https://doi.org/10.51885/3134-8009_JES_2026_1_6
SRSTI 89.57.45

APPLICATION OF EARTH REMOTE SENSING DATA FOR PREDICTING AGRICULTURAL CROP YIELDS

АУЫЛ ШАРУАШЫЛЫҒЫ ДАҚЫЛДАРЫНЫҢ ӨНІМДІЛІГІН БОЛЖАУ ҮШІН ЖЕРДІ ҚАШЫҚТЫҚТАН ЗОНДТАУ ДЕРЕКТЕРІН ҚОЛДАНУ

ПРИМЕНЕНИЕ ДАННЫХ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ ЗЕМЛИ ДЛЯ ПРОГНОЗИРОВАНИЯ УРОЖАЙНОСТИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ КУЛЬТУР

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Keywords:
Earth remote sensing data, crop yield, Normalized Difference Vegetation Index (NDVI), satellite images, satellite image interpretation.

ABSTRACT
Agriculture in the Republic of Kazakhstan plays a strategic role in ensuring the country's food security and exports. This paper shows the effectiveness of remote sensing methods for assessing the productivity of grain crops. In this article, Sentinel-2 space images for the period from 2019 to 2023 are used. Normalized difference vegetation index (NDVI) was used to forecast crop productivity. Space images interpretation and calculation of the NDVI were carried out using ArcGIS software. The article reveals that NDVI values reflect well the biological productivity of agricultural crops during the growing season and show correlation with biomass and yield. The work indicates that the analysis of crop yields will be more accurate if along with NDVI index such indicators of climatic conditions as air temperature and precipitation are used. Forecasting yields is of great practical importance.

Түйінді сөздер:
Жерді қашықтықтан зондтау деректері, өнімділік, нормаланған айырымдық вегетациялық индекс (NDVI), ғарыштық суреттер, ғарыштық суреттерді дешифрлеу.

ТҮЙІНДЕМЕ
Қазақстан Республикасындағы ауыл шаруашылығы елдің азық-түлік қауіпсіздігін және экспортты қамтамасыз етуде стратегиялық рөл атқарады. Бұл жұмыста дәнді дақылдардың өнімділігін бағалау үшін Жерді қашықтықтан зондтау әдістерінің тиімділігін көрсетіледі. Бұл мақалада 2019–2023 жылдар аралығындағы Sentinel-2 ғарыштық суреттері пайдаланылды. Өсімдіктердің нормаланған айырымдық вегетациялық индексі (NDVI) дақылдардың өнімділігін болжау үшін пайдаланылды. Ғарыштық суреттерді дешифрлеу мен NDVI индексін есептеу ArcGIS бағдарламалық жасақтамасы арқылы жүзеге асырылды. Зерттеу нәтижелері NDVI көрсеткіштері вегетациялық кезеңдегі дақылдардың биологиялық өнімділігін дәл бейнелейтінін, сондай-ақ бұл көрсеткіштердің биомасса мен өнім көлемімен өзара тығыз байланысты екенін көрсетті. Сонымен қатар, өнімділікке талдау жасау барысында NDVI көрсеткішімен қатар

ауа температурасы, жауын-шашын мөлшері сияқты климаттық параметрлерді де ескерген жағдайда, болжаудың дәлдігі артатыны атап өтілді. Өнімділікті болжаудың практикалық маңызы зор.

Ключевые слова:
данные дистанционного зондирования Земли, урожайность, нормализованный разностный вегетационный индекс, космические снимки, дешифрирование космических снимков.

АННОТАЦИЯ
Сельское хозяйство в Республике Казахстан играет стратегическую роль в обеспечении продовольственной безопасности страны и экспорта. В данной работе показана эффективность методов дистанционного зондирования Земли для оценки продуктивности зерновых культур. В статье использованы космические снимки Sentinel-2 за период с 2019 по 2023 годы. Для прогнозирования продуктивности сельскохозяйственных культур был использован нормализованный разностный вегетационный индекс (NDVI). Дешифрирование космических снимков и расчет нормализованного разностного вегетационного индекса проводили с использованием программного продукта ArcGIS. В статье показано, что значения NDVI хорошо отражают биологическую продуктивность сельскохозяйственных культур в течение вегетационного периода, показывают корреляцию с биомассой и урожайностью. В работе указано, что анализ урожайности сельскохозяйственных культур будет более точнее, если наряду индекса NDVI использовать такие показатели климатических условий, как температура воздуха, количество осадков. Прогнозирование урожайности имеет большое практическое значение.

INTRODUCTION

Currently, the Republic of Kazakhstan is one of the largest producers of grain crops and this is a strategically important task. Due to changes in climatic conditions in the vast areas of agro-industrial complex of the Northern district of Kazakhstan in recent decades there are often sharp temperature fluctuations, uneven distribution of precipitation, which significantly affects the productivity of agricultural fields. Also grain crops are subject to diseases and various pests. Agricultural land is subject to erosion and degradation. In view of these problems, space monitoring and remote sensing methods are an important tool for agro-industrial complex. The use of Earth remote sensing (ERS) methods is relevant in the conditions of a vast territory of agricultural land, changing climate, and water resources deficit. Remote sensing methods allow to manage agricultural production more effectively, increase crop yields and reduce negative environmental impacts. And this is important in the conditions of land degradation, water scarcity, etc.

The aim of the research in this paper is to show the effectiveness of remote monitoring of productivity of grain crops on the example of the Northern district of Kazakhstan using satellite data and image processing methods.

LITERATURE REVIEW

Currently, unmanned aerial vehicles (UAVs) are increasingly being used to monitor agricultural land (GP Shetty et al., 2024a; Ridha Guebsi et al., 2024b). UAVs are becoming an important tool for transforming precision agriculture. UAVs used in agriculture can be categorized into the following classes based on the type of design: fixed wing drones; multi-rotor drones; hybrid drones; and folding wing drones (Ridha Guebsi et al., 2024). Each class of drones fulfils certain functions inherent to that design. For example, fixed wing drones are similar to aeroplanes and are designed in such a way that they can systematically observe large areas. Can operate at high altitudes and provide high-resolution images of the area being surveyed. They can be used for large-scale mapping (Matese, A., et al., 2015). Multirotor drones have increased maneuverability and hovering capabilities. They can take off and land vertically, which means they can be used in difficult terrain. Hybrid drones provide vertical take-off and landing are used for wide areas. Folding wing drones are mobile, used for small agricultural operations. Depending on the type of cameras mounted on the drones, they have different functional purposes. RGB cameras are widely used for visual inspection of crops, e.g. to assess the density of potato plantations (Abdou, B. et al., 2022). Thermal imaging cameras are used to detect water scarcity.

However, despite their advantages, UAVs have certain disadvantages that limit their application: insufficient autonomy of flight; sensitivity to wind; limited maneuverability and others. Regulatory, technological and economic problems are also significant obstacles to the use of UAVs.

Space-based monitoring using remote sensing data has several advantages over UAVs. Kazakhstan has vast agricultural lands, remote sensing can cover vast areas in a single pass (Natalya N. Karabkina et al., 2018), whereas UAV imagery requires multiple flights. Monitoring satellites update images regularly and are publicly accessible to all. Remote sensing allows surveillance of designated and inaccessible areas, extensive analyses of area change over a long period of time, identification of landforms, vegetation, soil moisture, etc. (Liu T et al., 2025).

Therefore, this paper will focus on the use of remote sensing to assess the productivity of cereal crops.

MATERIALS AND METHODS

To conduct crop yield forecasting in the example of Northern Kazakhstan, the climatic characteristics of the study region were considered. Satellite images of the target area from Sentinel-2 for the period from 2019 to 2023 were also used. These satellite images were obtained from the publicly available Copernicus Browser website: [https://browser.dataspace.copernicus.eu/?zoom=5&lat=50.16282&lng=20.78613&demSource3D=%22MAPZEN%22&cloudCoverage=30&dateMode=SINGLE].

Normalized difference vegetation index (NDVI) was used to predict crop productivity. The indices used in this study were calculated using the following formulas:

$$NDVI = \left(\frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}\right)$$

where, ρ_{NIR} – pixel values from the near infrared channel;

ρ_{RED} – pixel values from the red channel.

Space images interpretation and calculation of normalized difference vegetation index were carried out using ArcGIS software. Cartographic materials of the territory of Northern Kazakhstan from freely available websites (https://map.ikostanay.kz/; https://map.gov4c.kz/egkn/; https://data.nextgis.com/en/region/KZ-39/base/) were also used in the work. Calculation of normalized difference vegetation index was carried out for Denisovsky region of Kostanay district of Northern Kazakhstan.

The averaged mean annual (January - December) temperature anomalies for the periods under research were taken as deviations from the mean multiyear values for 1961 - 1990 for Kostanay region (RGP «Kazgidromet», 2019-2023).

Annual amounts of precipitation during the study period in northern Kazakhstan were taken from Kazhydromet data, considering the deviation of precipitation anomalies from long-term averages for 1961-1990 (RGP «Kazgidromet», 2019-2023).

The average yield of grain crops in Denisovsky region of Kostanay district was determined according to the data of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (dynamic tables for the North Kazakhstan region, 2019–2023).

RESULTS AND DISCUSSION

The territory of Denisovsky region of Kostanay district of Northern Kazakhstan was chosen for the research in this work. The land massif of the territory is a set of plots, which are mostly rectangular or trapezoidal in shape.

The largest arrays of agricultural arable land are concentrated in Northern Kazakhstan. According to natural zones Northern Kazakhstan belongs to steppe and forest-steppe zones. The geographical location of the study area is shown in Figure 1.

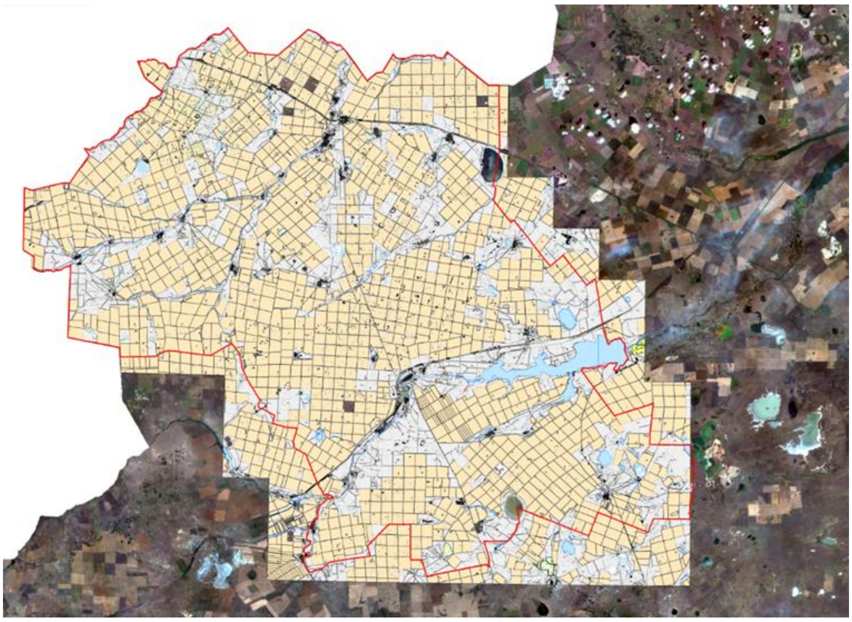


Figure 1. Researched territory – Denisovsky region

Note – compiled by the authors

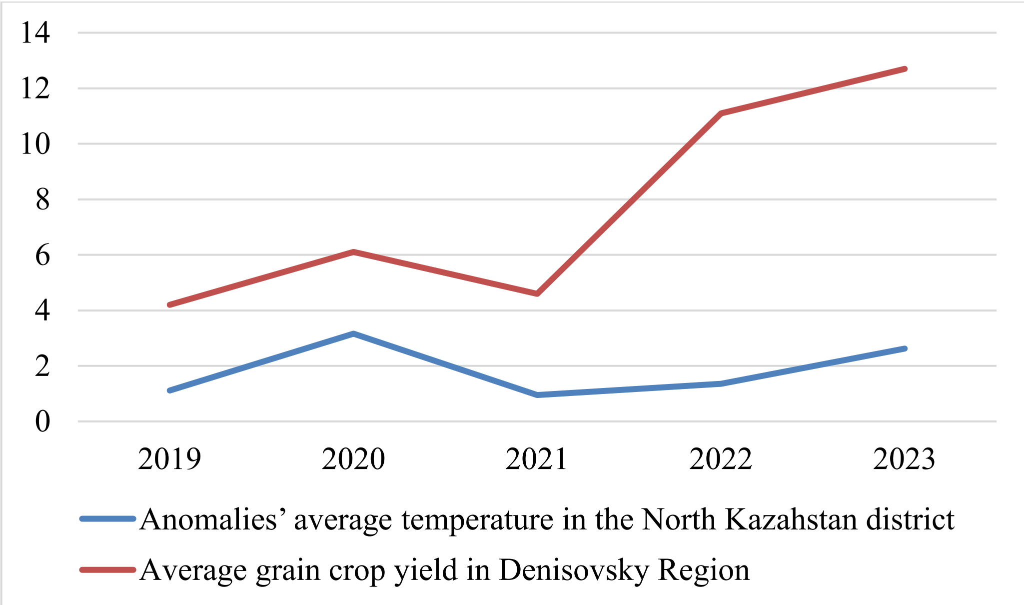
The researched territory is completely located in the subzone of moderately dry steppes on southern black soils of the steppe zone. Soil cover of the main part of the researched territory is southern normal black soils. In the valleys of the Tobyl and Kamysky Ayat rivers the soil cover is represented by southern carbonate black soils. In the western and south-eastern parts of Denisovsky District, complexes of southern solonetzified black soils with solonets are distinguished. Southern phosphoritic black soils are distributed in small areas of the southern part of the territory (S.S. Baisholanov, 2017).

The characteristics of soil cover, relief, and climatic conditions allow crop production to be defined as the main branch of agriculture in the researched territory. For the research territory in the work climatic indicators for Northern Kazakhstan and NDVI for the fields of Denisovsky region were analyzed.

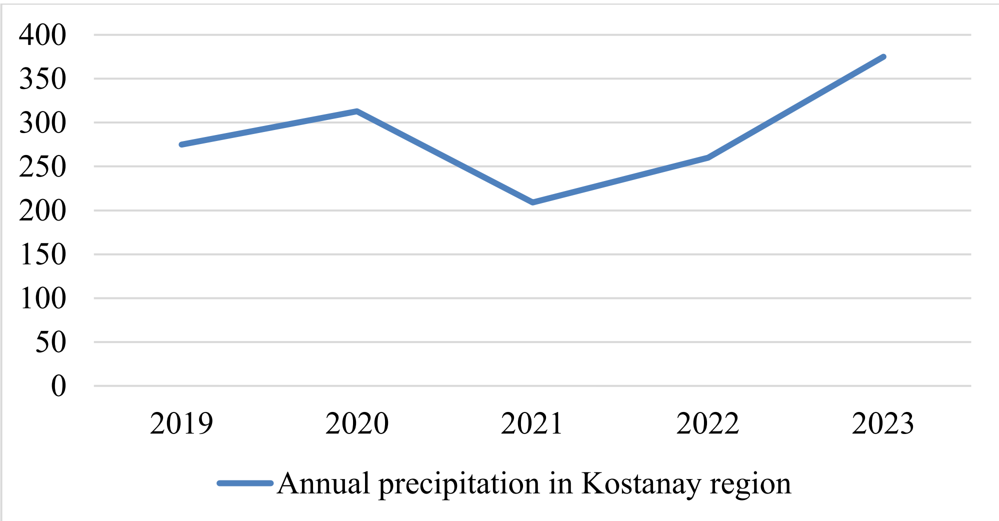
One of the most important climatic factors influencing the yield of grain crops is temperature. The influence of temperature due to increased evaporation of moisture from the surface and soil freezing is manifested at all stages of plant growth - from seed germination to grain ripening.

Along with temperature, moisture also has a significant impact on grain yields. Soil moisture controls the amount of water that seeps into the soil, recharges groundwater, and influences surface water drainage of moisture into the atmosphere. It affects the physiological processes of plants, determines the success of crop formation at each stage of crop development. Figure 2 shows the graphs of climatic indicators and grain crop yields in the researched territory for the period from 2019 to 2023.

As can be shown in Figure 2(a) - averaged mean annual (January - December) anomalies of temperature deviation from the mean multiyear values for 1961 - 1990 in the considered period of time have positive values. This positively affects the yield of grain crops. The least amount of precipitation in Kostanay district was observed in 2021 (Figure 2(b)). The year 2021 was due to acute drought. With lack of moisture, seeds of crops do not swell or give weak, non-viable sprouts. Lack of moisture with a positive trend in temperature anomaly, as can be shown in Figure 2(a), can lead to lower yields.



a)



b)

Figure 2. Climatic indicators and grain yields for the period 2019-2023:
a – average temperature (^{0}C), average grain yield (centners per hectare);
b – annual precipitation (mm)

Note – compiled by the authors

A recovery in yields was observed in 2022–2023 due to favourable weather conditions (Figure 2). The graph of annual precipitation in Kostanay region, where the researched territory is located, correlates with the yield. There is a deviation in 2019. Apparently, this is due to negative anomalies of average seasonal air temperature observed in the researched territory (RGP «Kazgidromet», 2019).

Nowadays, modern methods of remote sensing of the Earth's surface provide continuous and objective data for assessing vegetation conditions. Normalized relative vegetation index NDVI is one of the key indicators used in remote sensing of the Earth. NDVI shows the level of photosynthesis activity and, consequently, biomass in a certain area. This indicator is widely used in predicting crop yields. A high NDVI value of about 0.6 to 0.9 indicates healthy, dense vegetation with high photosynthetic activity. This corresponds to high yields. Low values of the order of 0.1 - 0.3 indicate drought, disease and low crop density. A low NDVI value is indicative of poor yield. NDVI allows tracking the vegetation stages of plants from germination to maturity. Figure 3 shows the relationship between normalized relative vegetation index NDVI and yield.

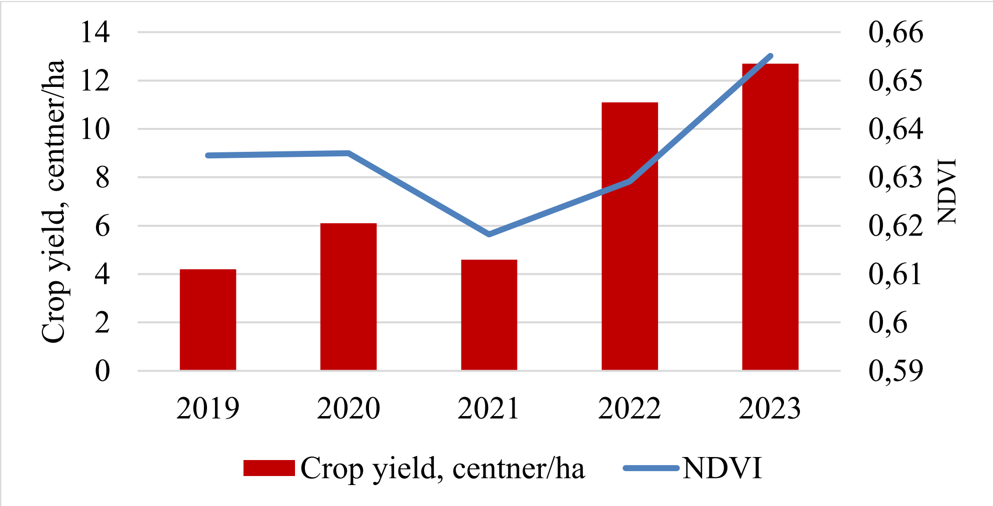


Figure 3. NDVI and yield in the researched territory for 2019-2023

Note – compiled by the authors

As can be seen from Figure 3, there is a certain relationship between the NDVI index of the researched territory and land use yields. Changes in the NDVI index indicator to a certain extent repeat the changes in crop yields for the research period.

CONCLUSION

Earth remote sensing methods can be effectively used in predicting vegetation yields. NDVI values reflect well the biological productivity of crops during the growing season. To some extent, NDVI can be used as a predictive tool to estimate future crop yields.

Analysis of crop yields will be more accurate if such indicators of climatic conditions as air temperature and precipitation are used along with NDVI index.

CONFLICT OF INTERESTS: The authors declare that there is no conflict of interest.

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