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ASSESSMENT OF REGIONAL FACTORS FOR SUSTAINABLE DEVELOPMENT OF AGROCENOSES BASED ON GIS AND REMOTE SENSING

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Abstract

As the population grows, so does the demand for agricultural products. Ensuring sustainable agricultural product and agrocenoses development is essential at this time. In this regard, we are researching the present issue. Our research area covers the Nakhchivan Autonomous Republic, which has favourable conditions for the sustainable development of agrocenoses. In the article, the sustainable development of agrocenoses existing here and the ways to ensure it was analyzed, geographical conditions were studied, and their role in the sustainable development of agrocenoses was analyzed. Modern methods were used in the research. The natural conditions in the area underwent analysis and mapping via satellite image processing. The researchers drew up a regional map of agrocenoses in the study area and divided it into different regions. The data processing from Landsat 5, 8, and 9 satellites in the ArcGIS program enables comparison with the previous situation. Based on the research conducted, it has been determined that agrocenoses develop more intensively in low to medium-mountainous areas and along river banks.

Key words: Nakhchivan AR, agrocenoses, sustainable development, satellite images, SAVI, NDVI

Introduction. The daily surge in demand for agricultural goods and the heightened production of agrocenoses impact the natural ecosystem in two distinct manners [1]. On the one hand, this process creates favourable conditions

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for utilizing natural agricultural resources to their full potential by strengthening technological capabilities and overcoming the limitations on agroecosystem productivity [3]. On the other hand, the appropriation of territory by farms leads to a change in the characteristics of agroecosystems, which in turn leads to a loss of self-regulation, self-recovery, and, ultimately, sustainability. This will result in irreversible processes expanding across a considerable area [6]. The degradation and violation of the natural system will expand as a consequence. Additionally, the stable increase in the production of agricultural products will decrease, resulting in a reduction in the biological productivity of agrocenoses and a subsequent decrease in production efficiency. Such a condition challenges the continuous growth of agrocenoses [8].

The concept of sustainable development emerged at the end of the 20th century with the primary objective of not posing a threat to future generations' livelihoods. In 1992, the term was first introduced at the United Nations Conference on Environment and Development held in Rio de Janeiro, which focused on the proficient use of natural resources. It has since evolved to encompass all aspects of society. In the present time, sustainable agrocenoses development has emerged as a pressing issue [9].

Considering the initial conditions for the development of green agrocenoses, it is crucial to use the landscape-ecological approach which includes the study of natural phenomena and processes and the inventory of their resource potential. At present, it is essential to focus on the subsequent procedures in untouched ecological systems [5].

1. The assessment of natural systems is conducted in relation to their potential uses.

2. Predictions are made about the potential changes that may occur due to the use of natural complexes.

3. Approaches are developed for managing the processes of change in natural complexes resulting from anthropogenic influence. This includes determining ways and means of regulating the changes.

4. Justified recommendations are created for optimizing agrocenoses.

Developing a sustainable agroecosystem map is crucial for the Nakhchivan Autonomous Republic. The issue has intensified due to the increasing daily food demand in contemporary times [4]. Inadequate topography and weather conditions have led to challenges in their progress. Hence, while designing a sustainable development map for agrocenoses in the research region, it is crucial to focus on agroecological evaluation of soils and strategies for adaptive landscape farming systems. The proposed methodology's land evaluation system differs markedly from the traditional system for developing on-farm land management projects, making it a crucial element in agrocenoses mapping.

Material and method. All the physical aspects of the area were considered, including land formations, rock structures, water systems, soil composition, and vegetation, when conducting the survey [7]. Mapping considers the independent factors of agriculture, including agrocenoses, such as geomorphological and lithological conditions. Appropriate evaluation of horizontal and vertical fragmentation is also crucial. Examining these conditions greatly aids the implementation of agrotechnical rules. The mapping of agrocenoses is influenced by both relief and climate. The development of agrocenoses is affected by the microclimate created by the relief. Precise calculation of agroclimatic resources is essential.

Other major components of mapping are soil, vegetation, and fauna. As an element of sustainability of agrocenoses (especially with increasing production intensification) – habitats of useful entomofauna, birds, and other animals are of special importance. Therefore, the determination of landscape fauna should become one of the parameters of agrocenoses mapping. Thus, for the mapping of agrocenoses, the initial cartographic basis should contain information about the landscape and its structure, geomorphological, lithological, hydrogeological, microclimatic, and geochemical conditions, as well as the characteristics of flora and fauna.

During the research, images of Landsat 5, 8, and 9 satellites were processed in the ArcGIS program, and SAV, NDV, NDW, NDM, and other indices were analyzed.

The Land Adjusted Vegetation Index (SAVI) is determined using the following formula

$$\mathrm{SAVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED} + \mathrm{L}}(1 + \mathrm{L}),$$

where L is the amount of green vegetation. This index has values between −1.0 and 1.0.

NDV index is determined based on the following formula

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}.$$

Here NIR is near infrared, RED is red.

The Normalized Difference Humidity Index (NDMI) is determined using the following formula

$$\mathrm{NDMI} = \frac{\mathrm{NIR} - \mathrm{SWIR1}}{\mathrm{NIR} + \mathrm{SWIR1}},$$

where SWIR1 is short-wave near-infrared.

NDW index is determined based on the following formula

$$\mathrm{NDWI} = \frac{\mathrm{Green} - \mathrm{NIR}}{\mathrm{Green} + \mathrm{NIR}}.$$

Research. The utilization of GIS for agrocenoses mapping in contemporary times permits the resolution of this convoluted issue to advance to a new standard. Establishing a foundation for precise agricultural practices requires utilizing GIS technologies, as they are integral to creating a soil evaluation framework [2].

The use of GIS technologies in the mapping of agrocenoses is primarily related to the digitization of cartographic material. Several digitization methods are used, depending on available equipment, software, and personnel expertise [4].

We utilized GIS technologies when creating the sustainable development map of agrocenoses in the Autonomous Republic. Technical abbreviations will be clearly defined upon first use in this document. Using this software, we examined the morphological characteristics of the research area's terrain (including inclination, slope, hypsometric height, and vertical and horizontal divisions), its climate and agroclimatic, hydrographic network, and soil and vegetation maps. In addition, we have analyzed the soil-adjusted vegetation cover, normalized difference humidity, and normalized difference water indices. These indices are crucial for developing a sustainable development map of agrocenoses.

The Soil Adjusted Vegetation Index (SAVI) minimizes soil brightness effects using a soil brightness correction factor [10]. SAVI is widely applied in arid regions with low vegetation (Fig. 1a, Table 1). The significance of studying this index is underscored by the selected climate of the study region exhibiting continentality.

As shown in Table 1, 61.1% of the Autonomous Republic exhibits an SAV index of 0.255, with an indicator of 960 for the phenological phase of vegetation. Drought has extensively affected the Buda region, impeding biocenosis development, ultimately leading to issues in agrocenoses cultivation. Therefore, the development of agrocenoses in these areas necessitates irrigation. The sections with a phenological phase between 960–2980 and an SAV index of 0.450–0.900 constitute 28% of the total area. Areas needing more vegetation account for approximately

Table 1

Classification codes according to SAVI and P.D. values

Classification codes	Vegetation (%)	SAV index	Phenological phases	Area, km^2 (%) 2022, June	Dynamics km^2	Dynamics (%)
A	0	Negative	0	88	918	−91
B	> 22	0–0.255	0–960	3363	−616	+22
C	23–37	0.255–0.450	960–1630	1107	−363	+49
D	38–52	0.450–0.675	1630–2300	722	−119	+19
E	53–65	0.675–0.900	2300–2980	221	121	−35
F	66–80	0.900–1.125	2980–3650	1	59	−98
G	81–93	1.125–1.306	3650–4350	—	—	—
H	94–100	1.306–1.500	4350–high	—	—	—
Total				5502		

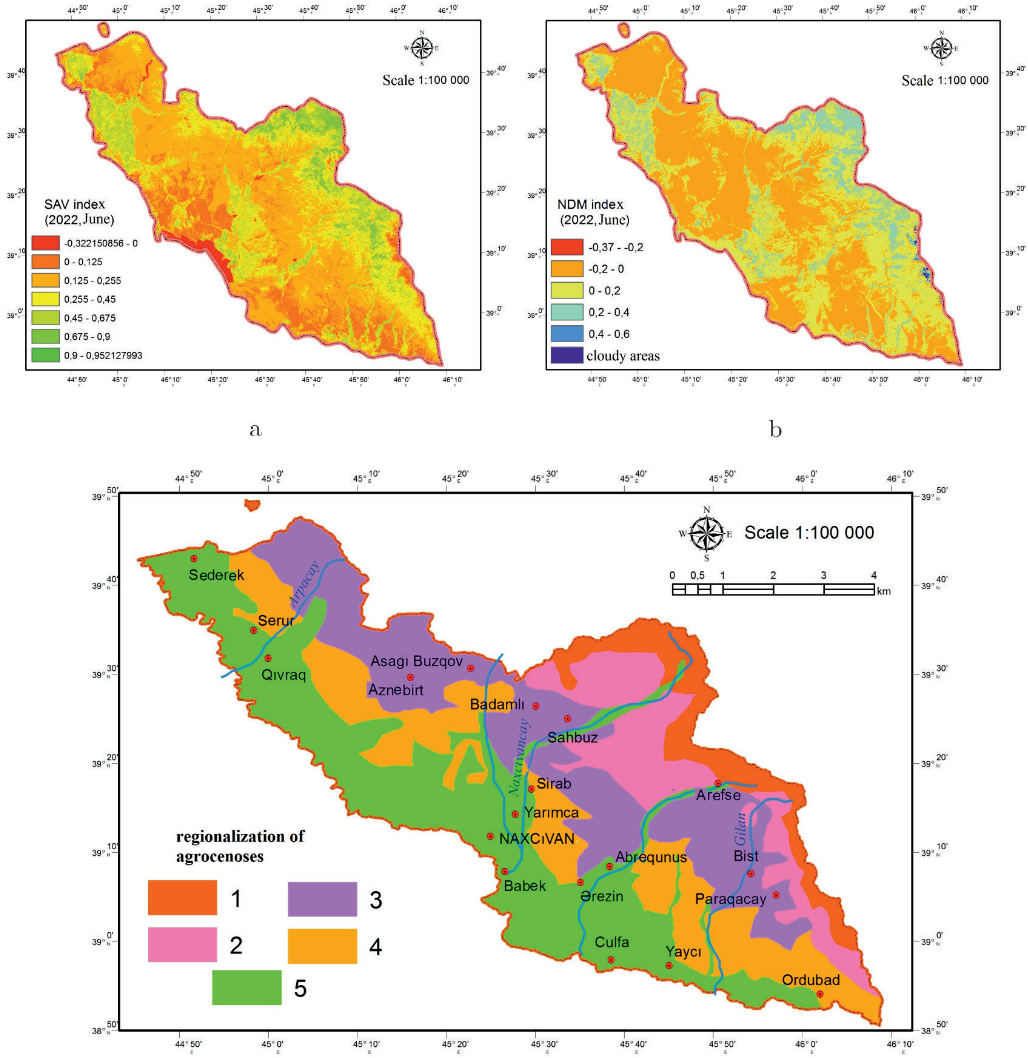

Fig. 1. a) SAV index, b) NDM index, and c) Regionalization of agrocenoses in the territory of Nakhchivan AR. Conventional signs: 1. Areas where natural conditions are not favourable for developing agrocenoses. 2. Areas where the landscape is unstable for the development of agrocenoses. 3. Areas where the landscape is weakly stable for the development of agrocenoses. 4. Areas where the landscape is moderately stable for the development of agrocenoses. 5. Areas where the landscape is more stable for the development of agrocenoses

1% of the area. The analyses indicate that the natural conditions in our research area are insufficient for the sustainable development of agrocenoses.

Another crucial factor in the sustainable development of agrocenoses is the utilization of the Normalized Difference Moisture Index (NDMI). This index is utilized to examine the moisture levels of agrocenoses. The agrocenoses in the study area, characterized by their strong continentality, suffer from drought. In this region, irrigation farming occupies a greater area than paddy cultivation. For this reason, it is essential to study the humidity index. Humidity index is a unit of measurement used to estimate the amount of moisture, including its presence, in a specific area or region. It is usually derived from various environmental factors such as precipitation, evaporation, soil properties, and vegetation. It provides a relative indication of the wetness or dryness of an area, helping to identify potential water stress or drought conditions. This index is a current approach to evaluating and observing the moisture levels in biocenoses and agrocenoses. To determine the moisture levels of biocenoses, we utilize satellite imagery and extrapolate to approximate the moisture levels of agrocenoses.

When analyzing the NDMI indicators in the study area, it was discovered that the regions with medium-to-low vegetation, high water stress, or low vegetation and low water stress were more expansive (Fig. 1b, Table 2). Such areas cover 52.6% of the total area. Medium vegetation covers those regions that experience high water stress or medium-low vegetation, whereas areas with low water stress comprise 38.9% of the overall study area. This data indicates that 91% of the Autonomous Republic experiences varying water scarcity and stress levels. Merely 31 km^2 of the region has adequate access to water. As a result, we conclude that prioritizing this aspect is crucial for charting the sustainable progress of agrocenoses in the region.

Our other index is the NDWI or Normalized Difference Water Index. Using this method, it is feasible to quantify and assess the water content or water-related characteristics within biocenoses. This enables us to ascertain the water content in agrocenoses. The index is valuable for identifying water bodies, monitoring

Table 2

Statistical indicators of the NDM index in the territory of Nakhchivan AR

NDMI	Interpretation	Area, km^2 (%) 2022, June	Dynamics km^2	Dynamics (%)
Low < -0.2	Low vegetation, dry or shallow vegetation, wet	6	0	0
−0.2–0	Medium-low vegetation, high water stress or low vegetation, low water stress	2896	254	+10
0–0.2	Medium vegetation, high water stress or medium-low vegetation, low water stress	2139	157	+8
0.2–0.4	Medium tall vegetation, high water stress, or medium vegetation, low water stress	400	−261	−40
0.4–0.6	High vegetation cover, no water stress	31	−150	−77
0.6–0.8	Very high vegetation cover, no water stress	—	−10	−33
0.8–1.0	Full plant cover, no water stress/waterlogging	—	—	—
	Cloudy areas	30		
Total		5502		

changes in water availability, and assessing vegetation health. Additionally, it plays a crucial role in enhancing the irrigation system. Based on this, it will be possible to correctly place agrocenoses and ensure their sustainable development. The water index is calculated by analyzing the reflectance of near-infrared and green light bands from satellite or aerial.

The data analysis reveals that the water index is below 0 over 90% of the region, providing further evidence of water scarcity in our area. This once again proves that our region suffers from drought. Based on the research we have conducted, including the analysis of all the maps we have mentioned, we have drawn up a map of the regionalization of agrocenoses, taking into account the continuous development of agrocenoses. Based on the map of the Autonomous Republic, we have divided it into five regions based on the degree of development of agrocenoses (Fig. 1c, Table 3).

Table 3

Statistical indicators of regionalization of agrocenoses in Nakhchivan AR

No.	Regionalization of agrocenoses	Area	
		ha	%
1	Areas where the landscape is more stable for the development of agrocenoses	183 212	33
2	Areas where the landscape is moderately stable for the development of agrocenoses	112 673	20
3	Areas where the landscape is poorly stable for the development of agrocenoses	141 385	26
4	Areas where the landscape is unstable for the development of agrocenoses	68 854	13
5	Areas where natural conditions are not favourable for the development of agrocenoses	44 075	8
6	Total	550 200	100

It was found that 8% of the research area lacks favourable conditions for agrocenoses development. Nevertheless, one-third of the territory is considered stable for the growth of agrocenoses.

Result. Based on the conducted research, the following conclusions can be reached.

- The processing of satellite images shows that the water level in the water basins in the study area has decreased, the empty areas have been converted into crops and settlements, and the density of forests and bushes has decreased.

- The studied area has arid climatic conditions. For this reason, irrigation farming is more common in the area's agriculture. The studied area generally has favourable climatic conditions for cultivating grain, tobacco, sugar beet, fodder and melon plants, fruit, and berries. Grain, tobacco, sugar beet, fodder, and melon plants are grown mainly in the Araz plain, foothills, low and medium highlands.

- Depending on the climatic conditions, it is more suitable for the development of agrocenoses in the parts of the studied area up to 1000 m above sea level than in other areas.

- The analysis of the development of natural geosystems of the Nakhchivan Autonomous Republic shows that the structure of all geocomplexes of the territory has undergone a complete change. Here, the area of agricultural irrigation geosystems has increased significantly, and the area of irregularly used agrocomplexes has decreased significantly. In 1981, the area of agricultural irrigation complexes was 23.28 thousand hectares, while the area of cotton complexes was 4.92 thousand hectares. At present, the area of these complexes has increased to 31.97 and 5.56 thousand hectares, respectively.

- For the first time, the regionalization of agrocenoses was carried out in Nakhchivan AR. It was determined that the areas where the landscape is more stable for the development of agrocenoses make up 33% of the research area, the areas where the landscape is moderately stable for the development of agrocenoses make up 20%, the areas where the landscape is poorly stable for the development of agrocenoses make up 26%. However, the areas where the landscape is unstable for the development of agrocenoses cover 13% of the research area, and the areas where natural conditions are not favourable for the development of agrocenoses cover only 8% of the research area.

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