IMPROVEMENT OF BIODIVERSITY MONITORING IN BUKHARA REGION BASED ON DIGITAL GEOTECHNOLOGIES AND ARTIFICIAL INTELLIGENCE

Murodova Khilola Umarqulovna
Bukhara State University PhD Student
E-mail: khilolamurodova08@gmail.com
Ibroyimova Bahor Iskandar qizi
Student of Bukhara State Technical University
E-mail: bahoribroyimova@gmail.com

Annotatsiya. Maqolada Buxoro viloyatida an'anaviy dala kuzatuvlarini raqamli geofazoviy texnologiyalar, masofadan zondlash, Geografik axborot tizimlari (GIS) va sun'iy intellekt bilan integratsiya qilish orqali biologik xilma-xillik monitoringini takomillashtirishning ilmiy va metodologik asoslari o'rganiladi. Buxoro viloyatining cho'l va yarim cho'l landshaftlari, suv ekotizimlari, tabiiy yaylovlar, voha ekotizimlari va muhofaza qilinadigan tabiiy hududlarida biologik xilma-xillikni baholash uchun ko'p manbali geofazoviy ma'lumotlarni integratsiyalashga asoslangan raqamli monitoring modeli taklif qilingan. Tadqiqot Sentinel-2 sun'iy yo'ldosh tasvirlari, GIS qatlamlari, meteorologik va gidrologik ma'lumotlar, dala kuzatuvlari va kamera tuzoq ma'lumotlaridan foydalanishni asoslaydi. O'simliklar dinamikasi, suv ekotizimining o'zgarishi va yashash muhitining o'zgarishini aniqlash uchun NDVI, NDWI va SAVI kabi spektral indekslarga asoslangan baholash algoritmi taklif qilingan. Ekologik xavf zonalarini avtomatik tasniflash va ustuvor biologik xilma-xillik monitoringi joylarini aniqlash uchun mashinani o'rganish algoritmlari taklif qilingan. Taklif qilinayotgan yondashuv Buxoro viloyatida biologik xilma-xillik monitoringini fazoviy aniq, vaqt bo'yicha uzluksiz, raqamli va qaror qabul qilishga yo'naltirilgan monitoring tizimiga aylantirishga hissa qo'shishi mumkin.

Kalit so‘zlar: Bioxilma-xillik, raqamli ekologiya, GIS, sun’iy intellekt, masofadan zondlash, Sentinel-2, NDVI, NDWI, mashinani o‘rganish, ekologik monitoring, Buxoro viloyati, ekotizim.

Аннотация. В статье исследуются научно-методические основы совершенствования мониторинга биоразнообразия в Бухарской области путем интеграции традиционных полевых наблюдений с цифровыми геопространственными технологиями, методами дистанционного зондирования, геоинформационными системами (ГИС) и искусственным интеллектом. Предложена цифровая модель мониторинга, основанная на интеграции разнородных геопространственных данных, для оценки биоразнообразия в пустынных и полупустынных ландшафтах, водных экосистемах, на естественных пастбищах, в экосистемах оазисов и на особо

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охраняемых природных территориях Бухарской области. Обосновано использование спутниковых снимков Sentinel-2, слоев ГИС, метеорологических и гидрологических данных, результатов полевых наблюдений и данных фотоловушек. Предложен алгоритм оценки, базирующийся на таких спектральных индексах, как NDVI, NDWI и SAVI, для выявления динамики растительности, изменений водных экосистем и трансформации мест обитания. Для автоматической классификации зон экологического риска и определения приоритетных участков мониторинга биоразнообразия предложено использование алгоритмов машинного обучения. Предложенный подход может способствовать преобразованию системы мониторинга биоразнообразия в Бухарской области в цифровую, пространственно-ориентированную и непрерывную во времени систему, обеспечивающую информационную поддержку принятия управленческих решений.

Ключевые слова: биоразнообразие, цифровая экология, ГИС, искусственный интеллект, дистанционное зондирование, Sentinel-2, NDVI, NDWI, машинное обучение, экологический мониторинг, Бухарская область, экосистема.

Abstract. The article investigates the scientific and methodological foundations for improving biodiversity monitoring in Bukhara Region through the integration of conventional field observations with digital geospatial technologies, remote sensing, Geographic Information Systems (GIS), and artificial intelligence. A digital monitoring model based on the integration of multi-source geospatial data is proposed for assessing biodiversity in desert and semi-desert landscapes, aquatic ecosystems, natural pastures, oasis ecosystems, and protected natural areas of Bukhara Region. The study substantiates the use of Sentinel-2 satellite imagery, GIS layers, meteorological and hydrological data, field observations, and camera-trap data. An assessment algorithm based on spectral indices such as NDVI, NDWI, and SAVI is proposed to identify vegetation dynamics, water ecosystem changes, and habitat transformation. Machine learning algorithms are proposed for automatic classification of ecological risk zones and identification of priority biodiversity monitoring sites. The proposed approach can contribute to transforming biodiversity monitoring in Bukhara Region into a spatially explicit, temporally continuous, digital and decision-oriented monitoring system.

Keywords: biodiversity, digital ecology, GIS, artificial intelligence, remote sensing, Sentinel-2, NDVI, NDWI, machine learning, ecological monitoring, Bukhara Region, ecosystem.

INTRODUCTION.

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Nowadays, preserving biodiversity and ensuring the stability of ecosystems is one of the important directions of global environmental policy. Climate change, limited water resources, land degradation, urbanization, anthropogenic pressure and fragmentation of natural habitats are the main factors negatively affecting biodiversity. In Uzbekistan, protecting biodiversity, expanding protected natural areas and forming modern monitoring systems are also important directions of state environmental policy. Within the framework of the national strategy, the task of forming a single information base of state monitoring of biodiversity and the state cadastre based on modern GIS technologies has been set. It is also envisaged to unify monitoring of biodiversity components in protected areas into a single system. Bukhara region is of particular scientific importance from the point of view of this issue. The region is home to desert and semi-desert landscapes, oasis ecosystems, watersheds, natural pastures, and protected natural areas, which serve as habitats for various biological objects. However, water scarcity, drought, land salinization and degradation, anthropogenic impact, and climate change can affect the ecological stability of these ecosystems. Studies on the economic and environmental importance of biodiversity conservation in Bukhara region also indicate factors such as water scarcity, drought, and climate change as important environmental threats. Traditional biological monitoring is mainly based on field observations, route calculations, sampling, camera traps, and expert assessments. Although such methods are important, they are limited in their ability to systematically monitor large areas, quickly process data, and detect spatial changes. In this regard, the introduction of remote sensing, GIS, and artificial intelligence technologies into environmental monitoring is a modern and promising direction. Recent studies have shown that remote sensing and machine learning methods allow for systematic monitoring of biodiversity and habitats over large areas. However, there are methodological problems in the use of machine learning models based on geodata, such as spatial autocorrelation, sample selection bias, model transferability to other regions, and uncertainty assessment. Therefore, in the conditions of the Bukhara region, the integration of artificial intelligence and GIS technologies with biological data for environmental monitoring is of particular scientific and practical importance.

RESEARCH OBJECTIVE. The main objective of the study is to develop a digital model for assessing and monitoring the state of biodiversity in the Bukhara region based on GIS, remote sensing, and artificial intelligence technologies and to improve its methodological foundations.

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RESEARCH OBJECTIVES. To achieve this goal, the following tasks were set: Analyze the characteristics of ecosystems of the Bukhara region from the point of view of biodiversity monitoring;

Integrate existing biological, geographical, hydrological and environmental data into a single geodatabase;

Assess vegetation and water ecosystems based on Sentinel-2 and other remote sensing data;

Detect ecological changes using spectral indices such as NDVI, NDWI and SAVI;

Map the spatial state of habitats based on GIS technologies;

Automatic classification of ecological hazard zones using machine learning algorithms;

Identify priority monitoring areas for biodiversity;

Propose mechanisms for integrating digital monitoring results into the environmental decision-making process.

OBJECT AND SUBJECT OF RESEARCH. The desert, semi-desert, oasis, riparian and protected natural area ecosystems of the Bukhara region were taken as the object of research. The subject of the study is the assessment of spatial and temporal changes in biodiversity components in these areas using GIS, remote sensing and artificial intelligence technologies.

RESEARCH METHODOLOGY. A comprehensive ecological-geographic approach was used in the study. The methodological basis was the integration of remote sensing, geoinformation analysis, statistical analysis, machine learning and biological monitoring methods.

1. Formation of geodata. It is advisable to combine the following data groups for a digital monitoring system: Such a multi-source approach ensures that monitoring is based not on just one indicator, but on several characteristics of the ecosystem.

2. Assessment of vegetation cover based on NDVI. When assessing vegetation cover, the Normalized Difference Vegetation Index — NDVI is used:

NDVI = (NIR − Red) / (NIR + Red)

where:

NIR — near infrared range;

Red — red spectral range.

Temporal variation of NDVI values in vegetation

MONITORING BASED ON ARTIFICIAL INTELLIGENCE. The main advantage of using artificial intelligence in biodiversity monitoring is the ability to automatically process large volumes of images and geodata. In machine learning, algorithms such as Random Forest, Support Vector Machine, and Gradient Boosting can be used. In deep learning, CNN, U-Net, and other neural

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network architectures can be used to classify habitats and biological objects. Modern research shows that architectures such as YOLO, Faster R-CNN, U-Net, and ResNet are widely used to identify animals from remotely sensed images.

In the conditions of the Bukhara region, artificial intelligence can be used in the following tasks:

1. Habitat classification.

Based on satellite images:

desert;

semi-desert;

watershed;

oasis;

agriculture;

automatic separation of degraded areas.

2. Forecasting environmental hazards.

The model includes NDVI, NDWI, land cover, water distance, climate, soil and anthropogenic pressure indicators, and assesses the potential for environmental hazards.

3. Monitoring the animal world.

AI algorithms automatically process images taken by camera traps, allowing you to identify the animal species and place its recorded point on a GIS map.

4. Automatic detection of changes.

By comparing satellite images from different years, changes in ecosystems are automatically detected.

PROPOSED DIGITAL MONITORING MODEL. As a result of the study, the following conceptual model is proposed for the Bukhara region:

"Space - GIS - AI - Field - Decision" model

Its stages:

Stage 1. Space

Collection of Sentinel-2 and other remote sensing data.

Stage 2. Integration of GIS

Geodata into a single spatial database.

Stage 3. AI

Machine learning and automatic classification of images.

Step 4. Field monitoring

Conducting targeted field surveys in important areas identified by AI.

Step 5. Decision-making

Identifying protection and restoration measures based on ecological risk zones. In this approach, artificial intelligence does not completely replace field

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surveys. On the contrary, it serves as a tool for identifying priority areas for field surveys.

SYSTEM OF DIGITAL INDICATORS OF BIOLOGICAL DIVERSITY. It is proposed to divide monitoring indicators for the Bukhara region into five main groups.

1. Vegetation indicators
NDVI;
SAVI;
Vegetation cover area;
Seasonal dynamics of vegetation cover;
Share of degraded lands.
2. Aquatic ecosystem indicators
Water surface area;
NDWI dynamics;
area of riparian vegetation;
habitat change around the watershed.
3. Fauna indicators
number of recorded species;
frequency of recording in camera traps;
spatial distribution of species;
meeting points of rare species.
4. Landscape indicators
habitat fragmentation;
landscape heterogeneity;
ecological corridors;
level of anthropogenic impact.
5. Climate and environmental risk indicators
drought;
high temperature;
water scarcity;
land degradation;
salinization;
desertification trends.

FORMATION OF ECOLOGICAL RISK INDEX. An integrated ecological risk index is proposed to determine priority monitoring sites in the Bukhara region:

$$EHI = w_1V + w_2W + w_3D + w_4A + w_5F$$

where:
EHI — ecological risk index;

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V — vegetation degradation;
W — change in water factors;
D — drought impact;
A — anthropogenic pressure;
F — habitat fragmentation;
w_1–w_5 — weight coefficients of each factor.
Weight coefficients can be determined by expert assessment, AHP (Analytic Hierarchy Process) or statistical models.
As a result, the territories can be divided into:
low risk;
medium risk;
high risk;
critical risk
zones.

SCIENTIFIC NOVELTY OF THE RESEARCH. The main scientific novelty of the research is the following: firstly, a conceptual model of integrating remote sensing, GIS, field observations and artificial intelligence into a single digital ecosystem for monitoring biodiversity in the conditions of the Bukhara region was proposed; secondly, the methodology for assessing the state of the habitat was improved by combining spectral indicators such as NDVI, NDWI and SAVI with biological observations and landscape data; thirdly, an approach to automatically classifying ecological hazard zones and identifying priority monitoring areas using machine learning algorithms was developed; fourthly, an integration model "Space – GIS – AI – Field – Decision" was proposed for biodiversity monitoring; fifthly, a system of digital indicators was based on which spatial and temporal changes in monitoring ecosystems of the Bukhara region could be assessed together.

RESULTS. Methodological analysis of the research results shows that limiting biodiversity monitoring only to field observations reduces the possibility of rapid detection of environmental changes in large areas. Remote sensing technologies, on the other hand, allow for systematic monitoring of large areas, determining the dynamics of vegetation cover and water bodies. For example, in modern studies, satellites

CONCLUSION. The results of the study show that the use of digital geotechnologies and artificial intelligence capabilities in effective monitoring of biodiversity in the Bukhara region significantly increases the speed, accuracy and efficiency of ecological observations. In particular, the integration of geographic information systems (GIS), remote sensing data, digital mapping and artificial intelligence algorithms will expand the possibilities for a systematic assessment of

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the territorial distribution of flora and fauna, habitat changes, and the status of rare and endangered species. The introduction of digital monitoring systems in desert and semi-desert ecosystems, natural and artificial water bodies, protected areas and agro-ecosystems of the Bukhara region will help determine the impact of anthropogenic pressure, changes in water resources, salinization, desertification and climatic factors on biodiversity. Artificial intelligence-based automatic image recognition and classification technologies allow for rapid identification of biological objects, detection of changes in the number and distribution of species, and forecasting of ecological risk zones. Also, the integration of GIS and artificial intelligence technologies into a single digital monitoring platform is of great practical importance for systematizing information on biodiversity, conducting territorial analysis of the ecological state, and planning conservation measures on a scientific basis. This approach allows for the formation of modern mechanisms for the rational use of biological resources, the protection of rare and endangered species, and ensuring ecological stability in the Bukhara region. In general, biodiversity monitoring based on digital geotechnologies and artificial intelligence is an innovative tool that complements traditional observation methods and allows for a continuous, accurate, and forecast-oriented assessment of the ecological state of the Bukhara region. In the future, integrating these technologies with field observations, ecological databases, automatic photo and video monitoring devices, and remote sensing systems will further increase the effectiveness of preserving and restoring biodiversity in the region.

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