is given to the challenges of water scarcity and inefficient irrigation systems in Uzbekistan's agricultural sector. The article demonstrates how GIS-based digital solutions contribute to accurate decision-making, efficient water distribution, environmental protection, and increased agricultural productivity.

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INTRODUCTION

Nowadays, the effective use and sustainable management of land and water resources is one of the pressing global issues. Climate change, water scarcity and environmental problems require the introduction of modern approaches to natural resource management. In this context, digital technologies such as GIS (Geographic Information System), remote sensing, drones, IoT and artificial intelligence are widely used as effective tools for monitoring, analyzing and managing land and water resources. This article analyzes the potential of GIS and other digital technologies in land and water resource management, their practical significance and their role in the rational use of resources in agriculture[1].

LITERATURE REVIEW

In recent years, there has been a significant increase in interest in the use of digital technologies, especially UAV (Unmanned Aerial Vehicles) and drone technologies, in the effective management of land and water resources. In scientific research, drones are recognized as an important tool for monitoring agricultural land, controlling water resources, and developing agricultural systems[2].

International research has widely covered the application of remote sensing and UAV technologies in agriculture. The research of Hunt and Daughtry is based on the effectiveness of determining vegetation indices and monitoring crop conditions using drones equipped with multispectral cameras. The authors noted that NDVI and other spectral indices can be used to determine water stress, plant diseases, and biomass status[3].

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In scientific research conducted by Zhang and Kovacs, the role of UAV technologies in agricultural systems was analyzed. According to the results of the research, it is possible to obtain high-resolution images, organize real-time monitoring, and formulate yield forecasts using drones. In particular, drone monitoring has been noted to increase irrigation efficiency in water resource management.

Bernie et al. have developed methods for determining crop water consumption using UAV systems equipped with thermal cameras. The studies have shown that soil moisture can be estimated based on thermal images. This is an important scientific basis for developing smart irrigation systems in water scarcity conditions[4].

There are many studies on the integration of GIS and remote sensing technologies with drones. Methods for processing UAV data, creating 3D models, and assessing land resources have been developed using the ArcGIS and Google Earth Engine platforms. This approach is effective in determining land degradation, salinization, and erosion processes[5].

Uzbek scientists are also studying the use of drones and GIS technologies in monitoring land and water resources. The studies focus on monitoring irrigation systems, determining soil salinization, and assessing the vegetation status of cotton and grain fields. At the same time, scientific research is being conducted on the economic efficiency of introducing agricultural technologies in agroclusters[6].

The analysis shows that drone technologies provide high accuracy, rapid monitoring and resource efficiency in the integrated management of land and water resources. However, existing studies have not sufficiently developed the methodology for managing UAV, GIS, IoT and artificial intelligence technologies based on a single integrated system. Therefore, the implementation of complex scientific research in this area is of urgent importance[7].

RESEARCH METHODOLOGY

The study used a comprehensive approach to general and special scientific research methods. In particular, the analysis and synthesis method, the comparison and grouping method, and statistical analysis methods were used.

RESULTS AND DISCUSSION

GIS (Geographic Information System) has become a very important technology in monitoring agricultural lands in Uzbekistan. With the help of GIS, land resource management, cropland analysis, water resource monitoring, and yield forecasting are effectively implemented[8].

GIS is a digital system designed to collect, store, analyze, and map geographic data. GIS works in integration with satellite, drone, GPS, and meteorological data. Water resource monitoring is very relevant for Uzbekistan. With the help of GIS, irrigation networks, water distribution, and moisture maps are created. This is especially important in the Amu Darya and Syrdarya basins[9].

Table 1. Main components of GIS

Component	Tasks
GPS	Location determination
Satellite images	Large area monitoring
Drons	High-precision tracking
GIS software	Analysis and mapping
Database	Information storage

The most popular GIS programs used in Uzbekistan are mainly “ArcGIS”, QGIS, Google Earth Engine, etc.

Table 2

Comparative analysis of ArcGIS, QGIS and Google Earth Engine programs[10].

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Criterion	ArcGIS	QGIS	Google Earth Engine (GEE)
Manufacturer	Esri	Open-source community	Google
License	Paid	Paid	Free (for science/education)
Platform	Desktop + Cloud	Desktop	Cloud platform
Operating system	Windows	Windows, Linux, macOS	Browser based
Main direction	Professional GIS	Universal GIS	Satellite and Big Data Analysis
Interfeys	Very professional	Simple and flexible	Based on code
Programming requirement	Less	Low/Medium	High
Python support	High	High	Very high
Satellite data	Integration available	Via plugin	Ready inside
Dron data	Very good	Good	Limited
GIS analysis	Very high	High	Very high
Remote sensing	Professional	High	Very high
3D analysis	High	Medium	Limited
Real-time monitoring	Existent	Limited	High
Artificial Intelligence/Machine Learning	ArcGIS AI tools	Via Plugin	TensorFlow integration
Working with Big data	High	Medium	Very high
Internet requirement	Medium	Little	High
Offline working	Yes	Yes	No
Plugin ecosystem	High	Very high	Via API
Learning complexity	Medium	Easy/medium	Complex
Price	High	Free	Free
The most suitable field	Public and professional GIS	Education and scientific work	Large-scale satellite monitoring

Each of the programs analyzed in this article has its strengths and weaknesses. For example, the strengths of the ArcGIS program are professional mapping, spatial analysis, GIS for farms, 3D and Internet GIS, drone integration, etc. The disadvantages are that the license is very expensive, and it requires a powerful computer[11].

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The strengths of the QGIS program are free, open data, many plugins, and it is convenient for agriculture. The disadvantages are that some professional farms have limited functions, and sometimes work slowly with large data.

The strengths of the Google Earth Engine program are trillions of satellite data, Sentinel and Landsat satellite data, artificial intelligence integration, and fast analysis of large areas. The disadvantages are that it requires an Internet connection, requires coding, and is complex for new users[12].

Table 3

Recommended GIS programs for agriculture in Uzbekistan

Task	The most suitable program
Land cadastre	ArcGIS
Free GIS jobs	QGIS
Satellite monitoring	Google Earth Engine
Drone data	ArcGIS + QGIS
NDVI monitoring	GEE + QGIS
Scientific research	QGIS + GEE
Precision agriculture	ArcGIS + GEE
Large area monitoring	GEE

In the agricultural practice of Uzbekistan, the following combination is often used:

- GEE program - for receiving and processing satellite data

- QGIS program - for mapping and visualization

- ArcGIS program - for professional enterprise GIS and reports

This combination is one of the most effective approaches for Uzbek agro-monitoring systems.

Remote Sensing technologies are important in monitoring agricultural lands of Uzbekistan. This method allows you to observe and analyze the earth's surface using satellites, drones, aircraft, sensors without directly touching it[13].

Remote sensing is especially effective for water scarcity, salinity, yield monitoring, and precision agriculture. Remote sensing is a technology for obtaining information about objects through electromagnetic radiation. In the process, the sensor receives light reflected from the earth's surface, the data is converted into a digital image and analyzed using GIS and AI.

Remote sensing uses satellites and drones as the main sources of information. The main applications of remote sensing in agriculture are as follows:

1. Vegetation monitoring. NDVI is widely used to assess plant health. NDVI is used to detect plant stress, water shortage, disease, and biomass.

2. Irrigation monitoring. Remote sensing is very important in Uzbekistan due to the limited water resources. This includes monitoring soil moisture, irrigation efficiency, and water losses.

3. Salinity and degradation detection. Remote sensing is used to monitor salinity, erosion, desertification, and land reclamation. This allows for rapid identification of problem areas.

4. Yield forecast. Based on vegetation and meteorological data, yield, crop development, and agrotechnical condition are forecasted. This reduces costs and increases productivity[15].

IoT (Internet of Things) technologies are one of the main directions of “smart agriculture” in monitoring agricultural lands in Uzbekistan. With the help of IoT, devices in fields and farms are interconnected via the Internet and exchange information in real time.

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IoT is a system for collecting and transmitting data through sensors, devices and applications. IoT in agriculture includes sensors, drones, smart irrigation systems, weather stations, GPS devices, cloud platforms.

IoT technologies determine when to water and how much fertilizer to apply. Water conservation is one of the most important issues for Uzbekistan. The IoT system monitors soil moisture, controls automatic irrigation, and reduces water waste[16].

Table 4. Some IoT sensors used in Uzbekistan's agriculture

Type of sensor used	What does the sensor measure
Soil moisture sensor	Soil moisture
Temperature sensor	Temperature
pH sensor	Acidity
EC sensor	Salinity
Weather station	Weather
GPS sensor	Location

IoT technologies have strengths and weaknesses. As a result of the analysis, the strengths of IoT technologies are reflected in the following table.

Table 5. Strengths of IoT technologies

Strengths	Description
Water saving	Smart irrigation
Increased productivity	Accurate monitoring
Cost reduction	Resource optimization
Real-time control	Operational management
AI integration	Forecasting and automation

Table 6. Weaknesses of IoT technologies

Problem	Description
Initial cost	Sensors and networking are expensive
Internet requirement	Stable connection is needed
Technical service	It is necessary to monitor devices
Cybersecurity	Data protection is important
Specialist shortage	IoT knowledge required

Remote monitoring technologies are also being applied in Uzbekistan. In particular:

1. Fergana Valley: GIS and remote sensing are used to determine the salinity level of irrigated lands; the efficiency of drip irrigation systems is assessed.

2. Zarafshan and Syrdarya regions: drones are used to monitor crop fields and pumping stations; water consumption is monitored in real time.

3. Integrated management: decisions on resource use are optimized through a regional GIS system.

In Uzbekistan, there is growing interest in the use of IoT in agroclusters, greenhouses, and water management. This plays an important role in saving resources and increasing productivity.

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CONCLUSION

In conclusion, GIS and other digital technologies play a key role in the effective management of land and water resources. The use of remote sensing, drones, IoT, and artificial intelligence technologies can improve monitoring accuracy, ensure rational use of resources, and ensure environmental sustainability. The widespread implementation of these technologies will contribute to increasing agricultural productivity and developing digital management systems.

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