

ABSTRACT

Dissertation by Asset Amirkhanovich Arystanov entitled “Satellite monitoring of winter grain crops in the South of Kazakhstan based on modern geoinformation systems”, submitted for the degree of Doctor of Philosophy (PhD) in the educational program “8D07302 – Geoinformatics”.

The southern regions of the Republic of Kazakhstan, including Turkestan Region and adjacent foothill areas, combine high agricultural importance with pronounced climatic vulnerability. Winter cereal crops occupy a leading position in the regional land-use structure and, under limited water resources and prevailing rainfed farming, form a key component of food security. Cultivation of winter crops proceeds under an arid climate, strong interannual variability of precipitation, unstable temperature regimes, and marked spatial heterogeneity of agricultural landscapes.

Under these conditions, there is an increased demand for spatially detailed, timely, and objective information on the actual status of fields, the dynamics of crop development, and land-use sustainability. Conventional monitoring approaches, largely based on statistical reporting and partial ground surveys, do not provide full territorial coverage, have low temporal frequency, and are affected by delays in data delivery.

The use of Earth observation data and GIS shifts agricultural monitoring from statistical generalizations to spatially oriented analysis. Sentinel-2 multispectral imagery provides high temporal resolution and supports systematic observation of winter cereals throughout the production cycle—from autumn sowing to maturation.

However, a comprehensive methodological framework for satellite monitoring of winter cereals, adapted to the agroclimatic conditions and land-use characteristics of southern Kazakhstan, has not yet been formed in a complete manner. Many existing studies are limited to individual phenological phases and do not address re-sowing and land-use sustainability in an integrated way.

Relevance of the study

The relevance of the topic is substantiated by three key aspects:

food security;

implementation of digital technologies in the agro-industrial sector;

the need for objective monitoring of agricultural lands in southern Kazakhstan under climate risks.

The relevance is determined by the need for a reproducible satellite-based methodology for monitoring winter cereals under rainfed conditions in southern Kazakhstan. The methodology supports comparable delineation of cropped areas by years and agroclimatic zones (HTC-based zoning), assessment of crop condition (including weed infestation), determination of harvest dates from Sentinel-2 time series, and mandatory verification using ground observations. At the national level, increasing the efficiency of satellite monitoring of agricultural lands using artificial intelligence and conducting deeper analyses of land quality, productivity, crop condition, and spatial distribution have been identified as priorities.

Accordingly, developing a scientifically grounded system for satellite monitoring of winter cereal crops based on modern geoinformation technologies constitutes a relevant scientific and applied task.

Aim and objectives

The aim of the dissertation is to develop and scientifically substantiate satellite monitoring methods for winter cereal crops in southern Kazakhstan using Sentinel-2 multispectral data and GIS, with subsequent spatio-temporal assessment of cropping structure, vegetation development dynamics, re-sowing features, and land-use sustainability.

To achieve this aim, the following objectives were formulated and addressed:

- develop a method for identifying the actually sown areas of winter cereals using autumn satellite data;
- analyze the spatio-temporal dynamics of vegetation development using spectral indices;
- develop and test automated crop classification methods for rainfed farming conditions;
- detect re-sowing of winter cereals and analyze its spatial distribution;
- integrate the results into a GIS environment for comprehensive monitoring.

Object, subject, and spatial scope

The object of the study is winter cereal crops cultivated in the southern regions of the Republic of Kazakhstan.

The subject of the study comprises satellite monitoring methods based on Sentinel-2 data, spectral indices, and GIS, aimed at assessing the condition and development dynamics of winter cereals.

The study area mainly covers plain and foothill agricultural landscapes of Turkestan Region characterized by diverse agroclimatic conditions and land-use structure.

Input data and research methods

The primary data source was Sentinel-2 Level-2A multispectral imagery. The spatial resolution is 10 m, and the revisit interval is 2–5 days. The analysis spans multiple growing seasons to account for interannual variability of natural conditions.

The study employed the following methods:

- computation and analysis of NDVI and GRVI spectral indices;
- analysis of satellite time series;
- automated classification methods for agricultural crops;
- GIS-based spatial analysis and cartographic mapping;
- expert assessment of results and verification using ground observations.

All processing and analyses were performed in GIS, and a unified spatial database was created.

Main scientific results

The dissertation produced a set of results covering major aspects of satellite monitoring of winter cereal crops.

A method for identifying actually sown winter cereal areas using autumn Sentinel-2 data was developed. The approach enables construction of a crop mask immediately after sowing completion and its subsequent spring verification based on NDVI dynamics, thereby establishing the spatial basis for monitoring.

Using NDVI time series, spatio-temporal patterns of vegetation development of winter cereals were analyzed. During spring growth phases, NDVI values characterize biomass accumulation rates and spatial heterogeneity of agrocenoses.

The use of GRVI during maturation under decreasing NDVI was substantiated. GRVI highlights areas with preserved green vegetation cover and refines the interpretation of satellite observations.

An automated crop classification methodology for rainfed farming conditions based on Sentinel-2 data was developed and tested. The results demonstrate the applicability of automated approaches for regional monitoring of cropping structure.

Based on multi-year satellite data, re-sowing zones of winter cereals were identified and their spatial patterns were examined. Re-sowing was considered an indicator of land-use sustainability.

All results were integrated into a unified GIS covering the key stages of winter cereal cultivation.

Scientific novelty

The scientific novelty of the dissertation is defined by the following:

- For the first time for southern Kazakhstan, the Plowed Land Index (PLI) was determined and experimentally validated. The index supports high-accuracy identification of actually sown winter crops and was incorporated into the algorithm for constructing the autumn crop mask with subsequent spring checking.
- A differentiated approach to spectral assessment of winter crop condition by agroclimatic zones was scientifically substantiated. The assessment accounts for weed infestation, moisture-heat conditions, and re-sowing features. The influence of agroclimatic differences on the temporal behavior of NDVI was identified, and the detection of highly weed-infested plots using GRVI was demonstrated.
- A comprehensive satellite monitoring system for winter crops was developed, integrating Sentinel-2 data, agrometeorological indicators, and field survey information within a single GIS environment and covering remote observation from sowing to harvest.

Statements submitted for defense

1. The approach based on multi-temporal Sentinel-2 data, application of PLI, and spring validation using NDVI dynamics provides accurate crop-mask delineation. The method reliably identifies actually sown areas and forms the spatial basis of the satellite monitoring system.

2. Satellite assessment of winter crop condition during the growing season is based on analysis of NDVI temporal dynamics with agroclimatic zoning by HTC. Climatic conditions and cultivation features (including re-sowing) influence

the spectral development curves. The approach is used to assess crop condition, detect deviations in biomass accumulation rates, and identify highly weed-infested zones using GRVI.

3. Satellite monitoring covers the full production cycle of winter crops—from sowing to harvest. The harvest period is determined after the vegetation peak (after maximum NDVI) by a sharp and synchronous decrease of vegetation indices within a field. Under natural maturation, the index declines gradually; during harvest, a rapid drop occurs over a short interval. This criterion is used to determine harvest dates and their spatial dynamics in a unified GIS.

Practical significance and application areas

The practical significance of the results is associated with the applicability of the developed satellite monitoring methods to spatial analysis and assessment tasks for agricultural lands. The approaches rely on openly available Sentinel-2 data and do not require costly specialized sources, which supports reproducibility and scaling.

The method for identifying actually sown winter crop areas can be used by regional agro-industrial management bodies to analyze cropping structure, assess land-use changes, and compare results with official statistics. Spatially detailed maps refine the distribution of winter crops at the levels of administrative districts and agricultural blocks.

NDVI- and GRVI-based vegetation analysis methods can be used to monitor crop condition across phenological phases, identify zones of slowed development, and quantify spatial heterogeneity of agrocenoses. These methods provide a basis for agroclimatic risk analysis without direct transition to yield estimation.

Automated classification results can be applied when building and updating geoinformation land-use databases and when conducting scientific and analytical work on satellite monitoring of agricultural areas.

The study materials can be used in education and training of specialists in “Geoinformatics”, “Cartography”, and “Remote Sensing”, as well as in master’s and doctoral research.

Approbation of results

Key results of the dissertation were validated through scientific publications, research seminars, and international scientific cooperation. The methodological principles and results were tested in research projects focused on satellite monitoring of agricultural territories.

The results were published in international peer-reviewed journals indexed in Web of Science Core Collection and Scopus.

1. Arystanov, A., Karabkina, N., Sagin, J., Nurguzhin, M., King, R., & Bekseitova, R. (2024). Use of Indices Applied to Remote Sensing for Establishing Winter–Spring Cropping Areas in the Republic of Kazakhstan. *Sustainability*, 16(17), 7548. <https://doi.org/10.3390/su16177548>.

2. Arystanov, A., Sagin, J., Karabkina, N., Arystanova, R., Yermekov, F., Kabzhanova, G., Bekseitova, R., Aktymbayeva, A., & Kutymova, N. (2025). Automatic Classification of Agricultural Crops Using Sentinel-2 Data in the

Rainfed Zone of Southern Kazakhstan. *Agronomy*, 15(9), 2040.
<https://doi.org/10.3390/agronomy15092040>.

3. Arystanov, A., Sagin, J., Kabzhanova, G., Sarsekova, D., Bekseitova, R., Molzhigitova, D., Balkozha, M., Yeleuova, E., & Satvaldiyev, B. (2026). Winter Cereal Re-Sowing and Land-Use Sustainability in the Foothill Zones of Southern Kazakhstan Based on Sentinel-2 Data. *Sustainability*, 18(2), 1053.
<https://doi.org/10.3390/su18021053>.

The publications underwent independent peer review, confirming the correctness of the applied methods and the soundness of the conclusions.

Selected results were discussed at research seminars of the Department of Cartography and Geoinformatics and received positive assessments from specialists in geoinformatics and remote sensing. The discussions refined methodological aspects of spatio-temporal analysis.

Therefore, the approbation of results was conducted through both international publications and discussions within the professional scientific community.