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Geospatial technologies for early warning and assessment of climate change impacts on wheat yields in Azerbaijan

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Abstract

Global warming presents significant challenges to global agriculture, with notable implications for the Republic of Azerbaijan's economy and food security. This paper focuses on the use of Earth Observation data and geoinformation systems to provide early warning detection of climate-related risks to crop growth and yields. By analyzing satellite imagery and automated calculation of vegetation indices, the study models the relationship between climate effects and crop yield. Initial assessments using satellite images revealed that over 15% of Azerbaijani territory was affected by drought in 2021, making it the most drought-affected year in the past two decades. Test fields were selected based on this data, considering different adaptation capabilities to changing environmental conditions, focusing on the main crop type, wheat. Comparative analyses were conducted to assess crop growth and predict yields under various climate change scenarios. By developing maps and collecting statistical data, the study uncovered the dynamics of crop condition changes and forecasted yields during growing seasons. The research also tested a model for assessing climate change effects on crop yields. The findings of this study provide a valuable foundation for the efficient planning of climate adaptation and mitigation strategies in agriculture.

1. Introduction

Today, in the face of increased climate change impacts, early-warning and assessment systems play a crucial role in helping decision-makers anticipate agricultural needs, identify yield gaps, and comprehend the response of crops to local climatic conditions, especially for wheat. Earth observation (EO) data, specifically satellite-based remote sensing, have proven to be effective and scalable tools for monitoring crop growth and estimating yields (Majorova V.I, 2013).

The significance of this study lies in its contribution to the development of methodological support for early warning and assessment of climate change impacts on crop yields, as well as the formulation of mitigation plans. It aligns with national-level initiatives and the global sustainable development goals (SDGs). The primary objective is to explore the potential of remote sensing data and geoinformation technologies to develop dynamic decision support systems for wheat production in Azerbaijan, integrating satellite-based drought assessment with available climate data. Specifically, the study aims to develop an empirical model capable of predicting crop yields at the beginning of the growing season under climate change effects.

To achieve this goal, the study sets the following objectives: (1) assessing agricultural drought at the national level, (2) local monitoring of agricultural lands throughout the growing season, (3) testing a crop model for rainfed areas focusing on wheat cultivation.

2. Material and methods

2.1. Study area

The climatic conditions in Azerbaijan are diverse and unique, with over half of the territory covered by mountains and the remaining portion consisting of plains, lowlands, intermountain hollows, valleys, and volcanic highlands formed over geological periods. Wheat cultivation occurs in both irrigated and non-irrigated lands, with the duration from planting to full maturity varying from 228 days in the plains to 305 days in mountainous regions. Rainfed agriculture is predominantly practiced in mountainous regions and foothills, characterized by low productivity and agricultural communities that often face poverty. Harsh conditions often lead to migration and abandonment of land, with subsistence sustained through the cultivation of drought-resistant crops.

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For this research, two test fields were selected, one on irrigated land and the other on non-irrigated land, focusing on the main crop type, wheat. These fields were chosen due to their different adaptation capabilities to changing environmental conditions. The locations of these test fields are depicted in the map below (Figure 1).

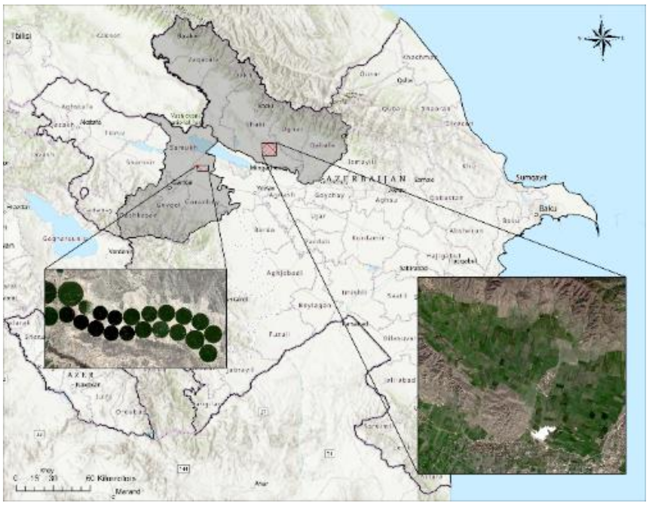

Figure 1. Location of Selected Test Fields

Two test fields were selected for this study, both primarily dedicated to cereal crops, specifically wheat. The first test field is an irrigated area located in the Ganja-Dashkasan economic region, while the second test field is a non-irrigated area in the Sheki-Zagatala region.

2.2. Dataset

Remote sensing plays a crucial role in agricultural drought assessment, providing valuable data on Earth's surface processes through various satellite missions worldwide (Liu, X., 2016). In this study, remote sensing data from two EO satellites, Aqua and Azersky, were utilized for national and local monitoring. Open-source data from the Aqua satellite's MODIS sensor were employed to determine the drought levels across the entire country. The assessment of long-term agricultural drought for the entire country relied on 21-year data from MODIS, employing the Vegetation Condition Index (VCI) developed by Kogan (Kogan F., 1995) and following the recommended practices by the UN-SPIDER (UN-SPIDER, 2017).

Based on the findings from the national assessment, specific test fields were selected. Recognizing the significance of spatial resolution in local monitoring, high-resolution imagery from the Azersky satellite was utilized in this study. Images taken from Azersky satellite images have been shown in figure 2.

Figure 2. Azersky satellite images, 15 April 2021

For this research, all available archive datasets of Azersky images were examined to analyze the phenological regime of the main study area. Data from the period of April to June, specifically from 2018 to 2021, were selected for analysis.

Wheat is a versatile crop that can thrive in various climates, with heat being a key factor for its growth. Temperature data plays a crucial role in providing essential climate information for studying its influence. Additionally, the research examined climate change scenarios proposed by the IPCC to understand the impact of climatic factors. To ensure accurate and reliable data, Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) was utilized, which has demonstrated a high accuracy rate of up to 90% in previous studies. Specifically, precipitation data during the wheat growing period were analyzed in this research. CHIRPS precipitation data, a combination of satellite estimates and ground-based rainfall data from weather stations, provides accurate and reliable information on precipitation. These data have been available since 1981, ensuring a comprehensive analysis of rainfall patterns (Funk, C. C. et al, 2014).

Ground data for this research were collected through collaboration with the research center and a survey conducted among farmers in the main test field selected. Figure 3 displays an image of the wheat crop taken from the field site.

Figure 3. Sheki Region Wheat Crop, 25 March 2022

To simulate the model, field data collected from land surveys were utilized, including crop types and corresponding coordinates. The field coordinates and crop types were recorded using a GPS E-Trex 10 device.

2.3. Methodology

The research methodology, as depicted in Figure 4, utilizes a modified crop model that combines drought-based indices using satellite imagery.

In the initial stage, the assessment of agricultural drought was conducted at a national level, covering the entire territory of the country. Satellite data from the Aqua satellite, based on international experience and recommended practices by UN-Spider, were employed for long-term agricultural drought monitoring over a period of 21 years.

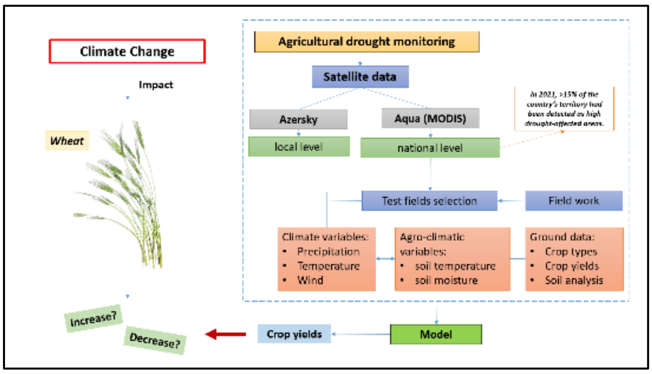

Figure 4. Methodological scheme

The results of the first stage revealed that more than 15% of the country's land is affected by severe drought conditions. These findings facilitated the identification of areas prone to extreme drought through national monitoring. Additionally, a survey was conducted among farmers and residents in the study area to gather local insights on agricultural drought and to test the Aquacrop model (Vanuytrecht, et al, 2014). The aim was to assess the impact of climate change on the yield of wheat cultivated in this specific area.

3. Results and Discussion

Initially, the VCI was tested in the first study area, yielding positive results. Subsequently, the obtained accuracy was applied to the entire country. The overall trend indicates an increased prevalence of drought compared to the 5-year period. However, there may be exceptions in specific months. For instance, in October 2020 (autumn), drought was observed in fewer territories compared to 2015, while dry areas expanded in other observed months. Notably, a significant difference was observed in April 2020 (spring) compared to previous periods.

In 2020, agricultural lands in the Ganja-Dashkasan region experienced a significant prevalence of drought, covering approximately 42% of the territory. To compare and validate the results, CHIRPS precipitation data was utilized. The analysis revealed an inverse relationship between the extent of drought and the amount of precipitation. Specifically, lower-than-average rainfall in March and early April led to a peak in drought during those months. Conversely, increased precipitation in May resulted in a decrease in drought levels, reaching a minimum during that month.

The experiments involved automated processing of a substantial amount of data using the Jupyter Notebook web-based computing platform. By comparing all the obtained results, it was determined that 2021 exhibited the highest drought severity compared to previous years. Figure 5 illustrates the spatial distribution of drought levels across the country in 2021.

Based on the classification of the obtained results, the study identified five levels of drought severity: no drought, light, medium, severe, and extreme. The analysis revealed that the extreme level of drought, represented by the color red on the map, covers an area of 13,809.1 km^2, accounting for 15.53% of the country's total territory.

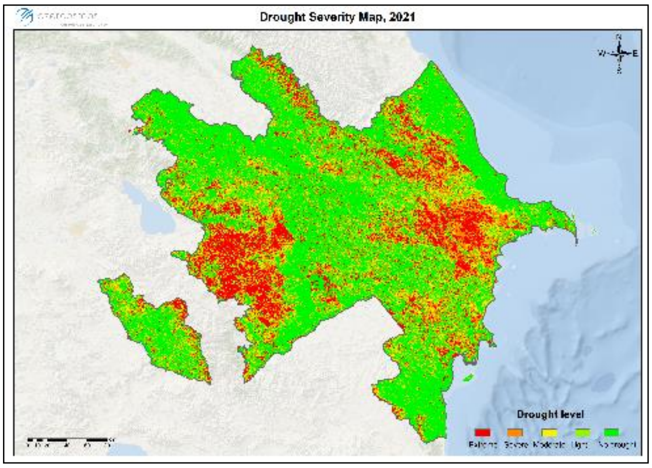

Figure 5. Drought Severity Map in Azerbaijan, 2021

The widely-used Normalized Difference Vegetation Index (NDVI) was computed. Additionally, the Chlorophyll Index (CI) was used to estimate the total amount of chlorophyll in plants. CI plays a crucial role in modern agriculture, providing valuable insights into crop development and aiding decision-making for food producers. CI values were computed for both test fields using Azersky satellite images taken on April 15, 2021. The resulting Chlorophyll concentration maps are depicted in Figure 6.

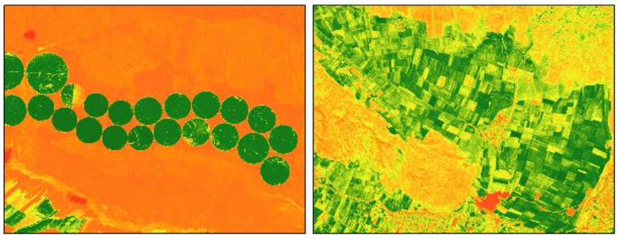

Figure 6. Chlorophyll concentration maps, 15 April 2021

In the chlorophyll concentration maps, green indicates high levels of chlorophyll during active vegetation growth, yellow represents average levels, and red represents low levels. The maps highlight the differences between irrigated and non-irrigated fields, with irrigated fields displaying a pronounced green color indicating high chlorophyll content. The chlorophyll content also varies within different crop parcels in the non-irrigated test area.

To monitor the crops, three images representing the 2022 growing season were processed on April 3rd, May 19th, and May 30th. These dates were selected for their minimal cloud cover. Figure 7 depicts the graphical representation of NDVI dynamics within three selected crop parcels. During the 2022 growing season, NDVI dynamics reflect the growth and biomass changes of crops. NDVI shows an increase at the beginning of the season, a plateau during flowering, and a decrease as the grain ripens.

The graph reveals a significant decline in NDVI from April 30 to May 19, indicating water scarcity due to drought in the region. Among the three index maps obtained, the highest vegetation level was observed in April 2022.

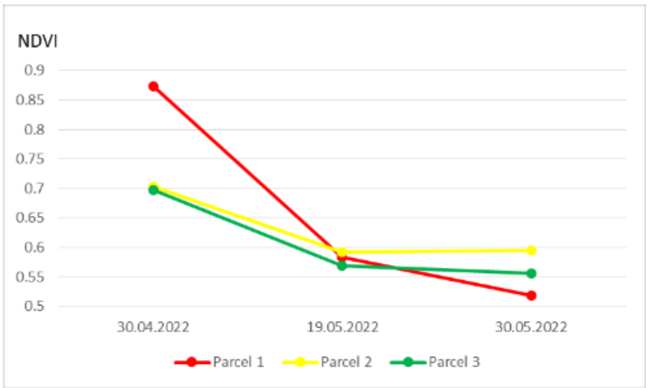

Figure 7. NDVI dynamics, growing season 2022

To assess temporal changes, images from 2018 were processed and compared with images from the same period in May, when vegetation is in the developmental and flowering stage. The vegetation index was calculated using Azersky images, as shown in Figure 8.

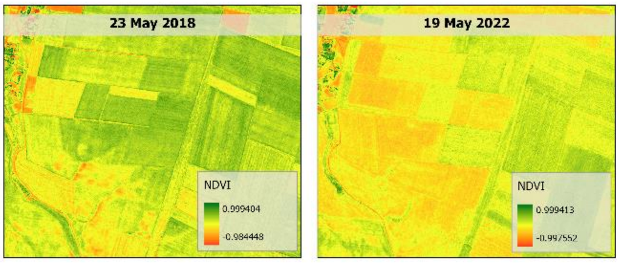

Figure 8. NDVI maps, May 2018 and 2022

The map highlights that vegetation development in May 2018 was superior to 2022, suggesting changes over the five-year period. However, it is important to acknowledge that these changes may be influenced by various natural factors not considered in this study. Comprehensive research combining remote sensing with ground-based work and long-term measurements is necessary for a more comprehensive understanding.

The third objective of this study was to evaluate the AquaCrop model's performance in simulating winter wheat growth under water deficit conditions in a rainfed test area. The model incorporates features such as canopy cover simulation, wheat growth simulation, and estimation. The AquaCrop model will be used to assess the impact of climate change on crop productivity through various scenarios.

The graph presented in Figure 9 reflects the crop's state on March 29th, showing normal development with a biomass of 4.716 t/ha. The absence of dry output indicates no water stress. It is important to note that the meteorological data used in the model came from a nearby meteorological station in Sheki city.

However, it is crucial to validate and refine the model results by incorporating accurate field-specific data, such as soil characteristics, temperature, precipitation, and evapotranspiration. Obtaining precise data has been challenging due to the lack of coordinated and parcel-specific information provided by farmers. To effectively utilize soil analysis information in GIS, it is necessary to plan fieldwork in the areas of interest over recent years.

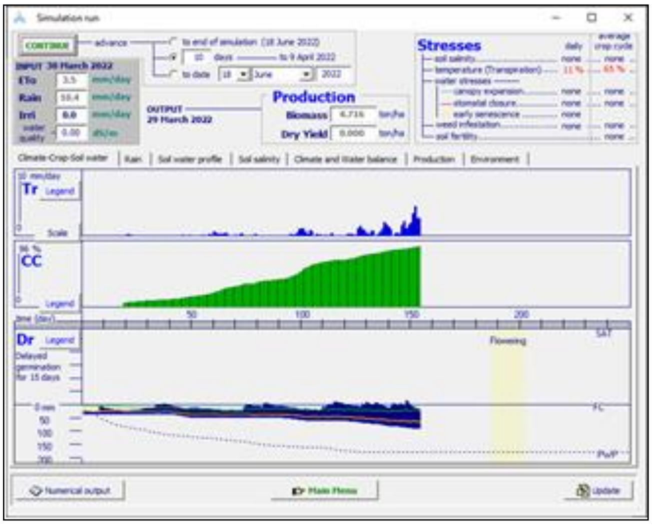
INPUT 30 March 2022
ETo 3.5 mm/day
Rain 10.4 mm/day
Irri 0.0 mm/day
water quality 0.00 dS/m
OUTPUT 29 March 2022
Production
Biomass 4.716 ton/ha
Dry Yield 0.000 ton/ha

Figure 9. Simulation Results of AquaCrop Model for Winter Wheat in 2022

4. Conclusion and Future Work

In the context of this scientific study, the following key findings have been obtained: (1) assessment of agricultural drought at the national level helped identify and quantify the areas affected by drought in the previous year; (2) monitoring of agricultural fields using vegetation indices revealed a strong correlation between NDVI and CI values and crop productivity in the selected parcels; (3) testing of the crop model for wheat production provided insights into the impact of climate change on crop yields, highlighting the importance of temperature and precipitation variations.

The research results have significant implications for understanding the potential effects of climate change on crop yields. They provide valuable knowledge for stakeholders and planners to develop appropriate strategies and plans to mitigate the impacts of climate change on agriculture.

Future research will focus on modifying and validating crop models to forecast crop yields more accurately. The development of a refined crop model will enable the tracking of changes in crop yields under different climate change scenarios. This information will be instrumental in implementing effective agricultural management systems and guiding land use and ecosystem management strategies.

Overall, the study highlights the role of geoinformation technologies in assessing and monitoring agricultural fields, including the impacts of climate change such as agricultural drought. The findings contribute to the understanding of ecological balance and provide a foundation for informed decision-making in agriculture and land management.

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References

Funk, C. C., Peterson, P. J., Landsfeld, M. F., Pedreros, D. H., Verdin, J. P., Rowland, J. D., ... & Verdin, A. P. (2014). A quasi-global precipitation time series for drought monitoring. US Geological Survey data series, 832(4), 1-12.

Kogan F., «Application of vegetation index and brightness temperature for drought detection» Advances in Space Research, 15(11), 100, 1995.

Liu, X., Zhu, X., Pan, Y., Li, S., Liu, Y., & Ma, Y. (2016). Agricultural drought monitoring: Progress, challenges, and prospects. Journal of Geographical Sciences, 26, 750-767. https://doi.org/10.1007/s11442-016-1297-9

Majorova, V. I. (2013). Kontrol' sostojanija sel'skohozjajstvennyh polej na osnove prognozirovanija dinamiki indeksa NDVI po dannym kosmicheskoj mul'tispektral'noj i giperspektral'noj s'jomki / V.I. Majorova, A.M. Bannikov, D.A. Grishko [i dr.] // Nauka i obrazovanie: jelektronnoe nauchno-tehnicheskoe izdanie, 199–228.

UN-SPIDER. (2017). Recommended Practice: Drought Monitoring Using the Vegetation Condition Index (VCI). Accessed, 10, 9206.

Vanuytrecht, E., Raes, D., Steduto, P., Hsiao, T. C., Fereres, E., Heng, L. K., ... & Moreno, P. M. (2014). AquaCrop: FAO's crop water productivity and yield response model. Environmental Modelling & Software, 62, 351-360.