

# NDVI DYNAMICS AND ITS RELATIONSHIP WITH CLIMATIC FACTORS IN THE SHELL RIDGE ISLAND OF THE YELLOW RIVER DELTA, CHINA

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**Abstract.** Understanding changes in Normalized Difference Vegetation Index (NDVI) and its impact factors is important for regional vegetation protection and restoration. Based on NDVI from the Landsat TM/OLI dataset and meteorological data, we analyzed the changes of NDVI and its relationships with climatic factors in the shell ridge island of the Yellow River Delta in China from 1991 to 2020. The results showed that NDVI significantly increased in the shell ridge island of the Yellow River Delta from 1991 to 2020, and the rate was 0.03/10 year. The mean value of NDVI was less than 0.20, indicating that the regional vegetation cover is low. The relationships between NDVI and climatic factors were different in the shell ridge island of the Yellow River Delta. The correlation between NDVI and precipitation was stronger than that of temperature in the study area. Compared to other climatic factors, there was a significant positive correlation between NDVI and precipitation in August during the study period. Our findings suggest that precipitation plays an important role in influencing NDVI in the shell ridge island of the Yellow River Delta.

**Keywords:** *NDVI, remote sensing, trends, climate change, Yellow River Delta*

## Introduction

Vegetation is a crucial component of the global terrestrial ecosystem and climate (Jiang et al., 2006). It plays an important role in soil preservation, water conservation, and atmospheric regulation (Gao et al., 2023; Wang et al., 2022). Moreover, changes in vegetation cover can reflect regional ecological conditions (Gu et al., 2018). Vegetation indices play an important role in detecting vegetation growth (Liu et al., 2019; Sun et al., 2015). As the development of remote sensing technology, vegetation index is widely used in monitoring vegetation dynamics at different spatial and temporal scales. Among vegetation indices, Normalized Difference Vegetation Index (NDVI) is highly sensitive to variations in vegetation growth (Gu et al., 2018; Huete et al., 1997). In addition, due to NDVI is a reliable indicator of vegetation dynamics, which has been widely used by many scholars (Liang et al., 2023; Muir et al., 2021).

Climate change has led to significant changes in vegetation cover in some regions of the world, such as Africa and China (Thi et al., 2023; Herrmann et al., 2005; Jin et al., 2022). The study of the characteristics of vegetation cover and its response to climate change is an important aspect of global change research (Muir et al., 2021). Vegetation index can characterize changes in vegetation cover, and studies on vegetation change have extended from regional to global (Muir et al., 2021; Liu et al., 2015). In recent decades, many studies have focused on monitoring vegetation dynamics (Herrmann et

al., 2005), regional NDVI characteristics (Dai et al., 2022) and its driving factors at different spatial and temporal scales (Liu et al., 2019; Bianchi et al., 2020). Besides, vegetation changes have been influenced by many factors, including climate change and human activities. In terms of climate change, the most direct and important influences on vegetation change are temperature and precipitation (Sanz et al., 2021; Wang et al., 2022). Owing to the different response of vegetation to climate change, the relationships between precipitation, temperature and vegetation index varied across different regions (Yue et al., 2019). For example, precipitation is the main driver of vegetation change in arid and semi-arid environments (Thi et al., 2023; Gao et al., 2022). In contrast, vegetation change in the eastern coastal areas of China is mainly influenced by temperature (Jin et al., 2023). Therefore, it is important to clarify the driving mechanisms between vegetation change and climatic factors, which helps to understand the response of vegetation to climate change.

As one of the three major ancient shell ridges in the world, the shell ridge of the Yellow River Delta plays an important role in maintaining regional biodiversity and ecosystem function (Tian et al., 2009). Due to natural and anthropogenic disturbances, vegetation degradation was found in some areas of the shell ridge ecosystems (Zhao et al., 2015). It poses a threat to regional ecological security and sustainable development. Moreover, the habitats of shell ridge island are markedly arid, and water is an important factor limiting regional plant growth (Zhao et al., 2015). In recent years, previous studies mainly focused on plant growth (Guan et al., 2019), photosynthetic physiology (Gao et al., 2017), community distribution and its relationship with environmental factors (Cui et al., 2010) in the shell ridge island of the Yellow River Delta. However, little attention has been paid to NDVI changes and its relationship with climatic factors in the shell ridge island of the Yellow River Delta. In this study, the aims are (1) to examine temporal patterns of NDVI, and (2) to identify the relationships between NDVI and climatic factors (precipitation and temperature). The results can provide theoretical support for the protection and restoration of regional vegetation in the study area.

## Materials and methods

### Study area

This study focused on Wangzi island (38°12'N-38°15'N, 117°53'E-117°57'E), which is located in Binzhou Shell Ridge Island and Wetland National Natural Reserve, Shandong Province, northern China (Fig. 1). The climate is characterized by a temperate continental monsoon climate, with an average annual temperature of 13.2°C and an average annual precipitation is 475 mm (Huo et al., 2021; Huang and Li, 2004). Precipitation is mostly concentrated in the months of June, July, and August. About 68% of the annual precipitation falls between June and August (Xu et al., 2017). These climate condition make the study area is vulnerable to changes in precipitation. The vegetation is dominated by shrubs, perennial and annual grasses such as *Tamarix chinensis*, *Phragmites australis*, *Artemisia mongolica*, *Zoysia macrostachya* and *Setaria viridis*. The natural reserve was established in 1999 to protect the shell ridge island and wetland ecosystems.

### Data sources and processing

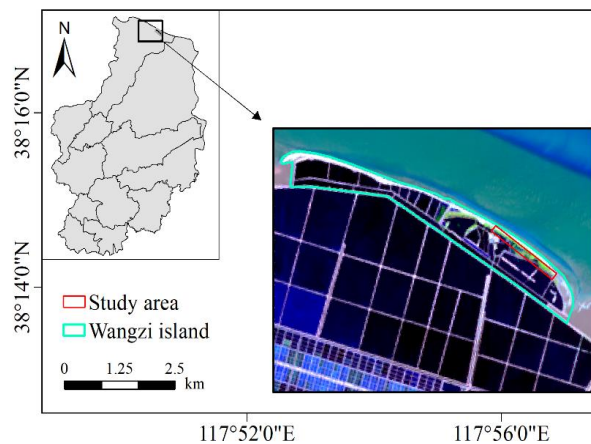
Landsat data during 1991-2020 were acquired from the Geospatial Data Cloud site, Computer Network Information Center, Chinese Academy of Sciences

(<https://www.gscloud.cn/>), including Landsat TM (before 2012) and Landsat 8 OLI (after 2013). These remote sensing images were selected in August or September, and 19 cloud-free images were used in our study. NDVI images with a spatial resolution of 30 m. These datasets were transformed into Krasovsky\_1940\_Albers by using ArcGIS software. According to previous studies, NDVI greater than 0 was used to identify vegetation areas, and none vegetation areas were excluded in the study area (Wang et al., 2013; An et al., 2017). NDVI data were extracted for each year using ArcGIS software, and the mean NDVI values were used to represent vegetation growth. The meteorological data were obtained from the NASA Prediction of Worldwide Energy Resources Data Access Viewer (<https://power.larc.nasa.gov/data-access-viewer/>), including monthly precipitation and temperature from 1991 to 2020.

The formula of NDVI is calculated as follows:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (Eq.1)$$

where NIR is the surface reflectance of near-infra spectrum; R is the surface reflectance of visible red spectrum. The NIR and R are the band 4 (0.76-0.90  $\mu\text{m}$ ) and band 3 (0.63-0.69  $\mu\text{m}$ ) for Landsat TM, respectively. The NIR and R are the band 5 (0.85-0.88  $\mu\text{m}$ ) and band 4 (0.64-0.67  $\mu\text{m}$ ) for Landsat 8 OLI, respectively.



**Figure 1.** Location of the study area

## Methods

### Trend analysis

The trend analysis is widely used to reflect the long-term changing trend of NDVI (Xu et al., 2016; Ali Shah et al., 2023). Therefore, the trend analysis was used in this study. The formula is calculated as follows:

$$\theta_{slope} = \frac{n \times \sum_{i=1}^n i \times NDVI - \sum_{i=1}^n i \times \sum_{i=1}^n NDVI_i}{n \times \sum_{i=1}^n i^2 - \left( \sum_{i=1}^n i \right)^2} \quad (Eq.2)$$

where  $\theta_{\text{slope}}$  represents the slope of NDVI;  $i$  represents the  $i$ th year,  $n$  represents the total number of years;  $\text{NDVI}_i$  represents the NDVI value for the  $i$ th year. If  $\theta_{\text{slope}}$  greater than 0 indicates an increasing trend, and vice versa.

### *Coefficient of variation*

The coefficient of variation ( $CV = \text{standard deviation}/\text{mean}$ ) is widely used to reflect the annual volatility of NDVI (Chen et al., 2021; Wang et al., 2013). Therefore, the  $CV$  was used to characterize the fluctuation of NDVI in this study.

### *Anomaly analysis*

The anomaly analysis shows the degree of deviation of NDVI from the mean value in each year. This can well reflect the characteristics of NDVI changes (Feng et al., 2023). The formula as follows:

$$\text{NDVI}_{\text{anomaly}} = \text{NDVI}_i - \text{NDVI}_{\text{mean}} \quad (\text{Eq.3})$$

where  $\text{NDVI}_{\text{anomaly}}$  represents the NDVI anomaly for the  $i$ th year,  $\text{NDVI}_i$  represents the value of NDVI for the  $i$ th year,  $\text{NDVI}_{\text{mean}}$  represents the mean value NDVI (1991 to 2020). When  $\text{NDVI}_{\text{anomaly}} > 0$ , NDVI for the  $i$ th year was higher than the multi-year average and vice versa.

### *Correlation analysis*

Climatic factors such as precipitation and temperature are the main influences on NDVI (Wang et al., 2022; Worku et al., 2023). In this study, the climatic factors including: annual precipitation, and average annual temperature, precipitation and temperature for each month from June to September, spring and summer. Pearson correlation analysis was performed between NDVI and climatic factors. The formula is as follows:

$$R = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \quad (\text{Eq.4})$$

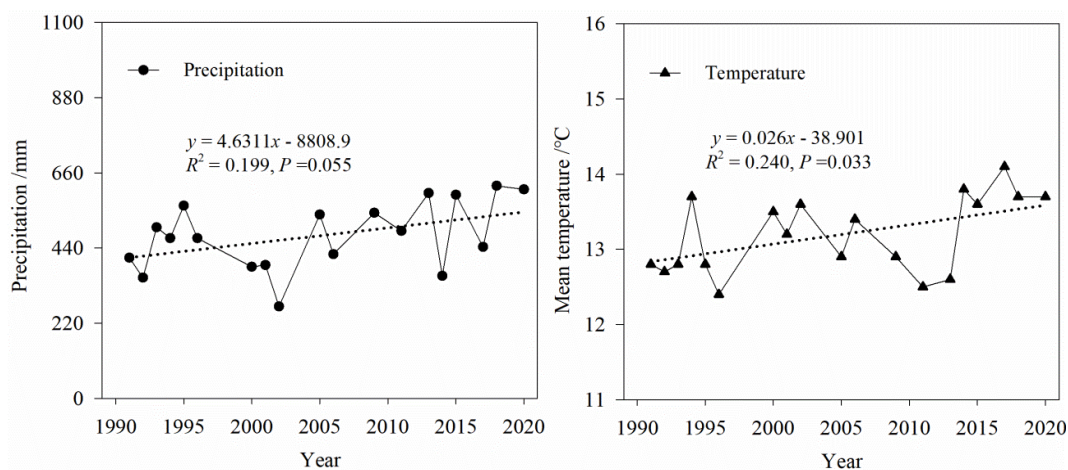
where  $R$  means the correlation coefficient between two variables ( $x$  and  $y$ );  $x_i$  represents the NDVI for the  $i$ th year;  $\bar{x}$  represents the mean value of NDVI;  $y_i$  represents the different climatic factors for the  $i$ th year;  $\bar{y}$  represents the mean value of different climatic factors.  $R$  ranges from -1 to 1. The larger the  $R$ , the stronger correlation is.

## **Results**

### ***Temporal changes of precipitation and temperature***

Figure 2 shows the temporal dynamics of precipitation and temperature in the shell ridge island of the Yellow River Delta from 1991 to 2020. Precipitation has an overall increasing trend from 1991 to 2020, at a rate of 4.6311 mm per year. The highest value

of precipitation was recorded in 2018 (622.3 mm), while the lowest value was recorded in 2002. Temperature showed a significant increasing trend at a rate of 0.026°C per year ( $P < 0.05$ ), which was similar to the trend of precipitation.

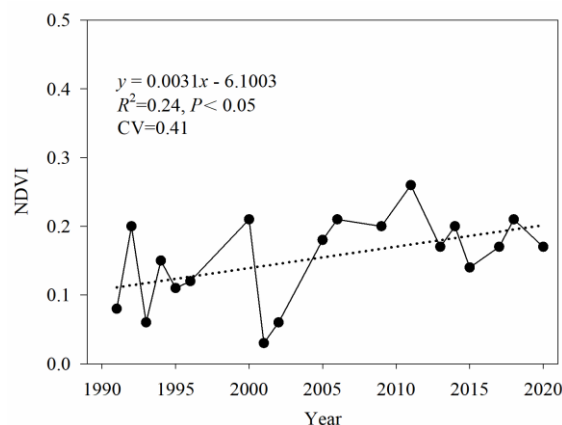


**Figure 2.** Changes of annual precipitation and average annual temperature in the shell ridge island of the Yellow River Delta from 1991 to 2020

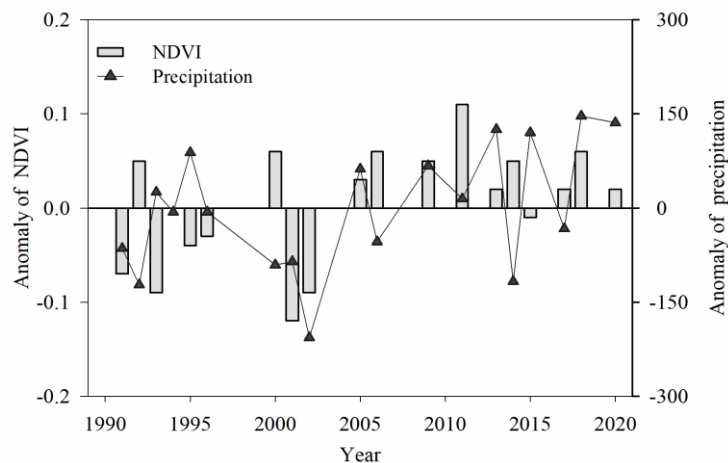
### Variation of NDVI and precipitation

NDVI showed a significant increasing trend in the shell ridge island of the Yellow River Delta from 1991 to 2020 ( $P < 0.01$ ), with an increasing rate of 0.0031 per year (Fig. 3). Meanwhile, a more rapid increase in NDVI was observed after 2001. In addition, NDVI ranged from 0.03 to 0.26. The highest value of NDVI was in the year 2011, while the lowest value of NDVI was in the year 2001. The average value of NDVI was 0.15, and the coefficient of variation of NDVI was 0.41.

Figure 4 shows the anomaly of NDVI in the shell ridge island of the Yellow River Delta from 1991 to 2020. In the years 1991, 1993, 1995, 1996, 2001, 2002 and 2015, NDVI was lower than the average value. In contrast, NDVI was greater than the average value for the rest of the year. Concurrently, a similar pattern was found for the anomaly of precipitation.



**Figure 3.** Temporal variation of NDVI in the shell ridge island of the Yellow River Delta from 1991 to 2020



**Figure 4.** Anomaly of NDVI and precipitation in the shell ridge island of the Yellow River Delta from 1991 to 2020

### Correlations between NDVI and climatic factors

The correlations between NDVI and climatic factors were different in the shell ridge island of the Yellow River Delta (Table 1). Except for precipitation in June and July and temperature in September and spring, positive correlations were observed between NDVI and other climatic factors. NDVI was significantly and positively correlated with precipitation in August (Fig. 5,  $P < 0.05$ ), with  $R^2$  of 0.236. In contrast, the correlations between NDVI and other climatic factors were not significant.

### Discussion

An increasing trend of NDVI was observed in the shell ridge island of the Yellow River Delta during the study period, especially after 2001. It reflects the improvement of the regional ecological environment. Similarly, previous studies reported that NDVI exhibited an increasing trend in China (Liu et al., 2021) and the Yellow River Delta (Liu and Lei, 2015). In this study, precipitation and temperature showed an increasing trend during the study period, which provide a favorable climatic condition for plant growth. Moreover, the implementation of ecological protection reduces the negative impacts of human activities on regional vegetation. It also maintains the stability of regional vegetation, and further helps to promote an increase in the regional NDVI. The Binzhou Shell Ridge Island and Wetland National Natural Reserve was established in 1999, and local governments take measures to protect regional vegetation such as the enclosure of protected area. Therefore, vegetation has been improved in some areas.

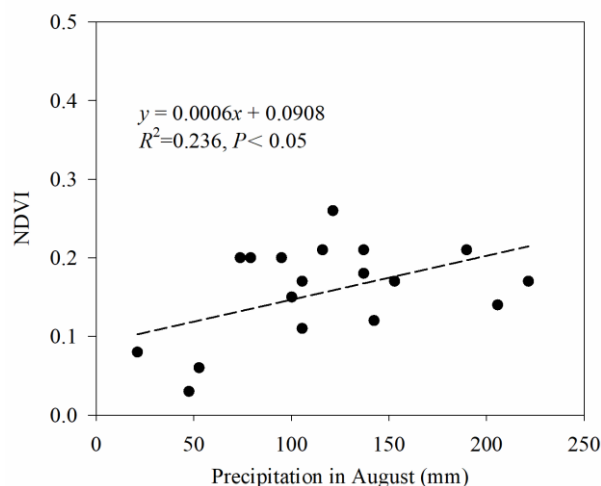
Changes in precipitation are the main driver of vegetation change in areas where vegetation is relatively sparse (Wang et al., 2014). NDVI is less than 0.30 in the shell ridge island of the Yellow River Delta, which can be characterized as low vegetation cover (Yue and Yue, 2023). As a result, NDVI was more sensitive to changes in precipitation in this study region. In terms of NDVI deviation, NDVI was significantly lower in the study area in 2001 and 2002. This is mainly related to the regional droughts that occurred in 2001 and 2002 (Ren et al., 2016). These results also reflected that regional vegetation growth was more susceptible to drought stress. Water resource is relatively scarce in the study area, where the average annual precipitation is less than

500 mm. Zhao et al. (2015) also reported that the shell ridge island is relatively dry, and regional plant growth is mainly limited by water. Plants altered the allocation of biomass to adapt to unfavorable conditions such as drought, which resulted in a reduction in the aboveground biomass of the community (Wu et al., 2013). Additionally, previous studies have shown that NDVI decreases as water becomes less available (Aguilar et al., 2012; Yin et al., 2016).

**Table 1.** Correlations between NDVI and climatic factors in the shell ridge island of the Yellow River Delta

| Climatic factor            | Correlation coefficient (r) | P     |
|----------------------------|-----------------------------|-------|
| Precipitation in June      | -0.35                       | 0.14  |
| Precipitation in July      | -0.11                       | 0.67  |
| Precipitation in August    | 0.49                        | 0.03* |
| Precipitation in September | 0.12                        | 0.63  |
| Precipitation in spring    | 0.30                        | 0.21  |
| Precipitation in summer    | 0.12                        | 0.62  |
| Annual precipitation       | 0.23                        | 0.34  |
| Temperature in June        | 0.08                        | 0.76  |
| Temperature in July        | 0.31                        | 0.19  |
| Temperature in August      | 0.16                        | 0.52  |
| Temperature in September   | -0.09                       | 0.70  |
| Temperature in spring      | -0.05                       | 0.85  |
| Temperature in summer      | 0.22                        | 0.36  |
| Average annual temperature | 0.08                        | 0.75  |

\* $P < 0.05$



**Figure 5.** Relationship between NDVI and precipitation in August in the shell ridge island of the Yellow River Delta

Climate change is a major driver of vegetation change. Many previous studies have focused on meteorological factors such as temperature and precipitation that influenced changes in NDVI (Ghebregabher et al., 2020; Chu et al., 2019). Among the climatic

factors, precipitation and temperature are the main factors influencing vegetation change. The precipitation is relatively low in northern China, where vegetation growth is highly dependent on precipitation. In this study, NDVI was strongly related to precipitation in August compared to temperature, suggesting that regional NDVI was more sensitive to precipitation than temperature in the shell ridge island of the Yellow River Delta. This is mainly due to the fact that precipitation is an important factor for vegetation growth in northern China (Di et al., 2021). Our result is in agreement with the result of An et al. (2017), who found that NDVI increases with increasing precipitation in the Yellow River Delta.

In terms of the relationship between NDVI and climatic factors, a significant correlation between NDVI and precipitation in August was observed in the shell ridge island of the Yellow River Delta. However, no significant correlation was found between NDVI and temperature. It indicates that the change in NDVI is mainly influenced by precipitation in August rather than annual precipitation in this study. Qu et al. (2009) reported that NDVI was mainly influenced by precipitation in June and July, not by annual precipitation in Horqin, northern China. In addition, Su et al. (2015) found that NDVI is positively correlated with mean monthly precipitation in the agricultural-pastoral area of northern China, with a relatively strong correlation in July. The above results suggest that the temporal distribution of precipitation effects on vegetation growth varies at different spatial scales in northern China. Moreover, the peak growing season (August) with high temperatures and vegetation needs more water to grow in the shell ridge island of the Yellow River Delta. Increased precipitation in August improved regional soil moisture conditions, which can promote the vegetation growth in the study area.

## Conclusions

This study investigated the inter-annual dynamics of NDVI and its relationship with climatic factors in the shell ridge island of the Yellow River Delta based on remote sensing data. NDVI displayed an obvious increasing trend in the shell ridge island of the Yellow River Delta from 1991 to 2020. At the temporal scale, NDVI exhibited a high degree of interannual variability. Compared to temperature, regional NDVI was more sensitive to changes in precipitation in the shell ridge island of the Yellow River Delta. Moreover, this study identified the most important climatic factors influencing NDVI in the shell ridge island. NDVI was strongly and positively related to precipitation in August, indicating that an increase in precipitation during the growing season can promote the growth of NDVI in the study area.

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