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Nozimjon Teshaev Nusratovich
PhD Student, Department of Geodesy and Geoinformatics, "TIIAME" National Research University
Bobomurod Makhsudov Yuldoshovich
Head of the Department for the Implementation of Agro-Space Technologies

REMOTE SENSING-BASED ASSESSMENT OF CLIMATIC DRIVERS AFFECTING AGRICULTURAL CROP DEVELOPMENT IN THE BUKHARA REGION

Abstract. This study investigates the influence of key climatic factors on cotton fields development using remote sensing data. The research was conducted in the Bukhara region, focusing on the correlation between vegetation indices (NDVI, EVI, MNDWI, SAVI) and climatic variables, including land surface temperature, air temperature, precipitation, solar radiation, and ET0. Pearson correlation analysis revealed that crop growth showed significant negative correlations with air temperature and evapotranspiration, while precipitation and solar radiation demonstrated positive associations with vegetation indices. These findings highlight the potential of integrating remote sensing and climatic datasets for crop monitoring and yield forecasting in arid environments.

Keywords: remote sensing, vegetation indices, cotton, climatic factors, NDVI, ET0, Bukhara region, correlation analysis.

ОЦЕНКА КЛИМАТИЧЕСКИХ ФАКТОРОВ, ВЛИЯЮЩИХ НА РАЗВИТИЕ СЕЛЬСКОХОЗЯЙСТВЕННЫХ КУЛЬТУР В БУХАРСКОЙ ОБЛАСТИ, НА ОСНОВЕ ДАННЫХ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ

Аннотация. В данной статье рассматривается влияние основных климатических факторов на развитие сельскохозяйственных культур на основе данных дистанционного зондирования. Исследование проведено в условиях Бухарской области с использованием вегетационных индексов NDVI, EVI, MNDWI и SAVI, а также климатических показателей: температура поверхности земли, температура воздуха, осадки, солнечная радиация и ЭТ0. Корреляционный анализ Пирсона показал значительные отрицательные связи роста культур с температурой воздуха и эвапотранспирацией, а также положительные корреляции с осадками и солнечной радиацией. Полученные результаты подтверждают эффективность интеграции данных ДЗЗ и климатических наблюдений для мониторинга и прогнозирования урожайности в засушливых регионах.

Ключевые слова: дистанционное зондирование, вегетационные индексы, хлопок, климатические факторы, NDVI, ЭТ0, Бухарская область, корреляционный анализ.

Introduction

Agricultural production is highly sensitive to climatic variability, particularly in arid and semi-arid regions where water availability and heat stress are critical determinants of crop growth [1-5]. Understanding the interactions between vegetation dynamics and climatic drivers is essential for sustainable agricultural management and yield forecasting [4]. Recent advances in remote sensing have provided powerful tools to monitor vegetation conditions, assess land surface parameters, and analyze the impacts of climate variability on crop development at regional and local scales [5-7, 10].

Vegetation indices such as the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Modified Normalized Difference Water Index (MNDWI), and Soil Adjusted Vegetation Index (SAVI) are widely used to characterize crop vigor, canopy cover, and soil moisture status [10-13]. When combined with climatic variables including air temperature, land surface temperature, precipitation, solar radiation, and reference evapotranspiration

(ET0), these indices allow for a comprehensive evaluation of the factors influencing crop growth [1, 6-9].

The Bukhara region of Uzbekistan represents a typical arid environment where agriculture is strongly constrained by climatic conditions. High summer temperatures, limited precipitation, and strong evapotranspiration rates create challenges for crop productivity and water management. Therefore, assessing the correlations between vegetation indices and climatic factors in this region provides valuable insights into crop–climate interactions and helps to identify the most influential drivers of crop development.

This study applies Pearson correlation analysis to quantify the relationships between vegetation indices and climatic parameters based on remote sensing and meteorological datasets. The findings contribute to a better understanding of climate–vegetation interactions in arid agricultural systems and highlight the role of remote sensing in supporting sustainable crop monitoring and management strategies.

Materials and Methods

Study Area

The study was conducted in the Bukhara region of Uzbekistan, which is characterized by an arid climate with hot summers and limited precipitation. Agriculture in this region is highly dependent on irrigation, making the evaluation of climatic drivers critical for sustainable crop production, especially for cotton.

Data Sources

Remote sensing data were obtained from the Sentinel-2 MSI (MultiSpectral Instrument) satellite, which provides high-resolution multispectral imagery with a spatial resolution of 10–20 m and a revisit time of 5 days. Climatic variables, including land surface temperature (LST), air temperature at 2 m height, precipitation, solar radiation, and reference evapotranspiration (ET0), were acquired from MODIS Terra/Aqua, ERA5 satellites.

Vegetation indices were calculated from Sentinel-2 spectral bands, specifically the red (B4: 665 nm), near-infrared (B8: 842 nm), and shortwave infrared (B11: 1610 nm; B12: 2190 nm) bands. The following indices were derived:

Normalized Difference Vegetation Index (NDVI):

$$NDVI = (NIR-Red)/(NIR+Red)$$

Enhanced Vegetation Index (EVI):

$$EVI = G*((NIR-Red)/(NIR+C1*Red-C2*Blue+L))$$

where G=2.5, C1=6, C2=7.5, and L=1

Soil Adjusted Vegetation Index (SAVI):

$$SAVI = (NIR-Red) *(1+L)/ (NIR+Red+L)$$

where L=0.5L = 0.5L=0.5 is the soil brightness correction factor.

Modified Normalized Difference Water Index (MNDWI):

$$MNDWI = (Green-SWIR)/(Green+SWIR)$$

where the green band is B3 (560 nm) and SWIR is B11 or B12.

Climatic Variables

Land Surface Temperature (LST) was retrieved from thermal remote sensing products. Air Temperature (2 m), precipitation, and solar radiation were obtained from the ERA5 reanalysis dataset. Reference evapotranspiration (ET0) was calculated using the FAO Penman–Monteith equation:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \frac{900}{T-273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.43u_2)}$$

ET0 - Evapotranspiratsiya ko'rsatkichi (mm/s), Rn-tashqi radiatsiya (MJ/m²), G- Tuproqdan chiqadigan energiya (MJ/m²), T - Havoning harorati (°C), u2 - Shamol tezligi (m/s), es - Havodagi to'yingan bug' gazining bosimi (kPa), ea - avodagi bug' gazining bosimi (kPa), Δ - Havodagi to'yingan bug' gazining bosimining haroratga bog'liq o'zgarishi (kPa/°C), γ - Psixrometrik doimiy (kPa/°C).

Statistical Analysis

Pearson correlation analysis was used to evaluate the relationships between vegetation indices and climatic factors. The Pearson correlation coefficient (rrr) was calculated as:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum ¿¿¿}$$

where xi and yi represent paired values of vegetation indices and climatic variables, and x¯, y¯ are their respective means. The correlation coefficient ranges from –1 (strong negative correlation) to +1 (strong positive correlation). Correlation matrices were generated to visualize the strength and direction of associations. This approach allowed for the identification of the most influential climatic drivers affecting crop development in the Bukhara region.

Results

The correlation analysis revealed distinct relationships between vegetation indices and climatic variables in the Bukhara region (Figure 1). The results demonstrated that vegetation indices were strongly associated with each other, while their correlations with climatic parameters varied in magnitude and direction.

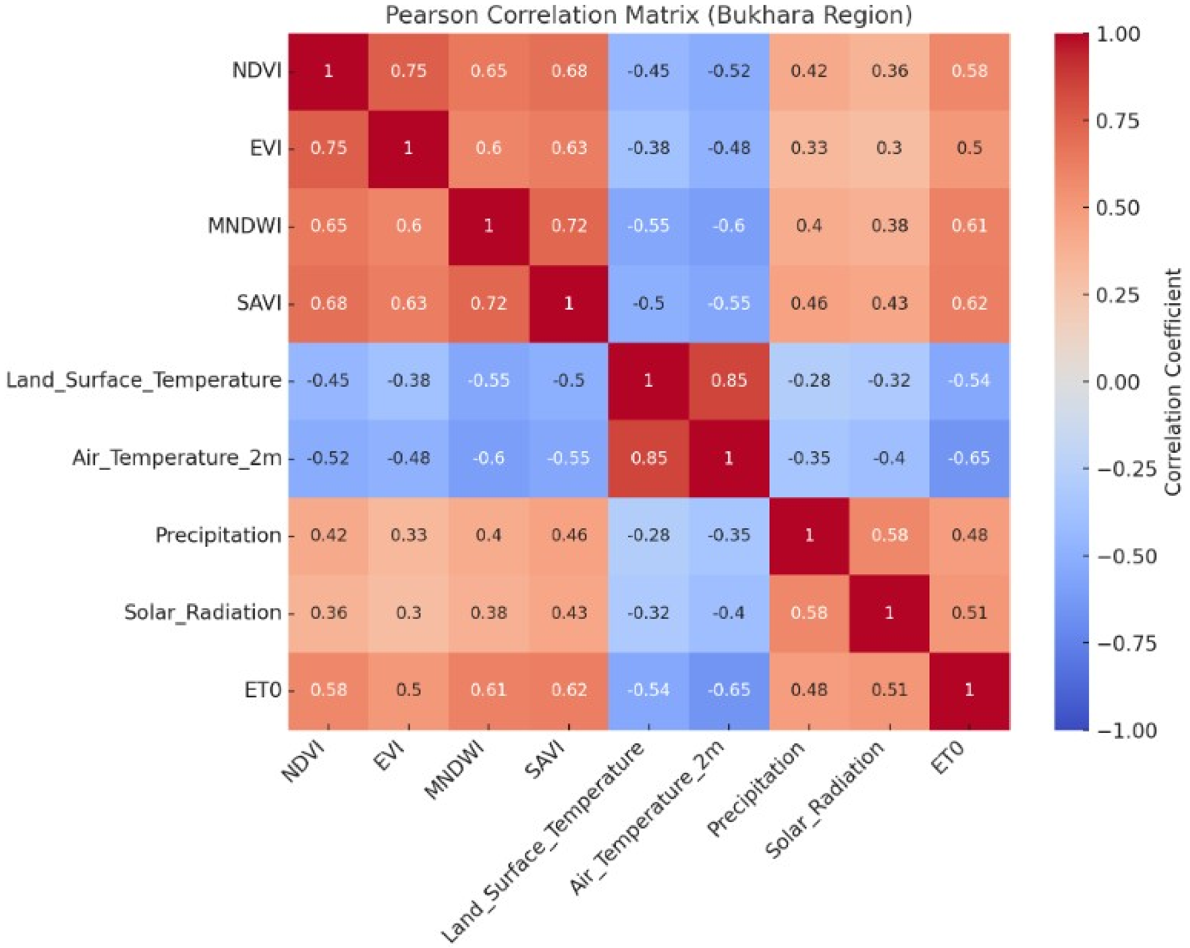

Figure 1. Pearson correlation matrix between vegetation indices (NDVI, EVI, SAVI, MNDWI) and climatic variables (air temperature, land surface temperature, precipitation, solar radiation, and ET0) in the Bukhara region. Positive correlations are indicated by warmer colors, while negative correlations are shown by cooler tones. The figure highlights the negative impact of temperature on vegetation growth and the positive role of precipitation and solar radiation.

Vegetation Indices Correlations: NDVI, EVI, SAVI, and MNDWI showed high positive correlations among themselves (NDVI–EVI: r = 0.75; NDVI–SAVI: r = 0.68; SAVI–MNDWI: r = 0.72), indicating consistency in detecting crop vigor and canopy dynamics. These indices reflect similar vegetation conditions, although MNDWI also accounts for surface moisture effects.

Temperature Effects: A strong negative correlation was observed between vegetation indices and both land surface temperature (LST) and air temperature at 2 m. For instance, NDVI was negatively correlated with air temperature ($r = -0.52$) and LST ($r = -0.45$). The highest negative correlation was between MNDWI and air temperature ($r = -0.60$), suggesting that higher thermal stress reduces vegetation activity and surface water availability.

Moisture and Radiation Effects: Positive correlations were found between vegetation indices and precipitation (NDVI–precipitation: $r = 0.42$; SAVI–precipitation: $r = 0.46$) as well as solar radiation (NDVI–solar radiation: $r = 0.36$; SAVI–solar radiation: $r = 0.43$). These results indicate that crop growth is favored under adequate rainfall and solar energy supply, both of which contribute to photosynthetic activity and vegetation greenness.

Evapotranspiration (ET0): Reference evapotranspiration (ET0) exhibited positive correlations with vegetation indices (NDVI–ET0: $r = 0.58$; SAVI–ET0: $r = 0.62$; MNDWI–ET0: $r = 0.61$). This suggests that periods of active crop growth are associated with higher evapotranspiration demand, reflecting increased vegetation water use. However, excessive ET0 values combined with high air temperature may also indicate water stress conditions in the absence of sufficient irrigation.

Overall, the results emphasize that crop development in the Bukhara region is highly sensitive to climatic variability. Temperature extremes exert a negative influence on vegetation dynamics, while precipitation and solar radiation contribute positively to crop performance. The correlation with ET0 highlights the dual role of evapotranspiration as both a driver of plant productivity and a potential stress factor under water-limited conditions.

Conclusions

This study demonstrated the usefulness of remote sensing techniques in assessing the influence of climatic drivers on agricultural crop development in the Bukhara region of Uzbekistan. By integrating Sentinel-2 vegetation indices

(NDVI, EVI, SAVI, MNDWI) with climatic variables (air temperature, land surface temperature, precipitation, solar radiation, and ET0), Pearson correlation analysis revealed several important findings.

First, vegetation indices were highly correlated with each other, confirming their reliability in capturing crop canopy dynamics under arid conditions. Second, strong negative correlations between vegetation indices and temperature variables highlight the detrimental impact of heat stress on vegetation activity. In contrast, positive correlations with precipitation and solar radiation emphasize their beneficial role in supporting crop growth. Finally, the significant associations between vegetation indices and ET0 underline the importance of water demand as both a productivity indicator and a potential stress factor when irrigation is insufficient.

Overall, the findings indicate that crop development in arid regions such as Bukhara is highly sensitive to climatic variability. The integration of remote sensing data with climatic parameters provides a valuable framework for monitoring crop performance, forecasting yield, and developing sustainable agricultural management strategies. Future work should focus on expanding the temporal scale of analysis, incorporating additional biophysical variables, and validating remote sensing–based results with in-situ field observations.

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