Advancing Rice Yield Forecasting and Crop Assessment in Kazakhstan's Kyzylorda Region: A Multisource Satellite Data Approach

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Abstract. The monitoring and prediction of rice yields are essential across various domains, including agriculture, environmental conservation, ecology, agricultural insurance, and land resource management. The precision of these yield predictions is eagerly awaited by analysts globally, given their direct influence on the valuation of world stock quotes for agricultural commodities. Numerous scientific studies consistently demonstrate the effectiveness of the Normalized Difference Vegetation Index (NDVI) as a reliable indicator for assessing crop conditions and ensuring stable grain harvests. Ultimately, these collective efforts substantially contribute to increasing crop yields, bolstering agricultural efficiency and profitability, with a notable impact observed within the crop industry. The research methodology involves comprehensive analysis of Sentinel-2 and Landsat-8 satellite data, harmonized with ground-based data analysis equips stakeholders with the capability to identify spatial disparities and disruptions within rice paddy fields and serve as vigilant oversight of adherence to agrotechnical farming practices. The integration of satellite and ground techniques tailored to evaluate crop conditions and forecast rice yields, accounting for the region's unique soil and climatic attributes.

1 Introduction

The central districts of Kazakhstan's Kyzylorda region, encompassing 70% of the total rice cultivation area, are of particular importance for ensuring national food security. The primary objective is to advance remote sensing techniques tailored to evaluate crop conditions and forecast rice yields, accounting for the region's unique soil and climatic attributes. The study provides a detailed flowchart outlining the sequential processing of remote sensing data and multifaceted findings. This study underscores the significance of addressing critical challenges across various sectors through benefiting agriculture, environmental preservation, ecology, insurance, statistics, and land management. The precision (R² values ranging from 0.82 to 0.91) of these yield predictions is eagerly awaited by analysts globally, given their direct influence on the valuation of world stock quotes for agricultural commodities. The research outcomes have extensive applications, particularly in making in the realm of agrotechnical interventions, all aimed at improving crop asset@ spaceres.kz, sin.asset@gmail.com.
channels in the red (ranging from 0.62 to 0.69 microns) and near-infrared (ranging from 0.75 to 0.9 microns) spectral ranges. The NDVI value exhibits a direct correlation with the total biomass of plants\[7\].

In the pursuit of accurate yield predictions, researchers have championed the use of NDVI mosaics, which take into account sowing dates and the accumulation of necessary temperature units during critical crop growth phases, such as earing or sweeping in the context of rice cultivation\[8\]. Rigorous scientific investigation has confirmed that NDVI mosaics tailored for specific crop development phases offer superior indicators of crop conditions and expected yields.

In addition to the NDVI index, researchers have advocated for the incorporation of modified indices, including CNDVI, VCI, IVCI, and other variants\[6,7\].

The methodologies described above are effectively deployed in various countries, including Russia, Kazakhstan, and neighboring nations, and can be categorized into the following primary methods:

1. Analysis of trend and cyclicity in yield dynamics: This involves identifying analogous years, providing critical insights into crop yield patterns over time.

2. Application of dynamic modeling: This approach relies on the establishment of mathematical representations of physiological processes occurring over extended time intervals within the plant-soil system and plant habitat. Examples include the "Weather-harvest" model\[11\] and the adaptation of EPIC bio-productivity models\[12\].

However, dynamic modeling methods require a comprehensive dataset of agrometeorological indicators with daily granularity, complex calculations, and extensive fieldwork to calibrate models to local soil and climatic conditions, presenting challenges for operational deployment\[13\].

In contrast, regression analysis emerges as the most widely embraced method for the operational forecasting of rice yields among grain crops\[14\]. This methodology involves correlation analyses of yield values with an array of predictors, including satellite data, notably NDVI during critical crop growth stages, as well as ground data, such as survey information and meteorological parameters\[15\]. Moreover, regression analysis considers the influence of spring and summer weather conditions on rice phenology. This multifaceted technique extends to crop condition, the timing of maximal biomass accrual, and, consequently, the initiation of the zenith of the NDVI within rice paddies. Collectively, these elements substantiate the overall condition and anticipated yield of rice crops\[16\].

In summary, the integration of satellite data, rigorous scientific methodologies, and a profound understanding of crop dynamics ushers in advanced and accurate yield forecasts. This convergence plays an indispensable role in contemporary agriculture and food security endeavors, exemplifying its critical importance across diverse sectors and regions.

2 Materials and methods

The research is centered on the southeastern region of Kazakhstan, specifically within the Kyzylorda region, where the primary focus lies on the cultivation of thermophilic grain crops, with rice being the predominant crop. In addition to rice, smaller portions of land within this region are dedicated to the cultivation of various other crops, including vegetables, melons, oilseeds, cereals such as corn, oats, millet, barley, and wheat, as well as perennial herbs. For the purposes of this study, our investigation is specifically concentrated on the key rice-producing areas situated in the Syrdarya, Zhalagash, and Karmakshi districts. These districts collectively encompass approximately 70% of the entire rice cultivation area within the Kyzylorda region, as depicted in Figure 1.
In order to evaluate crop conditions and predict rice yields, a method was devised involving a sequential process that integrates data from both satellite and ground sources, while considering agrometeorological conditions specific to each year. The research encompassed the following tasks: Utilization of satellite remote sensing data with medium spatial resolutions, including Sentinel-2 (10 m) and Landsat-8 (30 m), with the computation of relevant indices such as NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) for the period spanning April to August, incorporation of daily meteorological data, encompassing temperature and precipitation, for the duration of the crop's growth season, and integration of ground survey data from designated test sites. Figure 2 visually illustrates the distinctions in rice paddy images obtained through satellite imagery with varying spatial resolutions: A - LANDSAT 8, featuring an average spatial resolution of 30 m, provides a general spectral overview of agricultural fields; B - Sentinel-2, captured at medium to high spatial resolution (10 m), distinctly delineates rice field boundaries; C - PlanetScope, a high spatial resolution satellite image (3 m), offers the capability to identify dynamic changes occurring within rice paddies, highlighting their inherent heterogeneity. High-resolution images facilitate precise digitization of field boundaries and support crop recognition efforts.

The methodology for forecasting rice yields comprises two closely interconnected processing stages, as illustrated in Figure 3. In the initial stage, a comprehensive analysis is conducted based on several key factors, including maximum Normalized Difference Vegetation Index (NDVI) values, corresponding threshold values, and ground-based data. This analysis results in the classification of crop conditions into five distinct classes: excellent, good, satisfactory, poor, and very poor. Subsequently, output products detailing the condition of crops are generated. Moving on to the second stage, rice field conditions are categorized into five classes based on satellite data: S5 for areas where rice is in excellent condition, S4 for good condition, S3 for satisfactory condition, and S2 and S1 for poor and very poor conditions, respectively, measured in hectares (ha). Through regression analysis of the NDVI vegetation index during the phase of maximum biomass development, along with field yield data for rice paddies exhibiting typical conditions (Y5, Y4, Y3, Y2, Y1 in c/ha), the prediction of rice paddy yields for various crop conditions is computed. The outcome of the second stage of data processing for yield predictions for both the average regional rice yield and maps depicting expected rice yields for the central districts of the Kyzylorda region. The average rice yield per district (District) is determined by calculating the ratio of the total rice grain harvest within the district to the specified satellite-derived rice cultivation area:

\[ D = \frac{(Y5 \times S5 + Y4 \times S4 + Y3 \times S3 + Y2 \times S2 + Y1 \times S1)}{\text{Neighborhood}} \]

Where: D is district, Y (c/ha) represents the predicted rice yield on average within the district. S (ha) indicates the satellite-derived rice cultivation area across the entire district. Y (c/ha) correspond to the rice yield for various crop conditions, as determined through ground surveys conducted in the prevailing weather conditions of the current year.
The methodology for predicting rice yield in the central districts of the Kyzylorda region involves a systematic integration of remote sensing data and ground information, structured as follows:

1. Calculation of the NDWI index for the spring season (April to mid-June) and NDVI for the summer season using Sentinel-2 data.
2. Refinement of the rice sowing mask for the current year, including the identification of timing and areas of rice sowing during the spring and summer periods, with the creation of corresponding maps and tables.
3. Examination of agrometeorological conditions throughout the crop's growth cycle.
4. Conducting ground field surveys, aligning them with pre-survey NDVI maps, to clarify the mask of rice cultivation and its area for the current year. This involves gathering data on biometric parameters, crop status, and biological productivity of rice within test areas.
5. Generation of maps displaying maximum NDVI values between mid-July and mid-August, enabling the classification of rice condition classes by districts.
6. Establishing correlation relationships between maximum NDVI values and rice yield based on ground survey results.
7. Computation of rice yield predictions for each rice crop condition class, relying on the maximum NDVI of rice.
8. Preparation of satellite-based yield prediction maps for the current year and corresponding tabular data, organized by districts within the study region.

The timing and extent of rice sowing significantly influence plant growth, development, biomass accumulation, crop condition, and ultimately, yield. These factors vary each year based on the progression of spring processes and the timing of the average daily air temperature reaching 15 °C. For instance, in the spring of 2020, this temperature transition occurred on April 17, which was 7-12 days earlier than the average long-term dates. Consequently, the optimal period for delineating crop areas from Sentinel-2 images spans from April 15-20 to June 1. The method for determining sowing time involves calculating the difference between NDWI indices corresponding to different spring dates from Sentinel-2 imagery. The presence of water signals the initiation of sowing activities in rice paddies. During the summer, an additional check of rice field sowing is performed at the peak of rice vegetation (when maximum biomass is achieved) using Sentinel-2 images, specifically between July 15-20 and August 10-15, based on maximum NDVI values.
3 Results and discussion
3.1 Impact of Planting Dates on Rice Crops Using Satellite Data

The foundation of crop condition monitoring and the development of a methodology for predicting rice yields within the specific agrometeorological context of a given year relies on satellite-derived data from 2020. This data encompasses information about the regions where rice was planted and the associated planting dates. Figure 4 visually illustrates the rice planting dates for the year 2020, providing a graphical representation. Meanwhile, Table 1 presents a comprehensive breakdown of the rice planting areas categorized according to planting time. To facilitate the preparation of maps, the calculated rice planting dates for the entire planting season are grouped into distinct time intervals: early planting, spanning from April 20 to May 5; optimal planting, covering the periods of May 6-15 and May 16-25; and late planting, occurring from May 26 to June 10.

Fig. 4. The rice sowing dates in the central regions of the Kyzylorda region for the year 2020.

Table 1. The areas and dates of rice sowing derived from remote sensing data for the year 2020.

<table>
<thead>
<tr>
<th>District/Region</th>
<th>Categorized 2020 Rice Planting Areas by Timing Using Remote Sensing Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>early, (••)</td>
</tr>
<tr>
<td>Zhalagashsky</td>
<td>24</td>
</tr>
<tr>
<td>Karmakshinsky</td>
<td>28</td>
</tr>
<tr>
<td>Kyzylorda</td>
<td>34</td>
</tr>
<tr>
<td>Syrdarya</td>
<td>19</td>
</tr>
<tr>
<td>By central districts</td>
<td>24</td>
</tr>
</tbody>
</table>

The 2020 satellite monitoring results reveal that the primary rice-growing areas situated in the central regional distribution based on sowing times were distributed as 70% of the cultivated area at the optimal time (ranging from May 6 to May 25), 24% at an early date (from April 20 to May 5), and 6% at a late date (from May 26 until June 10).
3.2 Agrometeorological conditions during Rice Vegetation in 2020

Rice, being a thermophilic irrigated crop within the spectrum of grain crops, exhibits a biological minimum temperature requirement for seed germination and emergence, set at 15 °C. The crucial indicator for commencing rice sowing is the steady transition of air temperature beyond this threshold in spring. In the year 2020, this transition occurred across the region’s predominant rice-growing areas around mid-April, specifically on April 17, signifying an early arrival, approximately 7-12 days ahead of the long-term averages.

The spring of 2020 was marked by the active progression of spring and an accumulation of heat as confirmed by thermal resource metrics. By August 31, 2020, the cumulative sum of active air temperatures exceeding 15 °C reached 35-60 °C. This figure exceeded the average values observed in the analyzed recent years (2014-2020) and surpassed the long-term climatic norm by 90-100 °C.

However, it is noteworthy that both maximum air temperatures (ranging between 35-40 °C) and low minimum temperatures (12-17 °C) have detrimental effects on rice crops. Particularly, periods characterized by extreme high air temperatures, notably during early and mid-June, along with mid-July, reaching the maximum of 37-42 °C, were unfavorable for crop growth, tillering, and rice productivity formation. Conversely, during the remaining days of the summer season, generally favorable temperature conditions prevailed, supporting tillering and panicle formation in rice crops.

In addition to the heightened atmospheric temperatures, the year 2020 was marked by insufficient water resources. The scarcity of irrigation water predominantly affected the southern region of Syrdarya region under study. Overall, growing season of 2020 exhibited an active accumulation of thermal resources, which, when coupled with adequate water availability through irrigation, facilitated robust growth, active development, and the formation of rice crop yields.

3.3 Ground Surveys of Rice Crops in 2020: Validation and Assessment of Crop Conditions.

Ground surveys of agricultural fields reveals crucial factual insights into the condition and biological yield of rice test plots within the context of prevailing agrometeorological conditions. These on-site data are integral to the correlation analysis conducted between NDVI datasets and ground observations of surveyed rice plots, enabling the derivation of formulas and graphs for assessing crop condition and estimating rice crop yields.

Figure 5 depicts a schematic map outlining the survey route for rice test plots during the period from July 29 to August 10, 2020. The development of this survey route was informed by the calculated NDVI indexes, allowing for the selection of rice test plots in varying states of growth and health. Additionally, specific crop fields were identified for on-site verification.
Ground surveys encompass an array of field measurements and visual inspections conducted within rice fields. The fieldwork protocol involves the systematic acquisition of ground-level data, including monitoring the phenological development of rice crops, measuring plant height, evaluating the density of productive rice stalks, and assessing the extent of clogging within the fields. Identifying damage caused by adverse weather conditions or diseases affecting the crops. Providing a comprehensive condition rating for the crops, utilizing a 5-point scale ranging from 1 to 5. Additionally, during these examinations, samples of rice panicles are collected to facilitate an analysis of grain productivity within the panicles. Furthermore, the program includes measurements of water levels within the sampled fields, recorded in centimeters.

The assessment of the overall crop condition and determining the crop’s biological yield was conducted through a consideration of various factors, including the developmental stage, density, and uniformity of the emerging green biomass, biometric parameters, productivity components, contamination levels, as well as the presence of diseases or damage caused by adverse weather conditions. To illustrate, Figure 6 provides visual examples of both favorable and unfavorable rice crop conditions observed during the survey.

**Fig. 6.** Rice Crop Condition Assessment in the Kyzylorda Region in the Early August of 2020.

To estimate the biological yield of rice under various crop conditions using traditional agronomic methods, which involve collecting data on grain density and productivity within rice panicles, a methodology for predicting rice yields for distinct crop categories was developed. Rice cultivation, as is well-known, places significant demands on the irrigation regime, particularly during the flowering phase. Rice requires an adequate water layer of approximately 20-25 cm during the flowering phase, as a deficiency in the water level can result in wilting of the flowers. Field investigations revealed deviations in the flooding practices of rice fields during the summer in certain farms within the central region of the area. These nonconformities manifested as either the underestimation or overestimation of the required water levels in the rice fields. Underestimations or complete absence of water levels in rice fields were predominantly observed during the survey, primarily in the southern part of Kyzylorda city and certain locations in the Syrdarya region. Conversely, overestimations of water levels (ranging from 40-60 cm) were prevalent in the Karmakshi, Zhalagash, and selected areas within the Syrdarya districts.

### 3.4 Computation of correlation coefficients for forecasting rice yield in the central districts of the Kyzylorda region.

The collaborative analysis and algorithm formulation for forecasting rice yield in central Kyzylorda districts rely on a comprehensive dataset encompassing field surveys, biological yield data from test sites, satellite-derived sowing information, and current-year weather conditions. Satellite-based rice yield predictions are rooted in NDVI vegetation indices, categorized into five conditions ranging from excellent to very poor, establishing correlations with biological yield. Test site data encompass biometric parameters and expert assessments. The analysis is further enriched by additional data from the Kazakh National Institute of Rice Growing (2019-2020) and details on rice variety characteristics.
The timing of peak NDVI values in rice crops during July and August serves as an indicator of maximum biomass, subject to influences such as sowing timing, rice variety, weather conditions, field contamination, and agrometeorological factors.

Annual rice masks are delineated based on NDVI values, typically falling below 0.30–0.40, with supplementary validation for the presence of rice. Figure 7 presents the calculated maximum NDVI values for 2020 in Kyzylorda, which have undergone an assessment for their reliability.

Fig. 7. Max NDVI for Kyzylorda Rice in 2020 Summer (Sentinel-2).

The remote assessment of rice crop status relies on establishing correlations between the highest NDVI values and ground survey results for the specific year, as detailed in the 2019 report. Taking into account the prevailing agrometeorological conditions in 2020 and route data, Table 2 presents updated threshold values for the NDVI index corresponding to five distinct crop condition classes in the central Kyzylorda region.

<table>
<thead>
<tr>
<th>Rice condition rating</th>
<th>NDVI value (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.76–0.83</td>
</tr>
<tr>
<td>4</td>
<td>0.70–0.75</td>
</tr>
<tr>
<td>3</td>
<td>0.63–0.69</td>
</tr>
<tr>
<td>2</td>
<td>0.56–0.62</td>
</tr>
<tr>
<td>1</td>
<td>≤0.55</td>
</tr>
</tbody>
</table>

Following collaborative analysis, Figure 8 displays a satellite-generated map illustrating the status of rice crops. The areas corresponding to distinct condition classes were computed both at the district level and as an average for the entire region, as presented in Table 3. The results of the satellite-based assessment of rice crop condition closely align with the ground survey data. The predominance of rice crops classified as in good and excellent condition strongly supports the conclusion that favorable conditions prevailed in 2020, promoting the growth, development, and high yield of rice crops.
Fig. 8: Evaluation of 2020 Rice Crops in Central Kyzylorda Using Satellite Technology

For the purpose of predicting rice yields and generating corresponding maps, it is highly recommended to calculate the forecasted rice yield separately for each crop condition class. An extensive analysis of the calculated average NDVI values across different sowing dates and districts has revealed a clear correlation between rice yield and sowing timing. Specifically, rice crops sown during the optimal period exhibit the highest NDVI values, while those sown late display the lowest NDVI values.

<table>
<thead>
<tr>
<th>District/Region</th>
<th>State of rice sowing (% sowing area)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>excellent</td>
</tr>
<tr>
<td>Zhalagashsky</td>
<td></td>
</tr>
<tr>
<td>Karmakshinsky</td>
<td></td>
</tr>
<tr>
<td>Kyzylorda</td>
<td></td>
</tr>
<tr>
<td>Syrdarya</td>
<td></td>
</tr>
<tr>
<td>Central zone of</td>
<td></td>
</tr>
<tr>
<td>the region</td>
<td></td>
</tr>
</tbody>
</table>

Late-sown crops, characterized by poor and satisfactory conditions based on field surveys, often exhibit substantial field clogging, irregular growth, and developmental lag. Late sowing dates lead to an expansion of areas with poor rice conditions and a reduction in areas with good conditions, subsequently impacting yield and NDVI values.
### Table 4. Dynamics of Rice Crop Condition Class Areas (%) Based on Sowing Dates in 2020 Using Remote Sensing Data

<table>
<thead>
<tr>
<th>District</th>
<th>April 20 - May 5</th>
<th>May 6 - 15</th>
<th>May 16 - 25</th>
<th>May 26 - June 10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kyzylorda</strong></td>
<td>76.4</td>
<td>22.5</td>
<td>1.1</td>
<td>73.2</td>
</tr>
<tr>
<td><strong>Zhalagash</strong></td>
<td>82.2</td>
<td>16.9</td>
<td>0.8</td>
<td>87.6</td>
</tr>
<tr>
<td><strong>Karmakshinsky</strong></td>
<td>72.7</td>
<td>21.8</td>
<td>5.5</td>
<td>83.2</td>
</tr>
<tr>
<td><strong>Syrdarya</strong></td>
<td>85.7</td>
<td>13.0</td>
<td>1.3</td>
<td>87.1</td>
</tr>
<tr>
<td><strong>Regional average</strong></td>
<td>80.4</td>
<td>17.3</td>
<td>2.3</td>
<td>85.6</td>
</tr>
</tbody>
</table>

Conversely, early sowing dates demonstrate greater productivity in comparison to their late-sown counterparts. Early crops tend to have a smaller proportion of poor condition areas, emphasizing their superior performance relative to late-sown crops. Tables 4-5 depict the dynamics of crop condition class areas (%) and NDVI values as they relate to the timing of rice sowing.

### Table 5. NDVI and Rice Yield Dependency on Sowing Dates in Central Kyzylorda Region

<table>
<thead>
<tr>
<th>Sowing Time</th>
<th>Analysis via Remote Sensing</th>
<th>NDVI and Yield Dependency by Seeding Time in Central Region</th>
<th>NDVI via Remote Sensing</th>
<th>Crop Yield per Hectare (Remote Sensing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 20 - May 5</td>
<td></td>
<td></td>
<td></td>
<td>0.717374</td>
</tr>
<tr>
<td>May 6 - 15</td>
<td></td>
<td></td>
<td></td>
<td>0.724212</td>
</tr>
<tr>
<td>May 16 - 25</td>
<td></td>
<td></td>
<td></td>
<td>0.725782</td>
</tr>
<tr>
<td>May 26 - June 10</td>
<td></td>
<td></td>
<td></td>
<td>0.709754</td>
</tr>
</tbody>
</table>

Through rigorous data analysis conducted on experimental plots, we have established correlations that enable the computation of projected rice yields for the Syrdarya, Karmakshi, and Zhalagash districts within the region (Figure 10).

The predictive equation for estimating the yield of rice plots classified as being in good and excellent condition \((Y_c/ha)\) in the central regions of the territory is expressed as follows:

\[
Y = (243.6X - 124.3); \quad R^2 = 0.83
\]

where \(X\) represents the maximum NDVI value, averaged across the check mask, for the period spanning July 15 to August 18.

The prognostic equation for calculating the yield of rice checks in a satisfactory condition \((Y_s/ha)\) for the central regions of the region has the following form:

\[
Y = (161.87X - 68.049); \quad R^2 = 0.81
\]
where $X$ is the maximum NDVI value for the period July 15 to August 18.

The predictive equation for estimating the yield of rice plots classified as being in poor and very poor conditions ($Y_c$/ha) in the central regions of the territory is expressed as follows:

$$Y = (221.2X^2 + 162.24X + 44.089); \ R^2 = 0.91$$

Where, $X$ represents the maximum NDVI value for the period spanning July 15 to August 18.

The correlations obtained exhibit a notably strong relationship ($R^2 = 0.82 - 0.91$), providing a high degree of reliability for predicting rice yields. For the individual prediction of rice yield for the Kazakh National Institute of Rice Growing named after I. Zhakhaev, a reasonably reliable correlation ($R^2 = 0.8676$) was established (Figure 10 (D)). This analysis incorporated data on the actual yield of rice from 65 field checks conducted on the farm in 2019. The polynomial power dependence equation for this context is given as follows:

$$Y = (167.01X^2 - 111.34X + 49.53); \ R^2 = 0.87$$

Where, $X$ is the maximum NDVI value for the period from July 15 to August 18, averaged across the check mask.

**NDVI max as a Predictor for Rice Yield in Satisfactory Condition**

Fig. 10. Correlation Dependencies for Rice Yield Prediction Based on NDVImax (15.07 - 18.08) Using Sentinel-2 Data in Central Kyzylorda Region (A - for the good condition of the crops; B - for the satisfactory condition; C - for the poor condition; D - for all classes of rice KazNII Growing named after I. Zhakhaev)
Projected Rice Yield in the Kyzylorda Region for 2020

At the final stage, we have compiled a satellite-derived map illustrating the predicted rice yield and corresponding tabular data for the central districts of the Kyzylorda region in 2020. The yield projection for rice in the central regions of the Kyzylorda region for 2020 indicates an expected increase compared to the average values of the past 5 years. These predictions suggest that the highest yields are anticipated in the Zhalagash and Syrdarya districts.

Figure 11 presents a satellite-based map depicting the projected rice yield across the various districts of the Kyzylorda region for the year 2020.

4 Conclusion

Remote sensing application techniques are used to assess and forecast rice crop conditions and yields in the Kyzylorda region districts represents a key advancement in modern agriculture. The capacity to conduct non-invasive assessments of rice crops throughout their growth stages, leveraging the reflective properties of their green biomass, is instrumental in providing timely insights into crop health and development. Satellite data enables the rapid detection of field variability and potential issues, empowering farmers to make informed agrotechnical decisions that can lead to improved crop conditions and consistent harvests. The ability to monitor sowing area and timing, along with tracking the crop conditions and yields, through space-based observations further enhances the precision and efficiency of rice production.

The research's significance extends beyond the agricultural sector, considering the broader context of global food security. As competition intensifies in the grain market and the demand for rice continues to rise worldwide, it becomes imperative to optimize rice production processes. The remote sensing methods developed in this study offer a promising avenue for achieving this optimization. By providing a cost-effective and rapid means of monitoring changes in rice fields, these techniques are poised to revolutionize rice production management not only in the Kyzylorda region but also on a national scale.

Furthermore, the groundwork laid by this research paves the way for the establishment of a comprehensive and unified system for monitoring and managing rice production throughout Kazakhstan. Such a system, informed by remote sensing data, holds the potential to drive increased agricultural productivity, reduce resource wastage, and bolster the nation's role as a key contributor to global food security. In essence, this research aligns with the broader goals of sustainable agriculture and resilient food systems, making it an invaluable asset in the quest to meet the world's evolving nutritional needs.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Author Contributions:

N.K., N.B., and B.B. contributed to the conceptualization of the research problem and data identification. R.K., A.Y., and N.K. were primarily responsible for data integration, while A.K. and S.I. provided support during data analysis. All authors participated in designing the research methods, collaborating on the entire research framework, engaging in discussions and analyses, and contributing to manuscript review. All authors have reviewed and approved the final version of the manuscript for publication.

References


