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# Features of Creating a System of Space Monitoring of Water-Supplied Territories for Irrigation in the South of Kazakhstan

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**ABSTRACT**

The location of a significant part of the agricultural territories of Kazakhstan in the risk agriculture zone implies the development and further application of an objective monitoring system for irrigated territories. The purpose of the study was to develop methods for on-the-spot and long-term recognition of irrigated massifs and verification of methods in the conditions of the territories of southern Kazakhstan. The paper describes the methods of on-the-spot recognition of irrigated fields, the general assessment of irrigated areas for the growing season, as well as the method of recognizing promising areas for irrigation. The on-the-spot recognition of the fields is based on the use of such spectral indices as the Global Vegetation Moisture Index, Green Normalized Difference Vegetation Index, Normalized Difference Vegetation Index, and the xanthophyll index, combined into a single system by the Decision Tree algorithm. The assessment of irrigated areas is based on differences in the physiological state of plants in conditions of normal water supply and plants experiencing a lack of moisture. The evaluation system includes the calculation of the temperature difference according to the corresponding satellite data and the calculation of the difference in vegetation indices for the same period. The difference in vegetation indices in irrigated fields has positive values due to a steady increase in green biomass, and the temperature difference, on the contrary, is negative or zero, since healthy plants, with normal water supply, actively evaporate moisture to maintain optimal temperatures of biochemical processes. To develop these methods, ground data from 2017–2021 were used. Verification of the methods with ground data demonstrated acceptable accuracy (87% in the on-the-spot assessment of irrigated fields; 60–90% in the general assessment of irrigated areas), while the methods have significant potential for further improvement.

**Keywords**: irrigation, spectral indices, decision tree, monitoring, evaluation.

## INTRODUCTION

Southern Kazakhstan is situated in the risk agriculture zone since the amount of moisture entering the soil with precipitation is insufficient for successful crop cultivation. According to the Köppen and Geiger climate classification [Kottek et al., 2006], the territory of Southern Kazakhstan occupied for irrigation agriculture is located in the BSk (Arid/Desert/Cold) and Dsa (Cold/Dry summer/Hot summer) zones. The shortage of water resources in combination with the current economic situation in Kazakhstan leads to a reduction in water consumption in the country. Currently, water intake for agriculture has been reduced to 15 km$^3$ (compared to 26 km$^3$ in 1992), and the area of regular irrigation has halved [President of the Republic of Kazakhstan, 2006]. In Kazakhstan, irrigation agriculture accounts for more than 70% of water intake. Irrigation agriculture is the most important branch of the economy, for which efficient and rational use of water resources is very important [Medeu et al., 2015]. In 2020, more than 1.5 million ha of irrigated lands were used in Kazakhstan, including about 1.2 million ha of regular irrigation lands in the southern regions (about

85% of all irrigation lands of the Republic of Kazakhstan (RK)): in South Kazakhstan (30.7%), Almaty (36.6%), Kyzylorda (11.6%), and Zhambyl (9.6%). Over the next 5 years, work will continue on the restoration of 600 thousand ha of irrigated land. Thus, the irrigated land area in the southern regions will be increased to 2.2 million ha. From 2025 to 2030, it is planned to put into circulation up to 800 thousand ha of new land. In total, Kazakhstan plans to gradually increase the area of irrigated land to 3 million ha. One of the most pressing problems, according to experts [Medeu et al., 2015], is the problem of introducing agroecological monitoring, which implies constant monitoring and control over the quantity and quality of land resources in irrigation conditions.

Currently, the southern regions of Kazakhstan have 17.1 billion $m^3$ of surface water in an average water supply year and 13.34 billion $m^3$ in a low-water year. Of these, 14.01 billion $m^3$ and 10.25 billion $m^3$ can be used for regular irrigation in medium- and low-water years, respectively. The water intake for regular irrigation of the southern region of Kazakhstan in recent years is presented in Table 1. Due to the decreasing volume of cross-border river runoff and the growth of water consumption by economic sectors, the volume of available runoff is constantly decreasing. Soon, according to the most optimistic forecasts, the volume of possible water consumption for irrigation will be less than 11.5 billion $m^3$ [Government of the Republic of Kazakhstan, 2016].

One of the important tools for the development of measures to ensure the rational and targeted use of agricultural land is the analysis and systematization of statistical data on the area, structure, and location of agricultural land. The implementation of periodic analysis and monitoring of irrigated areas and the structure of agricultural lands allows not only to determine the intensity of agricultural development of the territory but also to form conclusions on the nature of the involvement of natural complexes in agricultural production and trends in the transformation of natural resource potential. Remote sensing is a recognized tool for monitoring irrigated lands, the effectiveness of which is recognized for various natural and climatic conditions around the world [Bastiaanssen, 1998]. Not only satellite imagery is used as an information source, but also multispectral data obtained from unmanned aerial vehicles (UAV) [Huang et al., 2010; Stagakis et al., 2012]. Satellite and airborne photography can be used together within the same project [Johnson and Belitz, 2012]. The combined use of objective satellite information, climate data, information about the landscape features of a certain area and powerful analytical tools of modern geographical information system (GIS) applications can provide close to real-time monitoring of water availability for crops [Yousaf et al., 2021].

Monitoring involves not only following a process or phenomenon, but also assessing changes, forecasting possible development scenarios, and developing measures to prevent dangerous consequences or maintain favorable trends. Remote sensing data becomes a means of monitoring the development of phenomena and processes, contributing to the adoption of effective management decisions. However, without ground-based monitoring, the decryption of space data will not be reliable. Only joint ground-space monitoring provides a reliable and reliable basis for the development of a system for effective monitoring of the condition of irrigated lands in the south of Kazakhstan.

The monitoring system developed jointly by National Centre for Space Studies and Technology (NTsKIT) JSC and the Kazakh Institute for Land and Water Management Research (KazNIIVKh) LLP is based on the integrated use of ground and satellite data during the growing season. As part of the monitoring system, two scenarios have been implemented: on-the-spot recognition of irrigated lands using satellite data and assessment of the irrigated area for the growing season. The

**Table 1.** Water intake for regular irrigation in the administrative regions of the south of the RK, million $m^3$

| Administrative areas | Years | | | | | |
|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Almaty | 3,296.6 | 3,006.6 | 3,100.0 | 3,315.0 | 3,167.2 | 3,251.0 |
| Zhambyl | 1,845.5 | 1,293.4 | 2,222.9 | 1,523.5 | 1,534.7 | 1,578.4 |
| Kyzylorda | 3,774.7 | 3,531.8 | 3,943.2 | 3,805.3 | 4,045.6 | 4,071.1 |
| Turkestan | 3,665.3 | 3,552.0 | 3,506.9 | 3,660.6 | 3,518.5 | 3,396.6 |
| TOTAL | 12,582.1 | 11,383.8 | 12,773.0 | 12,304.4 | 12,266.0 | 12,297.1 |

on-the-spot assessment is based on the use of several spectral indices describing the physiological state of vegetation. The indices used are processed by the Decision Tree algorithm. The assessment of the total area of irrigated massifs consists of a sequential series of on-the-spot data, which is refined by calculating the difference in vegetation indices and temperature channels over a relatively long period within the growing season of one year. In addition to the methodology for assessing irrigated areas, a methodology is being developed to identify promising areas for the introduction of irrigation agriculture based on the topographical wetness index (TWI).

## MATERIALS AND METHODS

Tools used during fieldwork:

1) Global positioning system (GPS) navigator, for accurate determination of geographical coordinates of the described points and boundaries of the study polygons;
2) UAV for aerial photo and video shooting of the studied territories, as well as a geodetic survey of the studied area;
3) A ST™ PRO PLUS non-contact thermometer for determining the temperature of the air, soil, and plants;
4) A camera for taking photographs in the nadir above the crop (for calculating the projective cover of the soil with vegetation) and in the perspective;
5) A tape measure (ruler) for determining the height and density of plants.

Specialized software (L3HARRIS GEOSPATIAL ENVI 5.2) was used to process satellite data, and statistical processing of ground and satellite data was carried out using STATSOFT STATISTICA 12 software, while cartographic representations of the results of the study were performed in ESRI ArcGIS 10.5 software. Satellite data from Landsat-8 OLI and Sentinel-2 were used to perform the calculations.

### Study area in 2021

The test areas were located in two administrative regions of the southern region of the RK, namely, the Almaty and Zhambyl regions (Figure 1). Detailed ground studies were conducted on the territory of the test areas in 2021. Test area in the Zhambyl region (Figure 1a). The test area

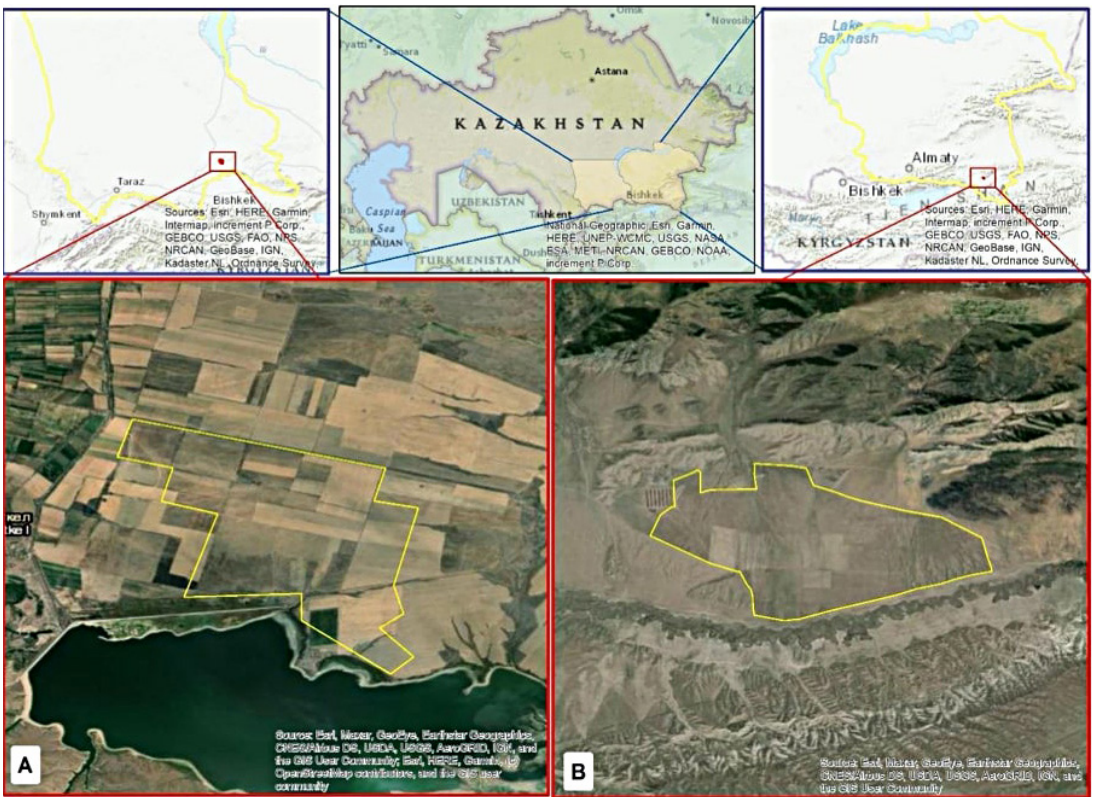


**Figure 1.** Test polygons of 2021, (a) test area in the Zhambyl region, (b) test area in the Almaty region

was located in the vicinity of Belbasar, 30 km southeast of Shu and 305 km northeast of Taraz. The main source of water in the region is the Shu River, which flows through the territories of Kyrgyzstan and Kazakhstan. The length of the river is 1,186 km, including 800 km within Kazakhstan. The catchment area is 67.500 km² [Medeu, 2010]. The main tributaries are Chon-Kemin, Yrgayty, Kakpatas, Alamedin, Aksu, and Kuragaty. Almaty region (Figure 1b). The test area is located in the Rayymbek district, in the valley of the Kegen river, 65 km from the district center (Nyrynkol). The test area was located at an altitude of 1,800-1,850 m above sea level. The main source of water supply is the Kegen river. The length of the river is 427 km, and the catchment area is 7,720 km². The river is mainly snow and glacier-fed. Floods and high water in the river continue from April to June. The river is used for irrigation purposes and timber rafting, and also for hydropower [Medeu, 2010].

## Satellite monitoring methods

### *On-the-spot irrigated land recognition methods*

The technique of on-the-spot recognition of irrigated fields using the Decision Tree algorithm was developed based on the processing of ground and satellite data in 2017, 2019, and 2021.

A set of 2019 field data was used to select indices and their threshold values when developing an algorithm for classifying irrigated fields. In the course of fieldwork in 2019, irrigated and rainfed fields, as well as the main classes of vegetation cover were recorded using GPS (Figure 2). For a sequential series of Sentinel-2 images, several spectral indices describing the state of soil and vegetation cover were calculated. The indices were calculated for 13 Sentinel-2 scenes obtained between May 5 and October 22, 2019. The behavior of each index for individual classes of vegetation cover during the entire growing season was studied, according to the results of which four indices for the Decision Tree algorithm were selected (Table 2), and their threshold values were established.

The Xanthophyll Index [Peñuelas et al., 1994] is designed to identify the pigments responsible for the yellow and red color of withering leaves. The appearance of xanthophylls in the fields before the ripening of cultivated crops is a sign of distress in vegetation cover. The study of the dynamics of the index indicators during the growing season (Figure 3) demonstrated a clear pattern

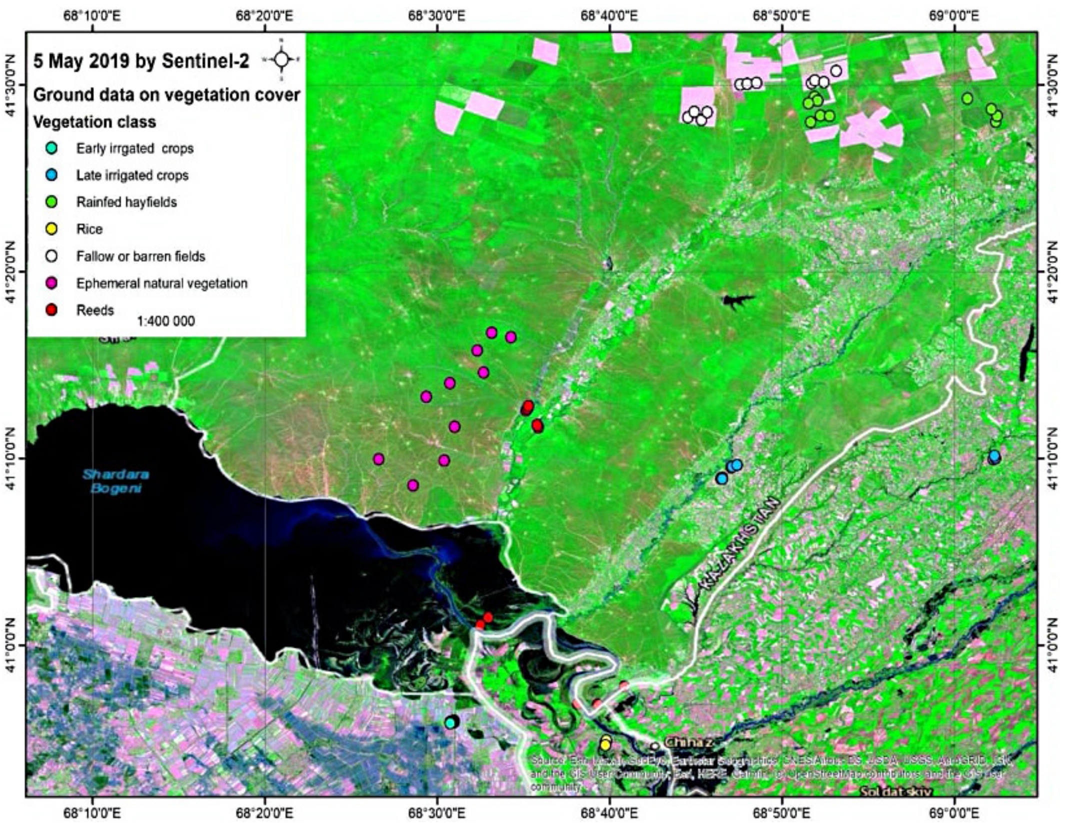


**Figure 2.** Ground data on vegetation classification, 2019

**Table 2.** Indices and their threshold values for use in the decision tree

| Index | Equation | Threshold | Reference |
|---|---|---|---|
| Xanthophyll Index | $XI = (RED - NIR)/(RED + NIR)$ | -0.3 | J. Peñuelas et al. [1994] |
| Global Vegetation Moisture Index (GVMI) | $GVMI = \frac{(NIR + 0.1) - (SWIR + 0.02)}{(NIR + 0.1) + (SWIR + 0.02)}$ | 0.2 | P. Ceccato et al. [2002] |
| Chlorophyll Activity or Green Normalized Difference Vegetation Index (GrNDVI) | $GNDVI = (NIR - GREEN)/(NIR + GREEN)$ | 0.3 | A. Gitelson and M. Merzlyak [1998] |
| Normalized Difference Vegetation Index (NDVI) | $NDVI = (NIR - RED)/(NIR + RED)$ | 0.4 | J.W. Rouse et al. [1974] |

showing that the index readings remained below the 0.3 value for healthy vegetation until maturation or harvesting. This circumstance was the basis for choosing the xanthophyll concentration index as one of the decisive rules for the Decision Tree classification with a threshold value of 0.3.

### *Global vegetation moisture index (GVMI) [Ceccato et al., 2002]*

The index is designed to assess the moisture concentration in vegetation. The diagram of the distribution of the index values during the growing season (Figure 4) shows that the index is very sensitive to the presence of vegetation cover. Only on exposed soils, the index values are negative, while on desert sands, even after the ephemera withers, a small positive range of values remains, corresponding to the presence of rare desert vegetation in summer. The values for the classes of irrigated fields are consistently high until the end of the growing season (harvesting). The GVMI value of 0.2 is accepted as a threshold for irrigated fields in the summer. The threshold value can be refined based on the results of additional field observations.

### *Chlorophyll activity or GrNDVI [Gitelson and Merzlyak, 1998]*

This index, in terms of physical meaning and features of seasonal dynamics, is close to NDVI. When considering the distribution of index values in the main classes during the growing season (Figure 5), it is noteworthy that the index values are consistently higher than 0.3 for irrigated fields and near-water vegetation throughout the summer. This value is taken as a threshold when constructing a classification tree. NDVI is the standard, most widely known vegetation index describing the concentration of chlorophyll in the vegetation cover [Rouse et al., 1974]. In this paper, the index is used at the final stage of classification as a rule separating healthy and distressed vegetation. The threshold value is assumed to be NDVI = 0.4. This threshold value can be changed, most likely upward, based on the results of field observations within the framework of the current project. The Decision Tree classification is based on four indices: NDVI, XI, Chlorophyll Activity, and GVMI (Figure 6). In the course of classification, each

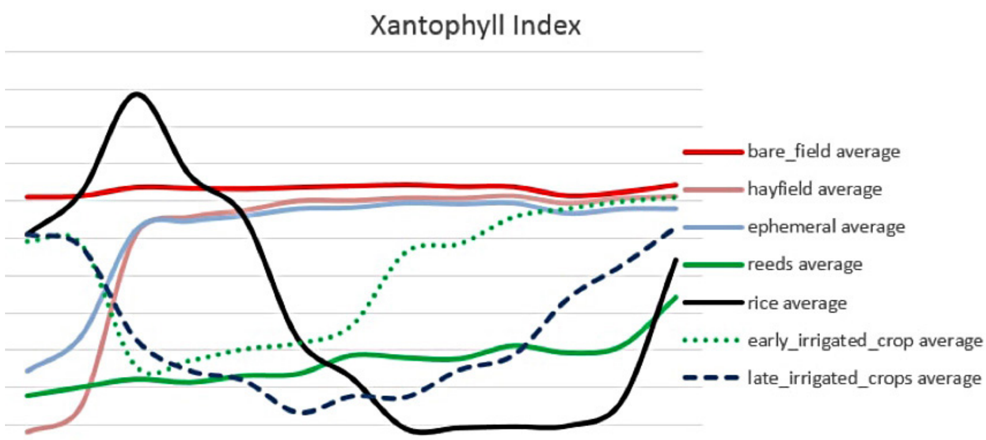


**Figure 3.** Dynamics of the distribution of XI index values among the main classes of soil and vegetation cover during the growing season

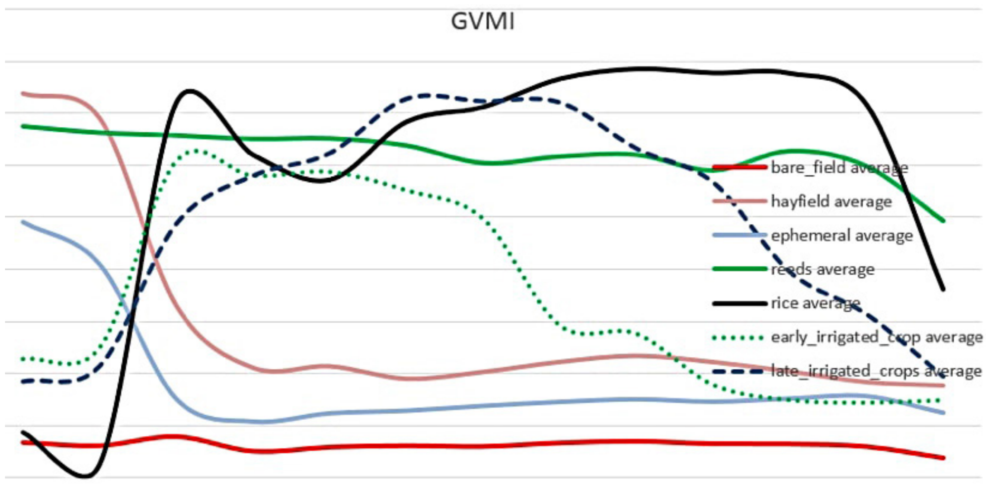


**Figure 4.** Dynamics of distribution of GVMI values among the main classes of soil and vegetation cover during the growing season

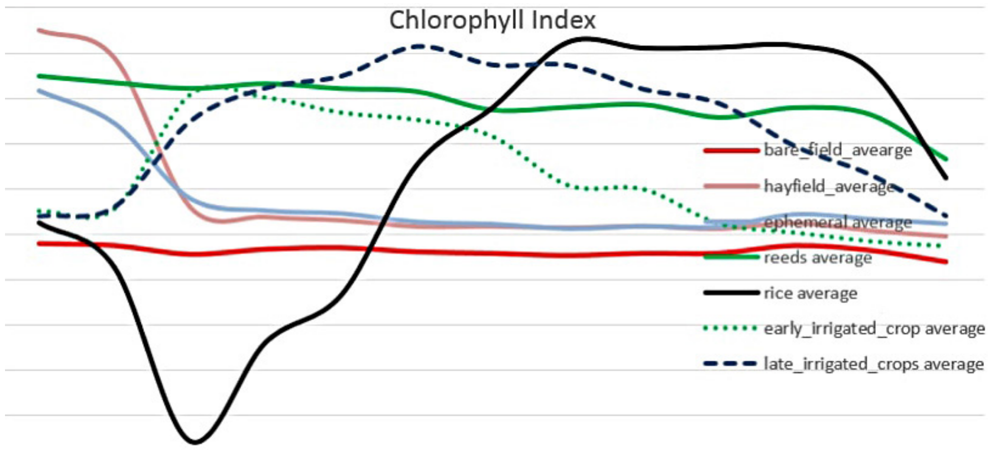


**Figure 5.** Dynamics of the distribution of chlorophyll index values among the main classes of soil and vegetation cover during the growing season

decisive rule gives two possible answers: "yes" or "no". In general, when the answer is "no", no further actions need to be taken, and the next rule applies to objects that have passed a positive check.

## Methods for the estimation of the total irrigated land area

The methods for the estimation of the total irrigated area by the difference of vegetation indices or temperature channels of satellite imagery have been described in detail above [Tsychueva and Malakhov, 2016]. The methodology is based on long-term field observations made by the NTsKIT JSC, confirming that in regularly irrigated fields, the difference in vegetation indices obtained by subtracting an early image from a later one will be positive due to an increase in green biomass, while vegetation in rainfed fields will not have a significant increase in biomass. In most cases, the index difference has a negative value due to the wilting of vegetation. The difference in temperature channels, also obtained by subtracting the early scene from the later one, has unchanged or negative values in irrigated fields since healthy vegetation that does not experience a deficiency actively evaporates moisture to maintain the optimal temperature of biochemical reactions [Medvedev, 2004]. In the absence of moisture or a significant shortage of it, vegetation withers, while the area of the evaporating surface of the living leaf is reduced, and the temperature of plants increases, up to the same temperature of the soil and dry vegetation in July and August.The calculated data on the temperature of the underlying surface and the data of vegetation indices make it possible

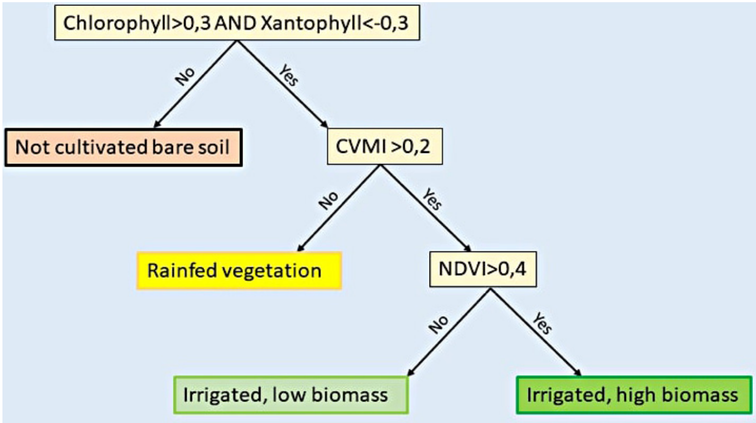


**Figure 6.** The decision tree diagram for identifying irrigated and rainfed fields

to identify territories with irrigation and rainfed farming systems. The processing of satellite information implies the calculation of the index difference according to the following scheme:

$$LST_{dif} = LST_1 - LST_2 \quad (1)$$

where: $LST_{dif}$ – the difference in ground temperatures, $LST_1$ – the temperature values calculated from the late image, $LST_2$ – the temperature values calculated from the early image:

$$V_{dif} = V_1 - V_2 \quad (2)$$

where: $VI_{dif}$ – the difference in the values of the vegetation index, $VI_1$ – the values of the vegetation index calculated from the late image, $VI_2$ is the values of the vegetation index calculated from the early image.

At the same time, negative and zero values of $LST_{dif}$ indicate active transpiration, i.e. the presence of sufficient moisture in the soil. Positive values of $LST_{dif}$ are characteristic, in particular, of natural, i.e. non-irrigated vegetation. Positive values of $VI_{dif}$ indicate the accumulation of moisture in green vegetation, and an increase in biomass over the observed period, i.e. regular irrigation. Negative or close to zero values of $VI_{dif}$ indicate a lack of moisture in the soil, slow accumulation of fluid in plant tissues, and lack of biomass growth, i.e. lack of irrigation in the period between the dates of the survey.

### Methodology for identifying promising areas for irrigation

TWI was used to identify promising areas for irrigation [Sørensen et al., 2006]. The index is a function of both the slope of the surface and the area contributing upstream per unit width orthogonal to the flow direction [Moore et al., 1993]. TWI is a constant index of soil moisture, not directly related to the amount of precipitation. TWI obtained based on a digital terrain model, is often used as an indirect indicator of soil moisture. The index is dimensionless [Beven and Kirkby, 1979]. In this study, the territories potentially suitable for the introduction of irrigation agriculture are the ones located within the optimal, i.e. "wet" TWI sites, where incoming moisture accumulates, regardless of its sources (rain, flood, artificial sources). In addition, prospective territories should not be located at a significant distance from existing massifs, which guarantees the presence of similar or identical soil types. For the final decision on the introduction of promising sites into the system of irrigation agriculture, a detailed ground survey should be carried out. The presence of moisture sources (channels, rivers, boreholes, wells) inside or near promising sites is a very important circumstance for making a final decision.

## RESULTS

### On-the-spot recognition of irrigated lands

The Decision Tree algorithm applied to individual satellite imagery scenes recognizes irrigated fields or their areas with high reliability. Using the example of the Kyzylsha Zher pilot area (Zhambyl region), where ground observations were carried out in 2021, Sentinel 2 data showed not only irrigated fields but also the dynamics of irrigation of individual fields during the growing season (Figure 7). Verification of the algorithm for recognizing irrigated fields was carried out using

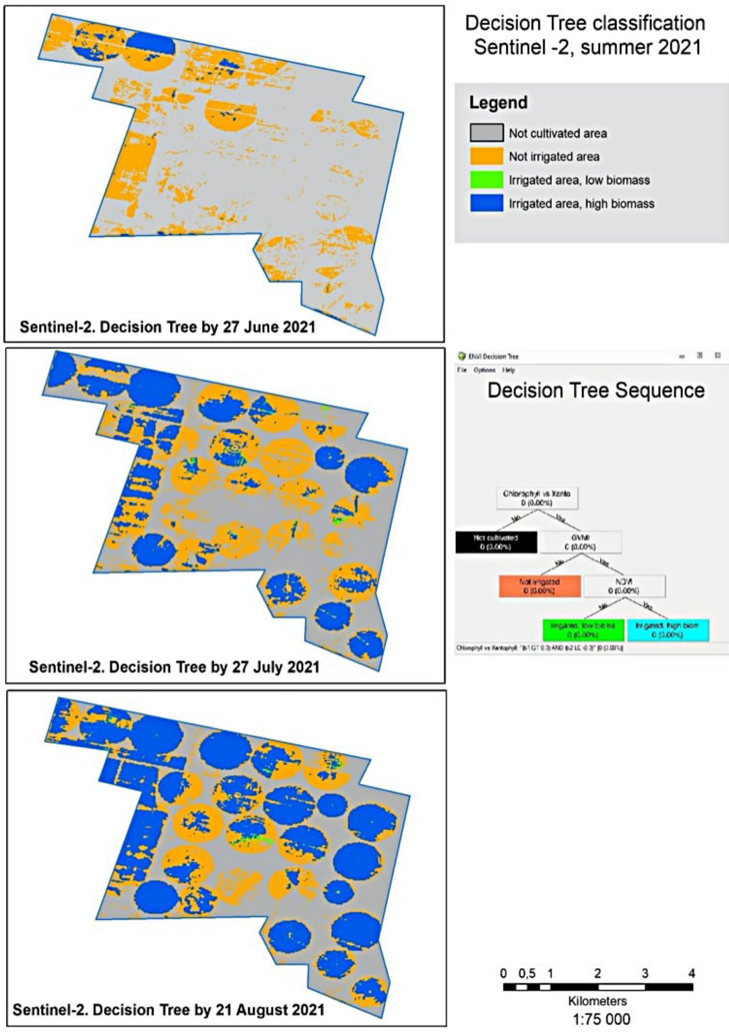


**Figure 7.** Dynamics of irrigation in the fields of the Kyzylsha Zher farm in the summer of 2021

ground and satellite data from 2017 (Figure 8). In 2017, fieldwork was carried out in Turkestan and Zhambyl regions, during which more than a thousand individual fields were marked and classified as “irrigated fields/rainfed fields/deposits/bare soil”. Landsat 8 data were used for calculation and verification. Within the Landsat 8 scene used to calculate and verify the Decision Tree algorithm, 147 fields of various types (irrigated, rainfed and fallow) were noted. Table 3 contains data for evaluating recognition accuracy within a single Landsat-8 scene. The accuracy of recognition of irrigated fields was 86%. For rainfed fields, the accuracy was lower (65%) due mainly to mixing this class with the class of fallow fields.

## Total irrigated land area

The correlations between short-term (16 days) and long-term (25 or more days) differences in spectral indices and the condition of fields in the irrigated zone indicate the promising character of using the selected methods of inventory of irrigated territories [Tsychueva and Malakhov, 2016].

The Pearson correlation coefficient was calculated from two pairs of images, where the first pair of images was dated June 16 and July 1, and the second pair of images was dated June 16 and July 10, 2017. The results are presented in Table 4 (significant correlations are highlighted in italics).

The differences in vegetation indices have the best correlation with the “irrigated fields” class. The correlation of the temperature difference with the presence of irrigation is weaker than the correlation of the differences in vegetation indices and has a reversed character. This fact can be explained if we take into account the amount of green biomass in irrigated fields and the large total area of the leaf surface, often completely covering the soil. A very important circumstance is the increase in the values of the correlation coefficient in absolutely all the cases

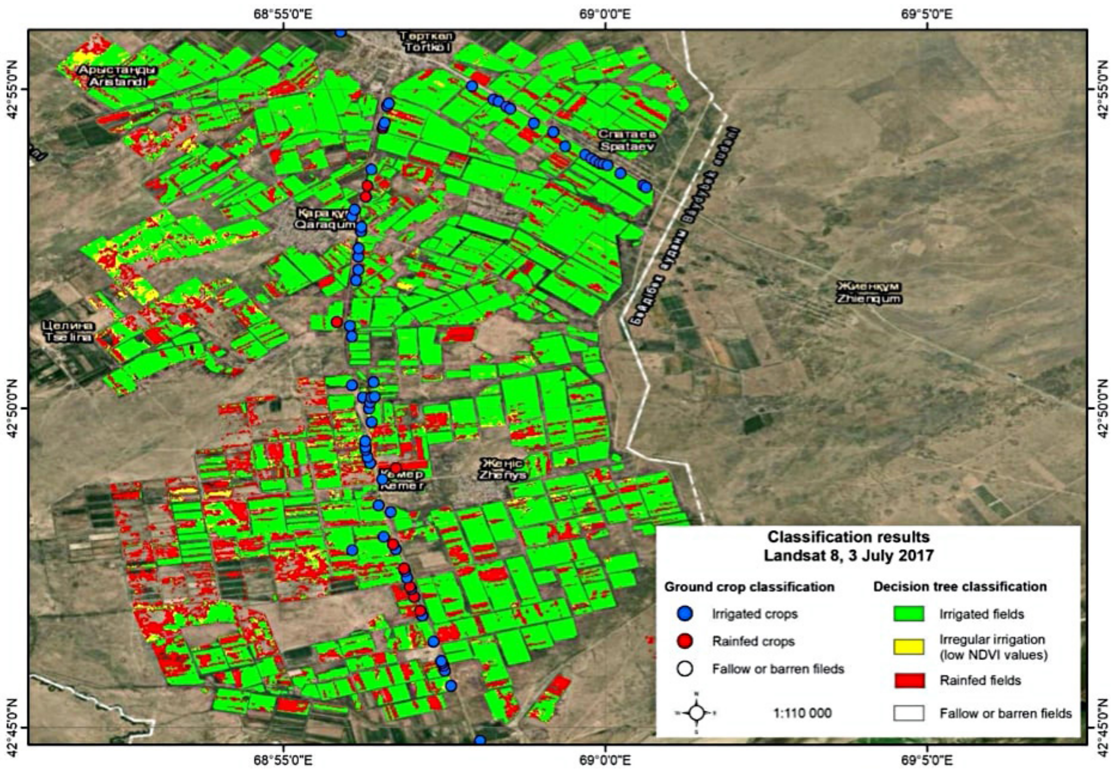


**Figure 8.** Verification of the decision tree classification results based on ground data (fragment of the Landsat-8 scene)

**Table 3.** Accuracy of recognition of certain categories of fields by the decision tree algorithm

| Irrigated by ground data | Rainfed by ground data | Barren fields by ground data | Total |
|---|---|---|---|
| 89 | 51 | 7 | 147 |
| Decision tree TRUE | Decision tree TRUE | Decision tree TRUE | |
| 77 | 33 | 6 | 116 |
| Decision Tree FALSE | Decision Tree FALSE | Decision Tree FALSE | |
| 12 | 18 | 1 | 31 |
| % of error | % of error | % of error | |
| 13.48 | 35.29 | 14.28 | 21.08 |

**Table 4.** Pearson correlation coefficient between the "irrigated fields" class and satellite data calculations

| Index | Enhanced vegetation index (EVI) $_{short}$ | $EVI_{long}$ | $NDVI_{short}$ | $NDVI_{long}$ | Soil-Adjusted Vegetation Index (SAVI) $_{short}$ | $SAVI_{long}$ | $LST_{short}$ | $LST_{long}$ |
|---|---|---|---|---|---|---|---|---|
| Irrigated fields | 0.0886 | 0.4047 | 0.1457 | 0.4507 | 0.1126 | 0.4172 | -0.1611 | -0.3693 |

**Note:** * – "short" means that the difference between the pictures equaled two weeks, "long" means that the difference equaled 25 days; ** – the marked correlations are significant at $p < 0.05000$, $n = 399$.

under consideration with an increase in the period between the dates when satellite images were taken. Additionally, the accuracy of recognition of irrigated fields was assessed based on satellite and ground data from 2017 (Table 5). It is shown that the error value in determining irrigated fields using differences in vegetation indices does not exceed 15% with a duration of observations of at least a month. Increasing the period between images should reduce the magnitude of the error, since, as shown above, the reliability of satellite observations increases as the time gap between the images increases. However, factors that cannot be identified or corrected by satellite calculations should be taken into account. Among them, for example, one can name the timing of sowing, the frequency of watering, and the frequency and intensity of the precipitation. The temperature difference demonstrates a high error, this approach is not recommended for use as an independent classification algorithm.

Based on the described methodology for calculating the difference in vegetation indices, maps of irrigated and rainfed areas were obtained (Figure 9). Some of the fields where the index difference is insignificant have an undefined status. To clarify the status of such fields, detailed information about the features of agricultural machinery is needed. Such information can be obtained only

**Table 5.** Reliability of classification of irrigated fields by index and temperature differences, %

| Maktaaral irrigated fields, *n* = 399 | |
|---|---|
| Index | Error, % |
| $EVI_{dif}$ | 13.08 |
| $NDVI_{dif}$ | 10.28 |
| $SAVI_{dif}$ | 12.77 |
| $LST_{dif}$ | 43.9 |

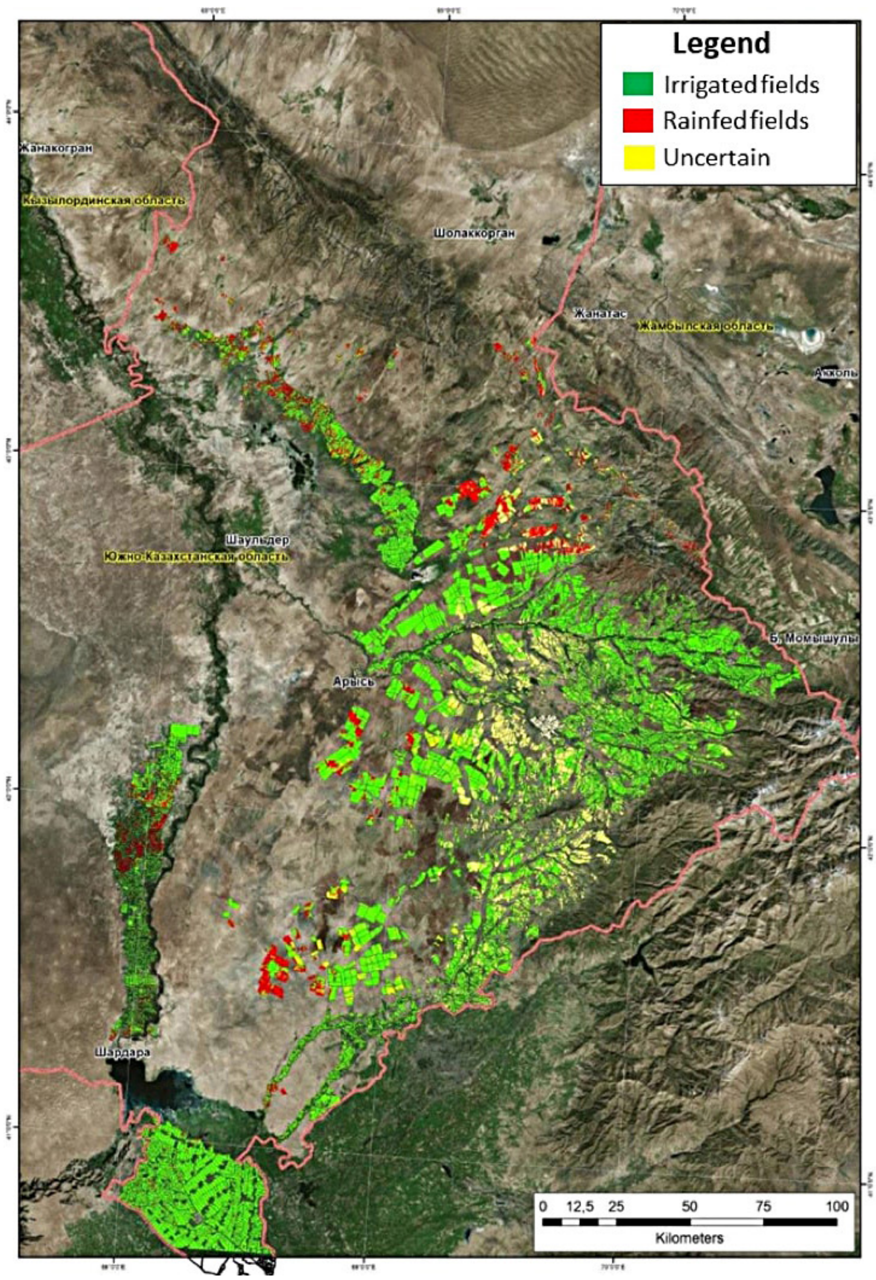


**Figure 9.** Irrigated and rainfed fields, Turkestan region, 2017

through direct contact with the farmer, which is difficult to do within the framework of monitoring on the scale of an entire region.

### Identification of promising areas for irrigation

TWI was calculated for the territory of the Shusky, Merken (partially), and Kordai (partially) districts, including the fields of the Kyzylsha Zher LLP, for which the crop rotation scheme of 2021 is known. The ratio of TWI classes and field types (irrigated and rainfed) in the Kyzylsha Zher farm is shown in Figure 10.

The highest values of the index correspond to reservoirs and coastal wetlands with excessive humidity. Analysis of the location of irrigation and rainfed fields allowed us to determine the ranges of TWI index values corresponding to the location of rainfed (“dry”) and irrigated (from “moderately humid” to “very humid”) fields. The territories where: a) the TWI index had optimal values, b) there were no agricultural fields, and c) near which there were natural or artificial watercourses, were marked as the promising ones for irrigation (Figure 11). The area of promising irrigation plots in the Zhambyl region amounted to 26,000 ha. Similar calculations were carried out on the territory of the Almaty region. The area of promising plots for irrigation in the Almaty region amounted to 10,000 ha.

For the named territories, it is necessary to conduct field studies to clarify the composition of soils and the availability of possible water sources, after which a final decision can be made on the recommendation of areas for introduction into the system of irrigation agriculture.

## DISCUSSION

The prerequisites for the recognition of irrigated and rainfed lands in Southern Kazakhstan are the dynamics of vegetation indices and temperatures of the underlying surface. For irrigated fields, the dynamics of vegetation indices should be positive (showing an increase in values) during the entire growing season. An increase in the values of vegetation indices means an increase in the amount of green biomass and, accordingly, an increase in the amount of chlorophyll in the tissues of healthy plants. For rainfed territories, the increase in the values of vegetation indices in the hot summer months has a negative trend due to the early harvest of winter crops and/or the depressed state of vegetation cover in non-irrigated fields.

The dynamics of temperature values on irrigated fields show a negative trend. In the early stages of the growth of cultivated plants, when the biomass is small, the main role is played by evaporation (i.e. passive evaporation of moisture

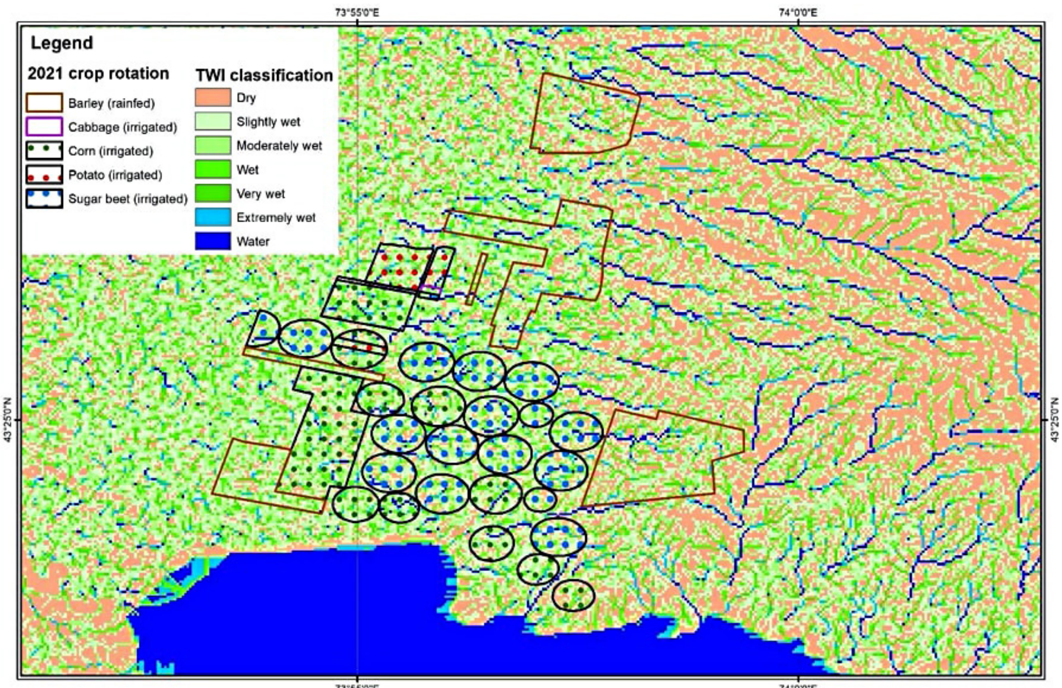


**Figure 10.** Distribution of irrigated and rainfed fields and TWI classes

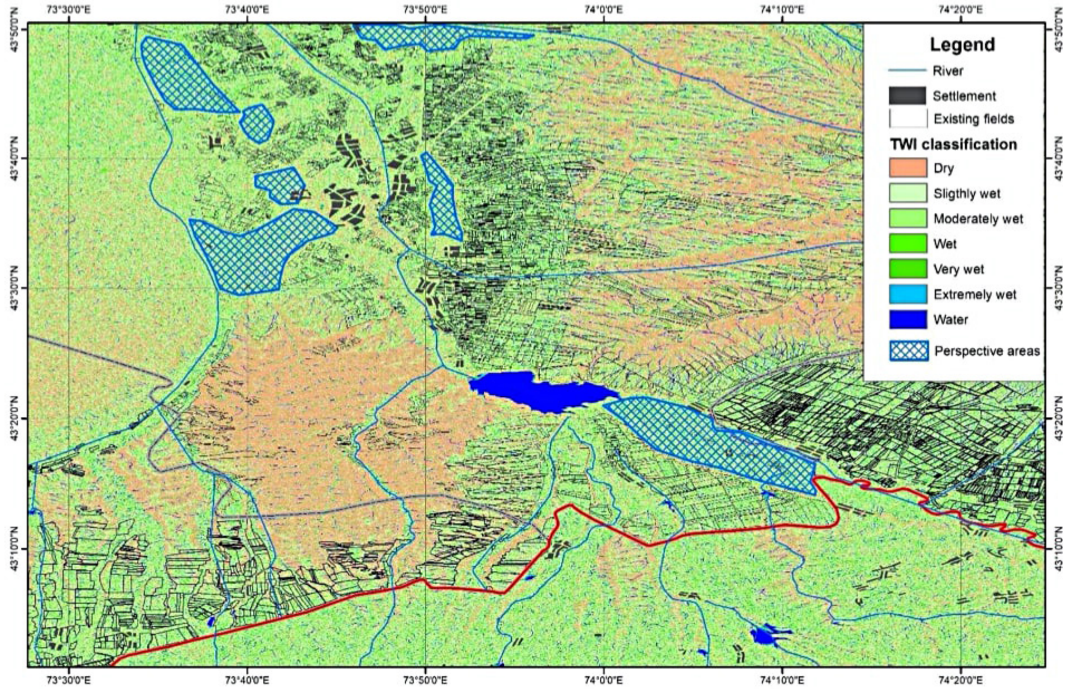


**Figure 11.** Promising areas for irrigation in the south of the Zhambyl region

from the soil surface), while with the growth of biomass and an increase in the total surface area of foliage, the role of transpiration increases. The temperature background of the underlying surface is regulated on the one hand by the amount of solar radiation (heating), and on the other by evaporation from the surface (cooling). In a hot and arid climate in the absence of developed green biomass, the soil temperature will gradually increase. With a developed vegetation cover, in conditions of irrigation agriculture, cooling of the underlying surface is carried out with the complex interaction of transpiration and evaporation (evapotranspiration). Evapotranspiration is one of the indicators of the state of vegetation. Numerous studies have been devoted to the study of methods for calculating evapotranspiration according to remote sensing data [Santos et al., 2008; French et al., 2015; Karimi et al., 2019]. An increase in the total area of the leaf surface leads to more intensive evaporation of moisture by plants and, as a result, a decrease in the temperature of the vegetation cover in irrigated fields compared to rainfed crops experiencing moisture deficiency [El-Magd and Tanton, 2005; Trezza, 2006; El-Shirbeny et al., 2015]. Our ground observations show that crops that do not lack moisture have a temperature in the range of 18–26°C at the hottest time of the day. At the same time, the temperature of the dry soil cover reaches the level of 60°C, and the temperature of vegetation lacking moisture can reach 30°C at the limit of the "viability" of the plant. The temperature of vegetation can rise further, while there are clear signs of withering vegetation cover. Studies devoted to the evaluation of fluctuations in the temperature of crops and the development of indices for remote assessment of the state of fields related to temperature have been conducted for decades [Moran et al., 2004; Ozdogan et al., 2010; Taghvaeian et al., 2012, 2013]. However, the direct application of temperature channels has a very high error in the recognition of irrigated and rainfed fields.

Methods of complex assessment of vegetation indices and temperature indicators are being developed concerning the problems of recognition of irrigated territories [Lu et al., 2008]. A discrete element method (DEM)-based approach to evaluate water potential in a form different from TWI was applied by Sujit Mondal [2012]. To improve the recognition of the dubious class of "conditionally irrigated fields", it is advisable to conduct a large-scale registration of field types, their condition, as well as sowing dates during fieldwork, with special attention to problematic fields in terms of regularity of water supply. For such fields (or regions), an additional study of humidity and aridity indices (perpendicular drought index (PDI), visible and shortwave infrared drought index (VSDI), and dynamic water stress index

(DWSI)), and possibly several others, should be carried out to introduce clarifying rules for the “conditionally irrigated field” class in the existing *Decision Tree*. Further development of the monitoring system of irrigated territories of Southern Kazakhstan implies the development of a comprehensive assessment of the condition of fields and identification of areas where vegetation lacks moisture, combining methods of recognition and classification of irrigated fields with methods for assessing the water balance and the condition of crops using the METRIC [French et al., 2015] and SEBAL models [Bastiaanssen et al., 1998] or other integral methods.

## CONCLUSION

The described algorithms for recognizing irrigated fields and determining potentially suitable territories for the introduction of irrigation agriculture represent the initial stage of the development of a national system of integrated monitoring of irrigation agriculture in Kazakhstan. At this stage, the methods for the on-the-spot and long-term recognition of irrigated massifs have been developed, the verification of those methods has been performed, and ways to increase their effectiveness have been outlined. Agricultural land is a strategic resource of the state, which determines the food security of the population. Effective management of resources and assets is largely determined by the awareness of the location, shape, size, and configurations of cultivated fields, fertility, agrochemical and agrotechnological properties of soils, and localization of infrastructure facilities. However, the lack of modern scientific and technical support hinders the development of competitive agricultural production, as well as the effective development of the water sector of the economy and water management policy.

In Kazakhstan, with its vast territory and strong differentiation in the level of development and potential provision of resources to the regions, there is no alternative to space-ground monitoring and all related applied work. Potential users of the results of space-ground monitoring are the Ministry of Agriculture of the RK, regional and district councils (akimats), and private entrepreneurs. These organizational structures are interested in the further development of technologies for remote monitoring of the state and the use of land resources, in the continuation of work on space monitoring.

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## REFERENCES

1. Bastiaanssen, W.G.M.. 1998. Remote sensing in water resources management: The state of art. International Water Management Institute, Colombo, 118.
2. Bastiaanssen, W.G.M., Menenti, M., Feddes, R.A., Holtslag, A.A.M. 1998. A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. Journal of Hydrology, 212–213, 198–212. https://doi.org/10.1016/s0022-1694(98)00253-4
3. Beven, K.J., Kirkby, M.J. 1979. A physically based, variable contributing area model of basin hydrology. Hydrological Science Bulletin, 24(1), 43–69. https://doi.org/10.1080/02626667909491834
4. Ceccato, P., Gobron, N., Flasse, S., Pinty, B., Tarantola, S. 2002. Designing a spectral index to estimate vegetation water content from remote sensing data: Part 1: Theoretical approach. Remote Sensing of Environment, 82(2–3), 188–197. https://doi.org/10.1016/s0034-4257(02)00037-8
5. El-Magd, I.A., Tanton, T.W. 2005. Remote sensing and GIS for estimation of irrigation crop water demand. International Journal of Remote Sensing, 26(11), 2359–2370.
6. El-Shirbeny, M.A., Alsersy, M.A.M., Nasser, H.S., Khaled, A.A.T. 2015. Changes in irrigation water consumption in the Nile Delta of Egypt assessed by remote sensing. Arabian Journal of Geosciences, 8, 10509–10519. https://doi.org/10.1007/s12517-015-2005-2

7. French, A.N., Hunsaker, D.J., Thorp, K.R. 2015. Remote sensing of evapotranspiration over cotton using the TSEB and METRIC energy balance models. Remote Sensing of Environment, 158, 281–294.
8. Gitelson, A., Merzlyak, M. 1998. Remote sensing of chlorophyll concentration in higher plant leaves. Advances in Space Research, 22(5), 689–692.
9. Government of the Republic of Kazakhstan. 2016. Decree of the Government of the Republic of Kazakhstan dated April 8, 2016 No. 200 "On approval of the General scheme for the integrated use and protection of water resources". Available at: https://adilet.zan.kz/rus/docs/P1600000200 (access date: January 20, 2022).
10. Huang, Y., Fipps, G., Maas, S.J., Fletcher, R.S. 2010. Airborne remote sensing for detection of irrigation canal leakage. Irrigation and Drainage, 59(5), 524–534.
11. Johnson, T.D., Belitz, K. 2012. A remote sensing approach for estimating the location and rate of urban irrigation in semi-arid climates Journal of Hydrology, 414–415, 86–98.
12. Karimi, P., Bongani, B., Blatchford, M., de Fraiture, C. 2019. Global satellite-based ET products for the local level irrigation management: An application of irrigation performance assessment in the sugarbelt of Swaziland. Remote Sensing, 11(6), 705. https://doi.org/10.3390/rs11060705
13. Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15(3), 259–260.
14. Lu, L., Zhihao, Q., Jingjing, L. 2008. Mapping the irrigation area of winter wheat farmland in North China plain using MODIS remote sensing data. Proceedings of SPIE 7104, Remote Sensing for Agriculture, Ecosystems, and Hydrology, 10, 71040P. https://doi.org/10.1117/12.800167
15. Mandal, S.M. 2012. Remote sensing and GIS based ground water potential mapping of Kangshabati irrigation command area, West Bengal. Journal of Geography and Natural Disasters, 1(1), 1-8. https://doi.org/10.4172/2167-0587.1000104
16. Medeu, A.R. (Ed.). 2010. Natsionalnyi atlas Respubliki Kazakhstan [National Atlas of the Republic of Kazakhstan]. Vol. 1. Natsionalnyi nauchno-tekhnologicheskii kholding Parasat, Almaty, 158.
17. Medeu, A.R., Malkovskii, I.M., Toleubaeva, L.S., Alimkulov, S.K. 2015. Vodnaya bezopasnost Respubliki Kazakhstan: Problemy ustoichivogo vodoobespecheniya [Water security of the Republic of Kazakhstan: Problems of sustainable water supply]. Institute of Geography, Almaty, 582. [in Russian].
18. Medvedev, S.S. 2004. Fiziologiya rastenii [Plant physiology]. St. Petersburg University Press, St. Petersburg, 336. [in Russian]
19. Moore, I.D., Gessler, P.E., Nielsen, G.A., Petersen, G.A. 1993. Terrain attributes: Estimation methods and scale effects. In: A.J. Jakeman, M.B. Beck, M. McAleer (Eds.), Modelling change in environmental systems. Wiley, London, 189–214.
20. Moran, M.S., Maas, S.J., Vanderbilt, V.C., Barnes, E.M., Miller, S.N., Clarke, T.R. 2004. Application of image-based remote sensing to irrigated agriculture. In: S. Ustin (Ed.), Remote sensing for natural resources management and environmental monitoring: Manual of remote sensing, 3 ed. John Wiley&Sons, New York, 4, 617–676.
21. Ozdogan, M., Yang, Y., Allez, G., Cervantes, C. 2010. Remote sensing of irrigated agriculture: Opportunities and challenges. Remote Sensing, 2, 2274–2304. https://doi.org/10.3390/rs2092274
22. Peñuelas, J., Gamon, J.A., Fredeen, A.L., Merino, J., Field, C.B. 1994. Reflectance indices associated with physiological changes in nitrogen- and water-limited sunflower leaves. Remote Sensing of Environment, 48, 135–146.
23. President of the Republic of Kazakhstan. 2006. Decree of the President of the Republic of Kazakhstan dated November 14, 2006 No. 216. On the concept of the transition of the Republic of Kazakhstan to sustainable development for 2007–2024. Available at: https://adilet.zan.kz/rus/docs/U060000216_/info (access date: January 20, 2022).
24. Rouse, J.W., Haas, R.H., Schell, J.A., Deering, D.W. 1974. Monitoring vegetation systems in the Great Plains with ERTS. Third ERTS Symposium, NASA SP-351, Washington DC, December 10–14, 1973. Vol. 1, 309–317. Available at: https://ntrs.nasa.gov/citations/19740022614
25. Santos, C., Lorite, I.J., Tasumi, M., Allen, R.G., Fereres, E. 2008. Integrated satellite-based evapotranspiration with simulation models for irrigation at the scheme level. Irrigation Science, 26, 277–288. https://doi.org/10.1007/s00271-007-0093-9
26. Sørensen, R., Zinko, U., Seibert, J. 2006. On the calculation of the topographic wetness index: evaluation of different methods based on field observations. Hydrology and Earth System Sciences, 10(1), 101–112.
27. Stagakis, S., González-Dugo, V., Cid, P., Guillén-Climent, M.L., Zarco-Tejad, P.J. 2012. Monitoring water stress and fruit quality in an orange orchard under regulated deficit irrigation using narrow-band structural and physiological remote sensing indices. ISPRS Journal of Photogrammetry and Remote Sensing, 71, 47–61.
28. Taghvaeian, S., Chávez, J.L., Hansen, N.C. 2012. Infrared thermometry to estimate crop water stress index and water use of irrigated maize in Northeastern Colorado. Remote Sensing, 4(11), 3619–3637. https://doi.org/10.3390/rs4113619
29. Taghvaeian, S., Chávez, J.L., Hattendorf, M.J., Crookston, M.A. 2013. Optical and thermal remote

sensing of turfgrass quality, water stress, and water use under different soil and irrigation treatments. Remote Sensing, 5, 2327–2347. https://doi.org/10.3390/rs5052327

30. Trezza, R. 2006. Evapotranspiration from a remote sensing model for water managementin an irrigation system in Venezuela. Interciencia, 31(6), 417–423.
31. Tsychueva, N.Y., Malakhov, D.V. 2016. Irrigated land detection technique using satellite data and GIS. In: Water resources of Central Asia and their use. Materials of the international research and practice conference dedicated to summarizing the results of the decade for action "Water for Life" declared by the UN. LLP „Nurai Print Sersis", Almaty, 182–188.
32. Yousaf, W., Awan, W.K., Kamran, M., Ahmad, S.R., Bodla, H.U., Riaz, M., Umar, M., Chohan, K. 2021. A paradigm of GIS and remote sensing for crop water deficit assessment in near real time to improve irrigation distribution plan. Agricultural Water Management, 243, 106443. https://doi.org/10.1016/j.agwat.2020.106443