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## VEGETATION DEVELOPMENT AND PRODUCTIVITY IN AGROLANDSCAPES USING SATELLITE IMAGERY AND GROUND SURVEYS

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### SUMMARY

The presented research comprised the study of vegetation development and productivity in agrolandscapes using satellite imagery and ground surveys in the Upper Shirvan economic region. Climate change with uncertainties and rapid population growth has a significant impact on agrolandscapes and their vegetation. For a rapidly growing population, food security is an important challenge worldwide. The expansion of cultivated fields and their proper management causes numerous constraints. This research identified four administrative districts located in the economic region and analyzed their vegetation cover at different points. For the study, the authors used the data from Landsat 8 and 9 satellites. The NDV (normalized difference vegetation) and NDM (normalized difference moisture) indices with different bands served to study the vegetation cover and their dynamics in different phases of development. Studying plant productivity entailed the collection of plant samples from the research areas before their analysis in the laboratory. The vegetation development revealed higher indicators in the Gobustan BTS and Ivanovka settlements, while the lowest were in the Narimankend and Arabgadim settlements.

**Keywords:** Agrolandscapes, vegetation cover, vegetation productivity and development, zero hunger, landsat satellites, remote sensing, NDVI, NDMI

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**Key findings:** Studies used multiple vegetation indices, such as SAVI (soil adjusted vegetation index), MSAVI (modified SAVI), OSAVI (optimized SAVI), ARVI (atmospherically resistant vegetation index), and SARVI (soil and atmospherically resistant vegetation index), derived from satellite data. Their combination with ground truth yield measurements achieved the highest predictive accuracy, with composite indices explaining over 83% of yield variance ( $R^2 \approx 0.84$ ). The findings highlighted those integrating high-resolution satellite-derived vegetation indices with ground measurements, which enhanced monitoring of vegetation dynamics and productivity across diverse agrolandscapes.

## INTRODUCTION

Vegetation indices provide information about the qualitative studies in crop plants, as well as the quantitative information about crop health and growth and development (Radočaj *et al.*, 2023). Understanding vegetation development and productivity in agrolandscapes is crucial for sustainable land management, climate resilience, and food security. Traditional field-based methods are accurate but often are labor-intensive, time-consuming, and spatially limited. Satellite remote sensing, as a powerful tool for large-scale monitoring of vegetation dynamics, offers information about the timely and repeated observations across diverse agricultural regions. Vegetation indices derived from satellite imagery, such as NDVI, EVI (enhanced vegetation index), and GCVI (green chlorophyll vegetation index), are widely used guides to estimate crop health, biomass, and eventually, yield potential. However, satellite data alone could face limitations due to cloud cover, sensor calibration issues, and insufficient local specificity. The ground survey provides essential validation data and helps in the calibration of remote sensing outputs, increasing the reliability of productivity assessments.

The integration of satellite imagery with in-situ observations allows for more precise and scalable evaluations of vegetation cover across the diversifying climatic and management conditions. In sensor technology and data analytics, current advancements have further enhanced the utility and resolution of the Earth's observation data for application in agricultural crops. This combined approach supports informed decision-making in precision agriculture, land use planning, and the creation of a sustainable policy about crop plants. The

agrolandscape can pertain to "a land mass comprising a complex of interacting natural components, as well as elements of an agricultural system with relatively autonomous water, thermal, and other regimes, with features of a single ecological system" (Khalilov and Eminov, 2024; Mammadov *et al.*, 2025).

An agrolandscape is a complexly organized, multidimensional ecosystem of the earth with certain appearances and corresponding structures, with its functioning based on agricultural systems (Mammadov and Abdullayev, 2024). An agrolandscape should comprise a territorial unit for solving the agricultural systems-related issues and land management on the ecological basis (Berra *et al.*, 2019). The agro landscape organization can also succeed in particular limited territories with the possibility of self-regulation, specific food, water, and thermal regimes (Mikayilov *et al.*, 2025). An agro landscape, being anthropogenic, materialized under the influence of human agricultural-related activities (Wang *et al.*, 2020). Consequently, the agrolandscape structure should reflect the component elements and the organization of the territory and agricultural systems (Stancescu and Sala, 2019).

The concerned study aimed to determine the main stages and methods of processing space images in the study of agrolandscape and structuring them into a generalized technological scheme. Similarly, the research analyzes the decoding features of major indicators of irrigated soil cover in space images. These studies continued considering the scientific and practical development in agro landscapes research using remote sensing data based on experimental and theoretical approaches.

The main technological blocks also attained identification, such as organizational and managerial, initial data, pre-thematic processing, and thematic decoding and GIS creation (Rossi *et al.*, 2019). Currently, various methods have emerged using space photography to assess the dynamic properties of the soil cover (salinization, erosion, and dehumification) both at the qualitative and quantitative levels (Sadigov, 2022b). The characterization of the current state of space methods for studying agricultural landscapes engaged the production of digital analysis tools (Berca and Horoia, 2022). This was in integration with geographic information system (GIS) technologies and the formation of an information field of open data sources (Zarasvand *et al.*, 2025). Therefore, the relevant study aimed to assess the vegetation development and productivity in agrolandscapes by leveraging both satellite-derived indicators and ground-based measurements.

## MATERIALS AND METHODS

This study used the traditional and modern methods. The collected soil and plant samples came from 37 different points in the study area before their analysis in the laboratory. The soil analysis results were unavailable in this manuscript. However, the plant samples entailed analysis in the laboratory, with their results presented in the article. Moreover, the authors determined the various quality indicators in the crop plants, i.e., grain yield (Y), 1000-grain weight (M1000), vitreousness (Vi), gluten (GI), gluten deformation index (GDI), and sedimentation (Sd).

In the economic region using ArcGIS software by processing satellite images, the two indices of vegetation cover (normalized difference vegetation—NDV and normalized difference moisture—NDM) also incurred assessments. For the analysis of the NDV index, the research used bands 5 and 4. The analysis of the NDVI index had researchers use the following formula:

$$\text{NDVI} = (\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4})$$

Where Band 5 = Near Infrared and Band 4 = RED.

In the analysis of the NDM index, the study utilized the following formula:

$$\text{NDMI} = (\text{Band 5} - \text{Band 6}) / (\text{Band 5} + \text{Band 6})$$

Where Band 5 = near infrared and Band 6 = short-wave infrared (SWIR).

In the study area, for the first time, the vegetation cover studies relied on both field surveys and satellite imagery. The results underwent comparison, with their consistency analyzed.

## RESULTS AND DISCUSSION

The coverage area included the Agsu, Ismayilli, Gobustan, and Shamakhi regions. The economic region sits in the southeastern foothills of the Greater Caucasus and the Shirvan Plain. With an area of 606,000 km<sup>2</sup>, the Upper Shirvan covers 7% of the country's territory. With most of the territory of the economic region consisting of a mountainous zone, problems arise in the development of agriculture. The region is within a seismically active zone. Climatic conditions are very diverse; mainly temperate-warm and cold climate types occur. Agroclimatic conditions allow for the cultivation of agricultural products in the mountains under rainy conditions and in the plains under irrigation.

The prevailing research took place in the four different districts, such as Gobustan, Shamakhi, Ismayilli, and Agsu, in the Upper Shirvan economic region. The researchers visited 37 research points in October 2023 and April and June 2024 to conduct field evaluations in the study area. The collected soil and plant samples sustained analysis; however, in this study only the results based on analysis of plant samples underwent summarization, as presented.

The increased crop productivity has primary influences from soil fertility, while the improved crop quality has incurred management of climate and its derivatives. Soil fertility diversity and cultivation technology elements also lead to diversity in plant

productivity and quality. In the analysis of plant samples, the assessed indicators included grain yield (Y), 1000-grain weight (M1000), vitreousness (Vi), gluten (Gl), gluten deformation index (GDI), and sedimentation (Sd) (Figure 1). Generally, the grain yield and quality variables of crop plants showed a wide range of variations, and the grain quality mainly corresponds to class III. However, among the four districts studied, the Ismayilli Region stood out from the others with more favorable agrophysical and agrochemical soil properties and relatively high grain yield and better quality. Adapted nutritional strategies based on soil and climate conditions can support regional cereal crop productivity and considerably contribute to food security (Gao *et al.*, 2025). In the studied regions in general, it was evident that crop yield and quality proved significantly dependent on soil-climatic conditions, soil properties, varietal biodiversity, nutritional conditions, soil cultivation practices, and fertilization (Amanova *et al.*, 2024b).

During field surveys, the Landsat-8 images appeared with a reliability of 93.7% and 91.9%. This has authenticated the benefits of using medium-resolution spatial representations of satellite images in agricultural surveys over larger areas (Moreno *et al.*, 2021). The said data have had a wide application in recent decades to identify and project the variability. Remote sensing data, such as Landsat and Sentinel data, emerged to be very useful for visualization, classification, and analysis of different terrains. The said data also differed for resolution, electromagnetic wavelength, and energy characteristics. Landsat satellite data contains several spectral bands and ranges with different wavelengths (blue, green, red, infrared, thermal, and panchromatic). Remote sensing data is an effective tool for monitoring and analyzing the temporal and spatial variability of ecological processes and phenomena at different scales (Hajiyeva, 2024; Sadigov *et al.*, 2024).

In the vegetation studies, the NDVI and NDM indices have long been serving as key indices to study the vegetation monitoring through remote sensing. Concerning this case, different bands further allow us to identify

variations in the vegetation dynamics (Nițu *et al.*, 2025). In addition to ground-based field studies, the research proceeded with satellite images (NDVI and NDMI). Furthermore, studying the vegetation cover resulted in the identification of two main indices. However, to conduct the presented study, we analyzed satellite images dated October 27, 2023, April 28, 2024, and June 7, 2024.

Accurate prediction of plant moisture and soil moisture, which can work as a crucial basis for precision agriculture, facilitates optimal irrigation scheduling, ensures efficient allocation of water resources in the field, and eventually enhances productivity. Analysis of this index can provide a sound framework for improving water management in crop fields (Koochikeradeh *et al.*, 2025). Past studies exhibited that the NDM index can aid in determining the moisture content in crop plants (Amanova *et al.*, 2024a). In the Ismayilli Region, the said index indicators were higher in October 2023. This may refer to both the climate and the better development of vegetation in these areas. One should also note that these areas were suitable for summer pastures. In the Gobustan Region, the lowest indicators resulted in the said index, with these areas regarded as arable lands, as no arable land existed during that period, and the said index has the lowest indicators.

In April 2024, the higher index revealed that the vegetation cover was already denser. However, it can be visible for the said index even high in the Gobustan Region. In the latest study, the foothill and mid-mountain areas manifested with considerable differences in vegetation cover. The crops in the foothill area and the summer pastures in the mid-mountain area caused variations in the NDM index for vegetation cover. Thus, in June 2024 in the foothill areas, the index was lower because the crops had finished harvesting (Figure 2). By comparing 37 research points for this index across the three mentioned periods, the highest indicators were evident in April 2024 (Figure 3).

In studying the vegetation cover, the other index was the NDVI, or the normalized difference vegetation index. NDVI is an

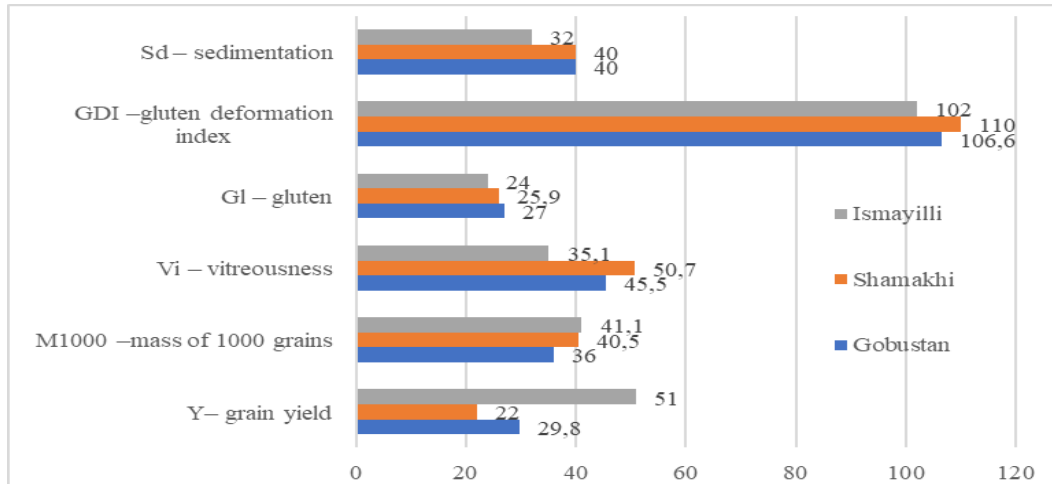


Figure 1. Grain yield and quality indicators of the vegetation cover.

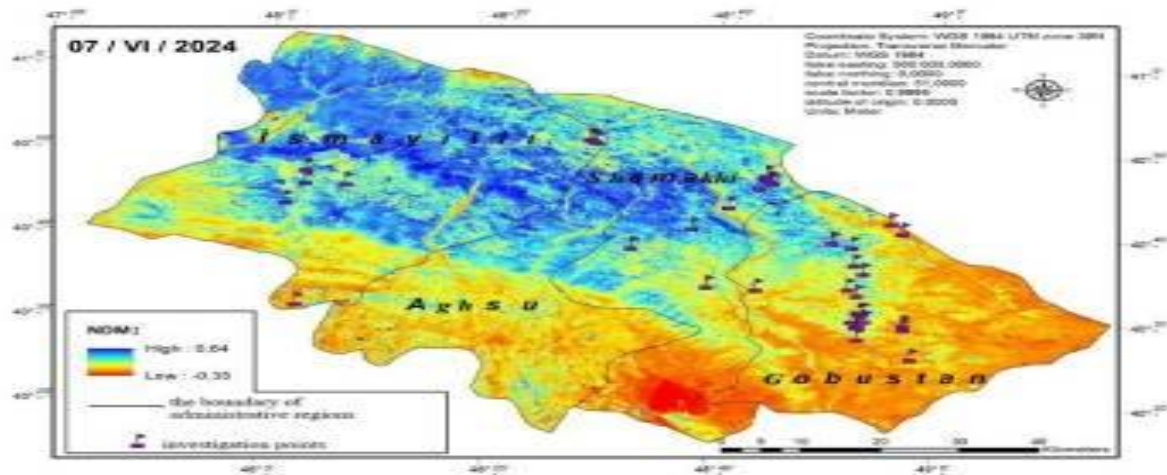


Figure 2. Map of the NDM index in the Upper Shirvan Region (July 7, 2024).

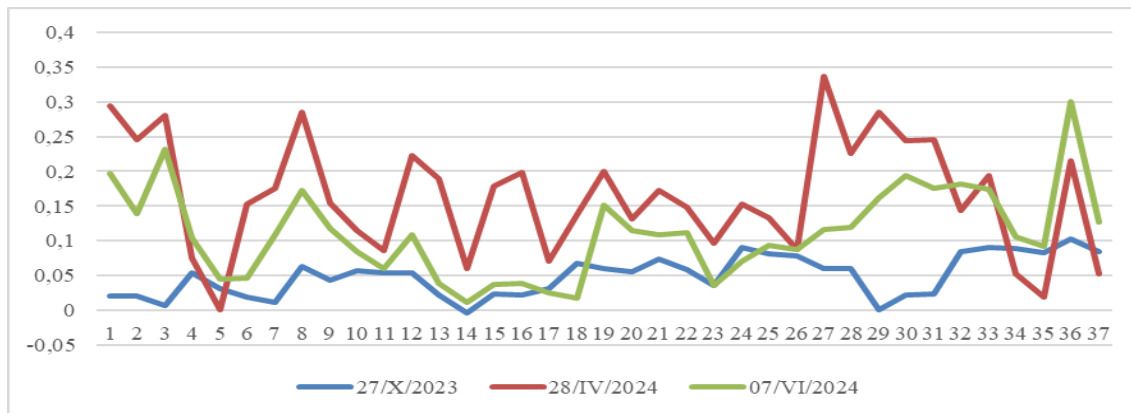


Figure 3. Dynamics of the NDM index by research points in the Upper Shirvan economic region.

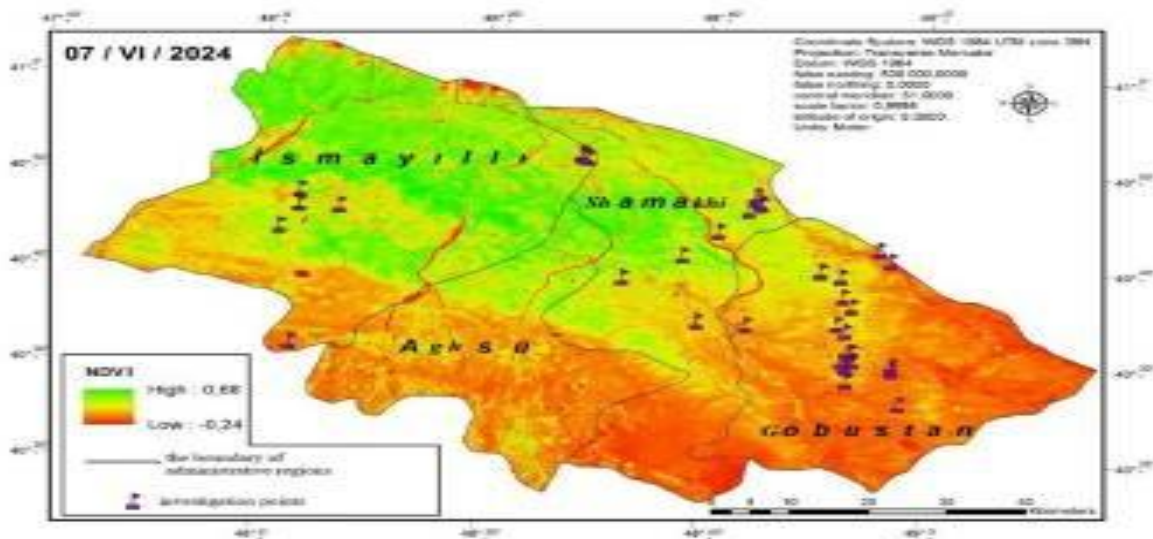
important remote sensing index widely used to assess the vegetation coverage and monitor crop growth and predict crop yields (Sadigov, 2018). Traditional NDVI calculation methods often rely on multispectral and hyperspectral imagery, which are costly and complex to operate. Thus, its application in small-scale farms and developing countries becomes limited (Wang *et al.*, 2025). Through this index, it is possible to determine the development dynamics and productivity of crop plants. The said index also received analysis on the same dates. The analysis carried out in October 2023 determined that the areas with denser vegetation were the foothills because the vegetation cover was weak in the middle mountainous areas. This may be due to the grazing carried out in July-September on summer pastures.

In April 2024, the vegetation cover began to develop, and the crops became denser in the fields. This development can be similar to the entire territory, especially apart from Gobustan. However, in June 2024, the NDVI index gradually decreased, which may be because of the crops' harvest. However, one should note that compared to April, in June the index was higher in the highlands of Ismayilli and Shamakhi districts. The results revealed the plants displayed sufficient development in

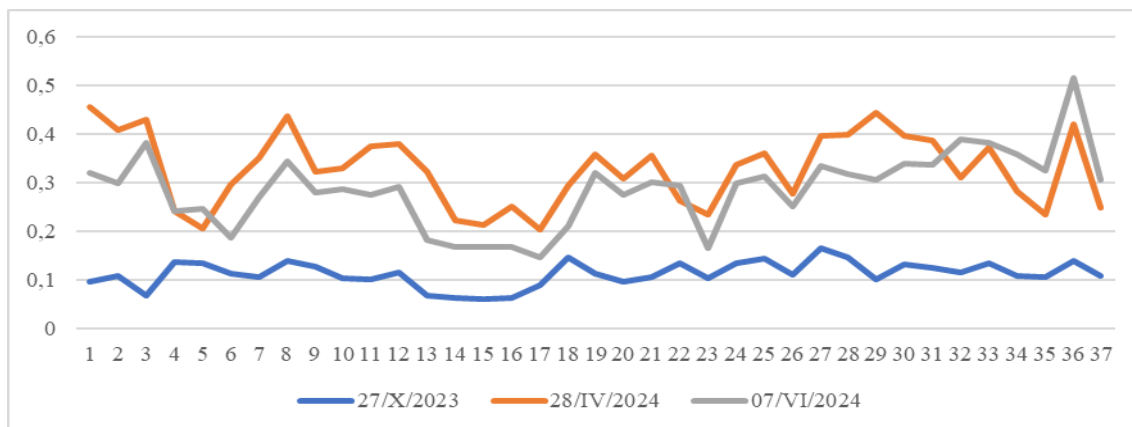
preparation for the summer grazing period (Figure 4). In the field study, the NDV index analysis ran at the 37 different points, which determined that the highest indicators resulted in April 2024 (Figure 5).

In 27 villages and settlements of Gobustan, Shamakhi, and Ismayilli districts, agrophysical and agrochemical properties of the topsoil, grain yield, and quality indicators of grain crops (barley and wheat) succeeded in determining at the 37 coordinate points. Remote sensing also continued in the area, covering different periods using Landsat 8 and 9 satellites according to geographical coordinates corresponding to the research areas. The detection and mapping of dynamics of vegetation and moisture indices characterizing the development state of vegetation cover were also successful.

Furthermore, the grain yield and quality of crop plants varied widely on a regional scale, and the grain quality mainly corresponds to class III. However, after harvesting, this difference changed between 0.05 and 0.23 in June, with a nonsignificant difference. On the eve of planting, this indicator had a low value. According to satellite images, the said value ranges from 0.007 to 0.02. The diversity of agroecological conditions, soil fertility, and cultivation



**Figure 4.** Map of the NDVI index in the Upper Shirvan Region (June 7, 2024).



**Figure 5.** Dynamics of the NDV index by research points in the Upper Shirvan economic region.

technology led to the considerable diversity in crop productivity and its quality (Sadigov, 2022a; Sadigov and Mustafayev, 2024).

However, among the studied regions, the Ismayilli Region stood out with more favorable soil properties and relatively higher grain yield and better quality. Remote sensing of grain and pasture areas in the Upper Shirvan economic region used Landsat satellites at different times. The processing of obtained images, determination, and mapping of NDVI and NDMI dynamics provided reliable information on the degree of soil-vegetation moisture and the state of plant development. In general, in the study areas, the indices differed and appeared with ranges of 0.2–0.4 (NDVI) and 0.1–0.3 (NDMI), which revealed the vegetation developed under water stress conditions. Based on the studies conducted in the Gobustan RES area, one can conclude that the images obtained in April showed the humidity index fluctuated between 0.00 and 0.29 during this period.

## CONCLUSIONS

In the Upper Shirvan economic region, the integration of satellite imagery and ground surveys provided a comprehensive understanding of vegetation development and productivity across diverse agroecological zones. Field analyses revealed soil fertility, climatic conditions, and crop management

practices significantly influenced crop yield and grain quality, and the Ismayilli Region showed the most favorable results. Satellite-based NDVI and NDMI indices effectively captured the seasonal vegetation dynamics, with the highest values recorded in April, indicating peak vegetation growth. The results highlighted the potential of combining remote sensing and field data to support precision agriculture and formulate region-specific land management strategies. The outcomes of this study can serve as a scientific basis for developing spatially explicit monitoring systems for crop productivity and soil-vegetation conditions. The integration of NDVI and NDMI analyses with field validation can help local agricultural authorities optimize irrigation scheduling, identify drought-prone areas, and improve crop rotation planning. Furthermore, the proposed approach may support early warning systems for yield prediction and sustainable agrolandscape management in regions affected by climate variability. These findings provide practical guidance for policymakers and land managers aiming to enhance food security and environmental sustainability in Azerbaijan and similar agroecological settings.

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