THE SPATIOTEMPORAL CHARACTERISTICS OF VEGETATION COVERAGE AND ITS DRIVING FACTORS IN THE YELLOW RIVER DELTA

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Abstract. Understanding the spatial-temporal dynamics of vegetation and its driving mechanisms is important for regional ecological restoration. Based on Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data, climate and human factors, vegetation dynamics and its driving factors were analyzed in the Yellow River Delta from 2000 to 2016. The result showed that NDVI experienced a significant increase trend over the past 17 years, and at a rate of 0.007 year^{-1}. The study area was mainly covered with high and extremely high NDVI (62.87%), which was mainly distributed in the southwest, middle, and northeast of the Yellow River Delta. The area of stable vegetation regions was higher than that of vulnerable vegetation regions in the study area. The area of degraded vegetation accounted for 13.97% of the study area, and the slightly and severely degraded vegetation was the main degraded vegetation types in the Yellow River Delta. Compared to other vegetation types, the area of degraded grassland was the largest. Areas of severely degraded vegetation were mainly distributed in the north and south of the Yellow River Delta, particularly in Hekou and Dongying. NDVI was significantly affected by growing season precipitation and population in the Yellow River Delta. In the future, considerable attention should be paid to the degraded regions especially in coastal areas in the Yellow River Delta.
Keywords: *vegetation dynamics, climate change, NDVI, spatiotemporal change, Yellow River Delta*

Introduction

Vegetation is an important component of the terrestrial ecosystem (Feng et al., 2021; Ghorbanian et al., 2022). It not only plays an import role in regulating the global carbon balance and maintaining climate stability, but also as an indicator reflects ecological and environmental conditions (Fokeng and Fogwe, 2022; Gao et al., 2022). As the global climate change has become increasingly prominent, people have paid more attention to the changes of the ecological environment. In recent decades, quantifying vegetation change becomes one of the hot research topics in global change research (Alemu et al., 2020; Sun et al., 2021; Wang et al., 2021). Moreover, vegetation index such as the Normalized Difference Vegetation Index (NDVI) has close relationships with vegetation cover and productivity, and it can well reflect vegetation dynamics (Yan et al., 2021; Worku et al., 2023). Thus, it has been widely used in monitoring vegetation changes at different temporal and spatial scales (Jia, 2013; Jiang et al., 2015; Bianchi et al., 2020; Guo et al., 2022).

Vegetation degradation is one of the important factors that limit regional ecological environmental improvement. It is an important ecological problem which draws much attention by scholars worldwide (Zhou et al., 2014; Zoungrana et al., 2018; Akinyemi and Kgomo, 2019). The obvious change of vegetation degradation was characterized by changes in vegetation structure and coverage (Li et al., 2015), and vegetation coverage is widely used to determine the status of vegetation degradation (Lu et al., 2017; Gu et al., 2018; Fokeng and Fogwe, 2022). Traditionally, monitoring vegetation coverage change is based on the field survey. However, it is not only time consuming, but also difficult to realize long term monitoring at large spatial scales (Kibler et al., 2019). As the development of remote sensing (RS) technology, long term monitoring regional vegetation coverage was available by remote sensing data. Due to the difference in human and climate factors between different regions, the degree of vegetation degradation varied among regions. Quantifying the degree of vegetation degradation is the primary task to carry out vegetation restoration in degraded ecosystems (Li et al., 2012). Therefore, studying the spatial distribution and temporal dynamics of vegetation contributes to a better understanding of vegetation degradation mechanisms (Akinyemi and Kgomo, 2019; Liu et al., 2019).

The Yellow River Delta is one of the youngest lands of the Chinese estuary, which is also designated as wetlands of international importance in China. Meanwhile, it plays a crucial role in maintaining regional biodiversity and ecosystem function, providing valuable habitat for wild birds, especially the valuable and rare birds such as *Ciconia boyciana* and *Grus japonensis* (Guan et al., 2019). Regional ecological environment is fragile due to the effects of natural and human disturbances in the Yellow River Delta (Li et al., 2011; Ottinger et al., 2013). In recent decades, the rapid population growth, economic development, agriculture reclamation, and oil exploitation have strengthened (Jiang et al., 2013; Shi et al., 2016), which resulted in vegetation degradation in some regions of the Yellow River Delta (Wang et al., 2012; Jiang et al., 2015; Cong et al., 2019). So far, previous studies have focused on the changes of wetland vegetation at the community level (Xu et al., 2015) and the spatial-temporal changes of vegetation (Jiang et al., 2013; Jin et al., 2020; Chang et al., 2022) in the Yellow River Delta. However, little attention has been paid to the changes of regional vegetation degradation and its driving forces in the Yellow River Delta. In this study, the Yellow River Delta was selected as the study area, vegetation dynamics and its driving factors were analyzed based on RS and geographic information system (GIS) techniques. The main objects of this study were to (1) quantitatively assess the spatial-temporal dynamics of vegetation, and (2) investigate the relationships between vegetation change and driving factors in the Yellow River Delta. Therefore, the result is crucial for regional eco-environmental protection and ecological restoration in the Yellow River Delta.

Materials and methods

Study area

The Yellow River Delta is located in the northeast of Shandong province, China (37°21′13″-38°8′50″N, 118°1′2″-119°17′32″E), and it is also distributed in the lower yellow river basin (*Fig. 1*). The study area is an alluvial plain, which covered an area of approximately 6876 km^2. The administration of the study area comprises Hekou, Kenli, Dongying, Lijin and Zhanhua. The climate in this region is controlled by continental monsoon, with the annual mean temperature of 12.1℃. The annual mean precipitation is 551.6 mm, and approximately 70% of the annual precipitation mainly concentrated

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during July and August (Song et al., 2018). The Yellow River Delta is mainly composed of croplands, grasslands, and wetlands.

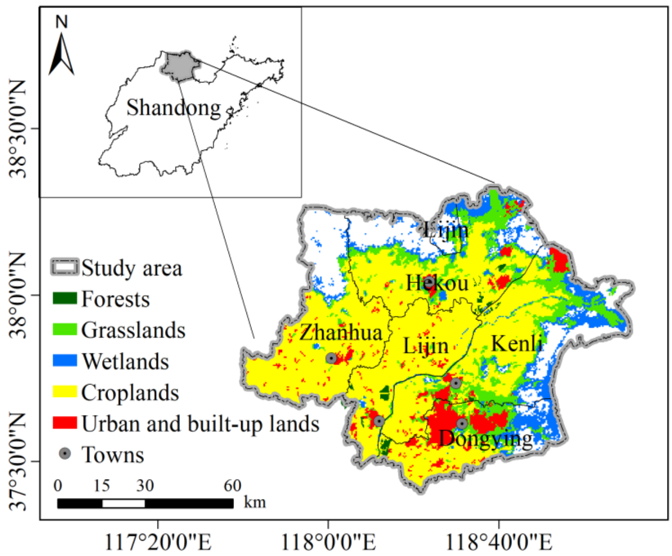

Figure 1. *Location of the study area (land cover map in 2016)*

Data sources and processing

MODIS NDVI datasets during 2000-2016 were downloaded from the Level-1 and Atmosphere Archive and Distribution System (LAADS DAAC; https://ladsweb.modaps.eosdis.nasa.gov/). The NDVI data have a spatial resolution of 250m, at 16-day intervals. These datasets were transformed into Krasovsky_1940_Albers by using ArcGIS software. In order to alleviate the effects of cloud cover on NDVI, the maximum value compositing (MVC) method was used to produce the annual NDVI datasets (Stow et al., 2007). According to previous studies, NDVI > 0 was used to identify vegetation areas, and no vegetation area was excluded in the Yellow River Delta (Wang et al., 2013; An et al., 2017). Vegetation type data was based on the MODIS land cover type product (MCD12Q1), which was downloaded from USGS (earthexplorer.usgs.gov). In this study, the vegetation types included forests, grasslands, wetlands, and croplands (*Fig. 1*). Precipitation and temperature data were obtained from China Meteorological Data Sharing Service System (http://www.cma.gov.cn). The population and gross domestic product (GDP) data were obtained from Dongying yearbook and Binzhou yearbook (2001-2017).

Methods

Vegetation coverage classification

NDVI can well reflect the status of vegetation coverage (Jin et al., 2022). In this study, the equal interval method was used to classify NDVI into five categories according to the previous studies (Jia, 2013; Lu et al., 2017): extremely low vegetation cover (NDVI<0.20), low vegetation cover (0.20≤NDVI<0.40), moderate vegetation cover (0.40≤NDVI<0.60), high vegetation cover (0.60≤NDVI<0.80), extremely high vegetation cover (0.80≤NDVI<1.00).

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Coefficient of variation

The coefficient of variation (CV) is widely used to reflect the annual volatility of NDVI (Wang et al., 2013; Chen et al., 2021). Therefore, the CV was used to illustrate the fluctuation of NDVI in this study. The CV of NDVI was classified into 4 levels: very stable (CV≤0.10), stable (0.10<CV≤0.20), vulnerable (0.20<CV≤0.30), very vulnerable (CV>0.30). The formula is calculated as follows:

$$CV = \frac{NDVI_{\sigma}}{\overline{NDVI}} \quad \text{(Eq.1)}$$

where $NDVI_{\sigma}$ is standard deviation of NDVI, and $\overline{NDVI}$ is the mean NDVI.

Vegetation degradation

The trend of NDVI is widely used to estimate vegetation degradation (Song and Ma, 2007; Akinyemi and Kgomo, 2019). In this study, the degree of vegetation degradation is classified into seven types (Song and Ma, 2007): severe degradation ($\theta_{Slope} \leq -0.0091$), moderate degradation ($-0.0091 < \theta_{Slope} \leq -0.0045$), slight degradation ($-0.0045 < \theta_{Slope} \leq -0.0010$), unchanged ($-0.0010 < \theta_{Slope} \leq 0.0010$), slight improvement ($0.0010 < \theta_{Slope} \leq 0.0045$), moderate improvement ($0.0045 < \theta_{Slope} \leq 0.0090$), significant improvement ($\theta_{Slope} > 0.0090$). The formula is calculated as follows:

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

where θ_{Slope} represents the slope of NDVI; *i* represents the *i*th year, *n* represents the total number of years; $NDVI_i$ represents the NDVI value for the *i*th year.

Driving forces of NDVI

NDVI is influenced by several environmental factors, such as rainfall, temperature and anthropogenic activities (Zoungrana et al., 2018). In our study, the driving factors including precipitation, growing season precipitation, temperature, growing season temperature, population, and GDP. Pearson correlation analysis was performed between NDVI and environmental factors (Fokeng and Fogwe, 2022). The formula as follows:

$$R = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}} \quad \text{(Eq.3)}$$

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 mean NDVI; y_i represents the different driving factors for the *i*th year; $\bar{y}$ represents the mean value of different driving factors.

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Results

Spatial and temporal changes of NDVI

The mean annual NDVI ranged from 0.43 to 0.62 in the Yellow River Delta (*Fig. 2*). The highest value of mean annual NDVI was 0.62 in 2016, while the lowest value was observed in 2000. The mean annual NDVI showed a significant increasing trend from 2000 to 2016 in the Yellow River Delta (R^2=0.59, P<0.01), and with an increasing rate of 0.0071 per year. For all vegetation types, the mean annual NDVI increased during 2000 to 2016 (*Fig. 3*). Croplands experienced the largest increase in mean annual NDVI, with an increase of 0.0086 per year (P<0.01). In contrast, grasslands showed the lowest increase trend (0.004 per year, P<0.05).

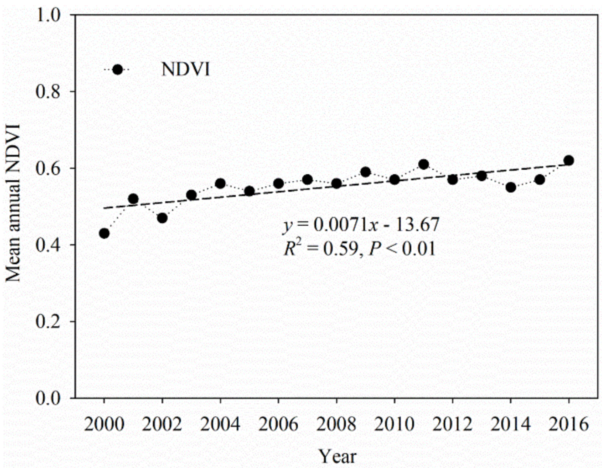

Figure 2. *Variation of NDVI from 2000 to 2016 in the whole region of the Yellow River Delta*

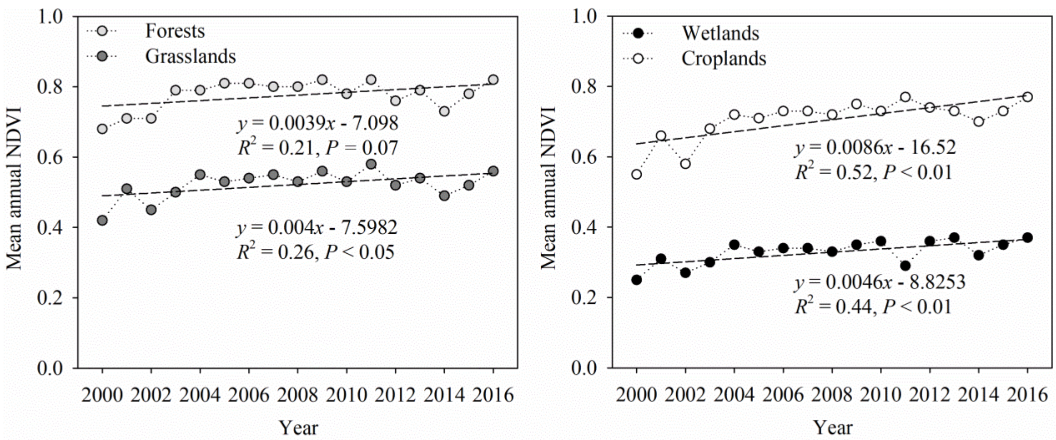

Figure 3. *Variations of NDVI for different vegetation types from 2000 to 2016 in the Yellow River Delta*

The spatial distribution of NDVI is shown in *Fig. 4*. The areas of high and extremely high vegetation cover were mainly occurred in the southwest, middle, and northeast of Yellow River Delta. The areas of extremely low and low vegetation cover were mainly located in the north and east of the Yellow River Delta. The area of high and extremely

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high vegetation cover was 4320.07 km^2, which accounted for 62.87% of the study area. The area of extremely low and low vegetation cover was 1096.07 km^2, covering 15.95% of the study area.

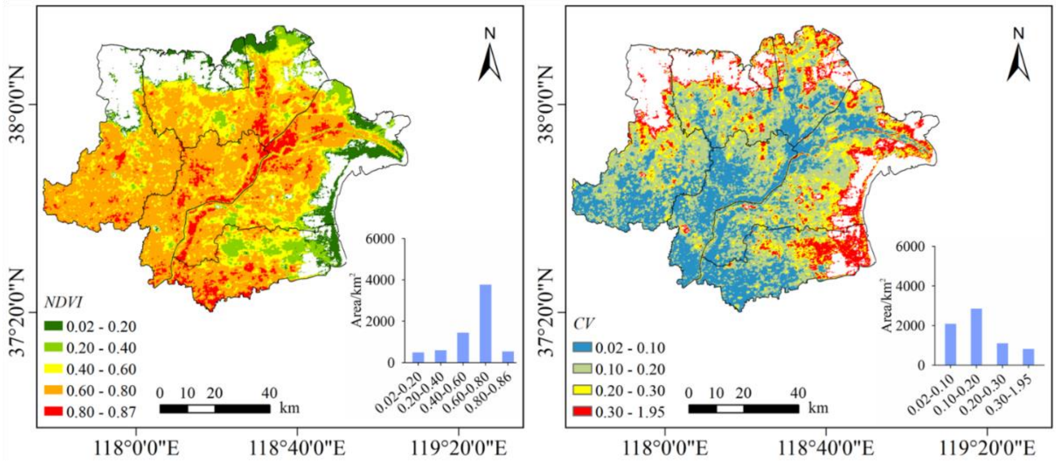

Figure 4. *Spatial distribution of mean NDVI and CV in the Yellow River Delta (2000-2016)*

The spatial pattern of CV of NDVI was consistent with that of NDVI (*Fig. 4*). The very vulnerable and vulnerable regions were mainly distributed in the north and east of the Yellow River Delta. The stable area was greatest (2853.50 km^2), accounting for 41.53% of the study area, followed by the very stable area (30.50%). The very vulnerable area was the smallest, accounting for 11.91% of the study area.

Characteristics of vegetation degradation

The area of improved vegetation was 5458.37 km^2, which accounted for 79.44% of the study area (*Fig. 5*). The area of degraded vegetation was 959.69 km^2, accounting for 13.97% of the study area. The area of unchanged vegetation was 453.38 km^2. Moreover, the area of slightly degraded vegetation was 414.50 km^2, followed by severely degraded vegetation. *Fig. 5* shows the spatial distribution of degraded vegetation in the Yellow River Delta. The areas of degraded vegetation were mainly located in the northern and southern regions of the study region. The area of degraded vegetation types is shown in *Table 1*. The area of degraded grasslands was the largest (308.45 km^2), followed by croplands (254.00 km^2). In contrast, the area of degraded forests was the smallest, and less than 9.30 km^2.

Driving forces of NDVI

The relationships between NDVI and driving factors are shown in *Table 2*. Except for grasslands, the NDVI of most vegetation types had significant positive correlations with mean precipitation and population (P<0.05). For all vegetation types, significant positive correlations between growing season precipitation, population and NDVI were observed (P<0.05). The NDVI of wetlands and croplands was significantly and positively correlated with GDP (P<0.05). NDVI exhibited significant positive relationships with growing season precipitation, population, and GDP at the whole region (P<0.05). However, correlations between mean temperature, growing season temperature and NDVI were not significant in the Yellow River Delta.

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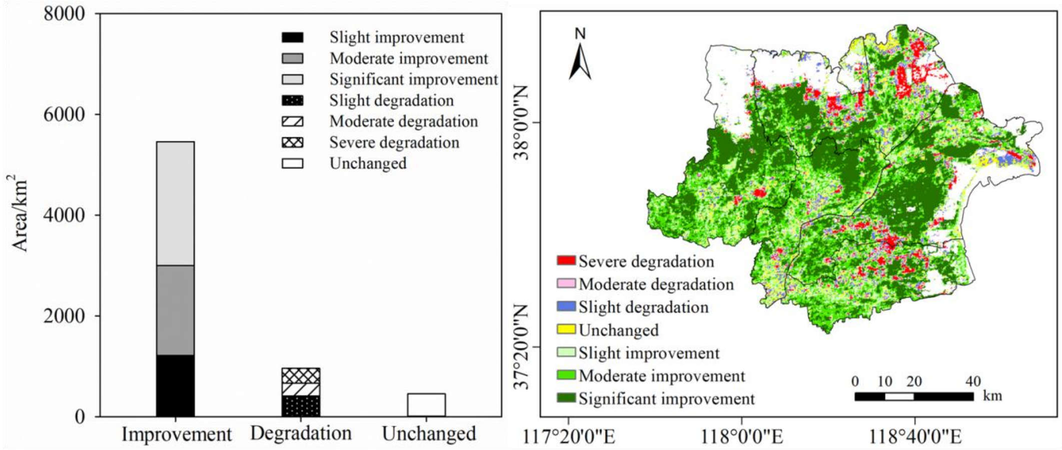

Figure 5. *Areas and spatial distribution of improved and degraded vegetation in the Yellow River Delta*

Table 1. *Areas of degraded vegetation types in the Yellow River Delta (km^2)*

Degradation type	Forests	Grasslands	Wetlands	Croplands
Severe degradation	1.98	123.57	73.80	35.02
Moderate degradation	3.23	86.86	48.30	68.01
Slight degradation	4.04	98.02	99.37	150.98

Table 2. *Correlation analysis of NDVI and driving factors*

Indicator	Forests	Grasslands	Wetlands	Croplands	Whole region
Mean precipitation	0.52*	0.44	0.53*	0.48*	0.46
Growing season precipitation	0.60*	0.56*	0.67**	0.59*	0.55*
Mean temperature	-0.20	-0.14	0.05	-0.09	-0.02
Growing season temperature	-0.34	-0.19	0.17	-0.10	-0.06
Population	0.53*	0.54*	0.65**	0.74**	0.75**
GDP	0.40	0.46	0.63**	0.69**	0.73**

Note: *represents P<0.05, **represents P<0.01

Discussion

Vegetation coverage is an important index in assessing regional vegetation degradation and ecological environment change (Li et al., 2015). In this study, vegetation coverage significantly increased from 2000 to 2016 in the Yellow River Delta. The result indicated that regional vegetation coverage has improved. This change has been reported in the previous studies (Jiang et al., 2013; An et al., 2017), and these results showed that vegetation index exhibited significant increases during two periods (1998-2009 and 2002-2013) in Yellow River Delta. At the spatial distribution, high NDVI and extremely high NDVI were mainly concentrated in the southwest, middle, and northeast of the study area. The spatial pattern of NDVI is in agreement with An et al. (2017), who found that the areas of high vegetation coverage were mainly along the Yellow River and Diaokou river where the water resource is available for vegetation growth.

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Vegetation degradation refers to decrease in vegetation productivity, which is influenced by both natural and human factors (Zhou et al., 2014). The essence of vegetation degradation is reverse succession of vegetation under disturbance (Li et al., 2012). In this study, the spatial distribution of vegetation degradation showed an obvious regional difference. Severe degradation regions were mainly took place in the north and south of the Yellow River Delta. Vegetation degradation was mainly due to the changes in water and sediment in the north part of the study area. The region of Diaokou estuary is ancient riverbed of the Yellow River in the north, and the river discharge decreased due to river diversion. It further aggravated the shore erosion, which resulted in vegetation degradation in this region (Huang et al., 2012). Since 2010, local government implemented projection of flow recovery of Diaokou river (Peng et al., 2015), which improved regional wetland ecological environment. Additionally, implementation of ecological water supplement hampered the retrogressive succession of vegetation, which contributed to the increase of vegetation coverage in some areas of the Yellow River Delta (An et al., 2017). However, vegetation degradation is still severe in the coastal areas under human exploitation activities such as expansion of construction land, saltpans, and aquaculture ponds (Cong et al., 2019). That is one of the reasons why vegetation became degraded in the northern and southern coastal areas of the Yellow River Delta. These results indicate that human activities play an important role in influencing the degradation of estuary wetland ecosystem of the Yellow River Delta (Jiang et al., 2013). Besides, the NDVI was more vulnerable in the coastal areas than that in inland areas. Therefore, local government should take measures to protect the vulnerable vegetation in coastal areas, and the restoration of degraded vegetation cannot be ignored in this region.

Water and sediment regulation scheme was implemented in the Yellow River estuary, which promoted the vegetation restoration (Jiang et al., 2013). However, there exists vegetation degradation in the coastal part of the study area. It is mainly due to the terrain is low-lying in coastal areas, and vegetation was more susceptible to the effect of saline water intrusion (Li et al., 2017). Moreover, the salt industry and aquaculture industry developed fast in the Yellow River Delta, and which led to the areas of saltpan and aquaculture ponds increased (Chen et al., 2011). The *Phragmites australis* wetland was mainly transformed into aquaculture ponds (Cong et al., 2019), which caused the decrease of NDVI. In addition, vegetation was destroyed by exploitation near coastal areas in the study area (Xu et al., 2015). As a result, the large area of vegetation was lost in the study region (Xu et al., 2015). The urbanization developed quickly in the Yellow River Delta, and construction land increased 57.46 km^2 from 1996 to 2016 (Cong et al., 2019). Urban expansion is mainly at the expense of vegetation area, which led to decreasing in vegetation coverage (Luo et al., 2021). Therefore, vegetation degradation was found in some regions near the towns of Dongying.

Regional NDVI was positively and significantly correlated with precipitation in the Yellow River Delta, which is in accordance with previous studies (Li et al., 2011; Lu et al., 2017). It is mainly due to more precipitation providing a favorable soil water condition for vegetation growth. Moreover, the relationships between precipitation and NDVI for different vegetation types were different. Compared to other vegetation types, the NDVI of wetlands showed the strongest response to precipitation. Because wetland vegetation growth is highly dependent on the availability of water (Wen et al., 2012). A previous study found that NDVI was positively correlated with temperature from 1998 to 2008 in the Yellow River Delta (Li et al., 2011). In contrast, NDVI was not significantly correlated with temperature during 2000 to 2016 in our study. It is attributed to the above

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studies were performed at different time scales. The result indicates the temperature is not the limiting factor that influences vegetation growth during the study period in the study area. Additionally, human activities play important roles in influencing vegetation growth (Du et al., 2020). More food was needed with population growth, which resulted in expansion of farmland in the Yellow River Delta (Jiang et al., 2013; Lu et al., 2017). With the economic development, the local government invested more money to implement ecological protection projects, which can improve regional vegetation conditions. Thus, NDVI had positive correlations with population and GDP in the study area. Compared to other vegetation types, the NDVI of croplands has the strongest response to population. Therefore, more attention should be paid to the effect of human activities on vegetation change in this region.

Conclusion

The vegetation coverage is significantly improved in the Yellow River Delta from 2000 to 2016. The area of improved vegetation was greater than that of degraded vegetation. The NDVI of different vegetation types is still experienced degradation in some areas, especially for the grasslands and croplands. The distribution of degraded vegetation exhibited spatial heterogeneity. Severely degraded vegetation was mainly occurred in the southern and northern parts of the Yellow River Delta. The decision makers should pay more attention to the degraded vegetation regions and continue to protect vulnerable vegetation in the coastal areas. This study identified the critical factors affecting NDVI in the Yellow River Delta. Population and growing season precipitation were the main factors limiting vegetation growth rather than temperature, which had positive effects on vegetation change in the Yellow River Delta.

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