Analysis of Spatial and Temporal Variations of Vegetation Index in Liaodong Bay in the last 30 years based on the GEE Platform

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Abstract. In order to determine the space-time characteristics of vegetation growing, aiming at the problems of poor efficiency in remote sensing information extraction of traditional methods, based on the Google Earth Engine (GEE) platform, NDVI data was extracted using Landsat image in the growing season from 1990 to 2019, and the space-time characteristics of vegetation were discussed with unitary linearity regression. The results showed that, 1) Taking 2010 as the turning point, NDVI of surface vegetation in Liaodong Bay showed a trend of first increase, then decrease and then increase during the past 30 years. The total area of vegetation cover have less change, while the proportion of medium-high coverage (0.6<NDVI<0.8) and high coverage (0.8<NDVI<1) increased significantly, 2) The spatial distribution of NDVI in Liaodong Bay have obvious differences, which shows a trend of gradual decrease from the Liaohe estuary delta to both sides. Affected by the development of coastal resources, NDVI increased firstly and then decreased from land to sea. In conclusion, the space-time change of NDVI in Liaodong Bay is affected by human development activities and ecological restoration. As an important quantitative factor, NDVI can provide basic data for the evaluation of environmental carrying capacity and ecological restoration.

1. Introduction
The coastal wetland of Liaodong Bay is an important waterfowl breeding and habitat in East Asia. Influenced by climate, geomorphology and hydrological conditions, the vegetation type in this area is mainly reeds and fin-alkali, but the relatively single vegetation type has many important functions such as improving soil, maintaining ecosystem succession, wind-proof embankment, tourism development and so on¹. However, due to human interference and the impact of climate change, the vegetation in the Liaodong Bay has been degraded in recent years, and the value of vegetation ecological services has been damaged. The Normal Differential Vegetation Index (NDVI) is the best indicator factor of vegetation growth and vegetation fraction, can reflect the change of region eco-environment². Therefore, it should be provided with scientific basis for regional ecological protection and restoration that to carry out study on the NDVI’s space-time change and its driving mechanism.

In recent years, the research on vegetation cover change by using remote sensing data has been more mature, the scale of research is diverse, the research scope is wide, the time is long. The space-
time distribution characteristics of NDVI in the vegetation-covered area were discussed in depth by the methods of monistic linear regression, Mann-Kendall non-parameter test and time series stability analysis. For example, Park, Piao et al. analyzed the change trend of NDVI in large-scale regions such as East Asia and Eurasia based on the long time sequenced NDVI data in the growing season, which were found that the change of vegetation cover has obvious time and space turning points\[^{[3,4]}\]. Cho et al. determined the optimum period for mapping vegetation cover by analyzing the trend of NDVI changes\[^{[5]}\]. There are scholars carried out NDVI change trend analysis for specific regional ecosystem\[^{[6]}\] or different vegetation types\[^{[7]}\].

In view of the vegetation in the Liaodong Bay, most of studies focused on the single vegetation type in the small or medium scale by using remote sensing technique, such as space-time dynamic change analysis, biomass inversion and estimation of carbon storage of suaeda heteropteran, while there is few research on the analysis of vegetation growth change in the long-time and large-scale in the Liaodong Bay. However, the vegetation cover change analysis of long-time and large-scale requires a large number of multi-source remote sensing images, and involves the image preprocessing process of radiation correction, geometric correction, cloud or snow mask, image mosaic, which are complex and low efficiency. Google Earth Engine is a platform for cloud computing of satellite images and other earth observation data. Some scholars have used GEE to analyze global vegetation cover change\[^{[8]}\], global terrestrial surface water change\[^{[9]}\], local ecological environment situation\[^{[10]}\] and wetland landscape pattern evolution\[^{[11]}\].

In this paper, based on the GEE platform, NDVI is calculated by the Landsat image with a total of 1952 scenes in the Liaodong Bay from 1990 to 2019. The spatial and temporal variation of the NDVI in the region is analyzed by the one-dimensional linear regression method, and the main driving factors of the NDVI change are further explored. The research results can help to correctly understand the vegetation change process, such as damage, stabilization and gradual recovery, which provides important basic data for evaluating the ecological environment quality, ecological restoration effect and bearing capacity of ecological environment of Liaodong Bay.

2. Overview of the study area

In this paper, Liaodong Bay is selected as the study area, which is located at the top of Bohai Sea and south of Songliao Plain. The area is an alluvial plain formed by a series of rivers such as Daling river and Liaohe river, the geographical range is 121.10 E~122.50 E, 40.55 N~41.40N. It is the largest coastal wetland of warm temperate zone in Asia, and also the largest coastal reed wetland in Asia after many years of natural and artificial breeding. The study area contains abundant animal and plant resources, is the habitat of red-crowned cranes, black-headed gulls and other wild animals, and has important ecological functions such as regulating water resources, purifying the environment and regulating climate. The study area has sub-humid continental monsoon climate with four distinct seasons and the same hot and rainy season. The average annual temperature is 8.3 - 8.4 °C, annual average precipitation 611.6 - 640.0 mm. The vegetation in the region is mainly meadow, with few trees. The dominant species are pterygium, reeds, typha, tamarix and trigonum, among which pterygium is a salt resistant pioneer plant that develops from land to coast in the Liaodong Bay.

3. Data sources and research methods

3.1. Data sources

GEE is the world's most advanced platform for scientific analysis and visualization of petabyte geographic data, which was developed by Google, Carnegie Mellon university and the United States geological survey. GEE provides users massive satellite image data sets and geographic data sets, including multi-year satellite image data (such as MODIS, Landsat, etc.) and ESA’s satellite image data (such as Sentinel, etc.). Meanwhile, GEE provides API interface with JavaScript and Python, analysis algorithm and tools, which is convenient for users to process, analysis and mining the mass data. Based on the GEE platform, the reflectance data of Landsat-5 TM and Landsat-8 OLI were used
as the data source. The cloud-free band was selected through JavaScript online programming by using
the quality band of the image. A total of 150 reflectance images from May to September each year of
1990 to 2019 were obtained as basic data, which can be used to analyze the space-time variation of
vegetation cover in the Liaodong Bay.

3.2. Research methods

3.2.1. NDVI calculating
NDVI has unique recognition ability for vegetation, and its calculation formula is shown in formula
(1), where \( \text{NIR} \) is the reflectance of near-infrared band, \( R \) is the reflectance of red band.

\[
\text{NDVI} = \frac{(\text{NIR} - R)}{(\text{NIR} + R)}
\]  

According to the multi-temporal NDVI data in every year, the NDVI's maximum value
composite can well reflect the vegetation coverage degree in the best vegetation growth period of the
year. The method is defined as: in a certain year, there are multi- temporal remote sensing data at each
pixel position, and each image corresponds to a NDVI value. The maximum NDVI value of each pixel
is selected to produce the annual maximum NDVI image of that year.

3.2.2. Trend analysis of vegetation cover change
Regression analysis is an important method to study the statistical relationship between multiple
variables, and it is more suitable for analyzing the change trend of vegetation cover over a long time
series. The mathematical relationship between a set of time independent variable \( x \) and NDVI
dependent variable \( y \), can be described by the following model:

\[
y = a + kx + \varepsilon
\]  

Where, \( a \) and \( k \) are unknown constants, \( \varepsilon \) is random error. The unknown parameter \( k \) can be
calculated by using the observed value \((x_i, y_i)(i = 1, 2, \ldots, n)\), and the calculation formula is:

\[
k = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}
\]  

Where, \( \bar{x} = \frac{1}{N} \sum_{i=1}^{n} x_i \) (\( x_i \) is the time series.), \( \bar{y} = \frac{1}{N} \sum_{i=1}^{n} y_i \) (\( y_i \) is the corresponding NDVI.)

For the long time series data of NDVI, the corresponding linear equation was obtained by linear
fitting with the least square method. The slope \( k \) of the equation may express the multi-year variation
trend of pixel’s NDVI value, if \( k > 0 \), vegetation activity was enhanced, if \( k < 0 \), vegetation activity was
weakened. Based on the \( k \) distribution map, it is obvious that the change trend and range of vegetation
cover in the study area from 1990 to 2019.

4. Analysis of vegetation coverage in the Liaodong Bay
According to the domestic and foreign related to achievement of study, there exist the very high
correlation between NDVI and vegetation coverage. Therefore, based on classification of NDVI,
vegetation coverage can be divided into five types: bare land, low cover, medium cover, medium-high
cover and high cover, as defined in Table 1.

| Table 1. Vegetation coverage classification. |
4.1. Analysis of spatial characteristic of vegetation change

According to the calculation results of NDVI in 2019, as shown in the Figure 1, in general, the vegetation coverage of the Liaodong Bay is relatively better, mainly medium cover and medium-high cover, accounting for more than 72%. Considering the spatial distribution characteristics of different vegetation coverage, medium-high and high vegetation coverage are mainly distributed in the Liaohe estuary nature reserve, which spans the east and west sides of the Liaohe river. There are two high vegetation covered areas in the east bank of Liaohe estuary. The vegetation coverage decreased with the extension of the Liaohe estuary to the east and west. Due to the reclamation aquaculture, port construction and other human development activities occupied tidal flats, vegetation coverage increased first and then decreased form land to sea. In the land-sea intertidal zone of Liaodong Bay, there is a small amount of medium vegetation coverage in the bare beach. Through statistical analysis, low vegetation coverage, medium vegetation coverage, medium-high vegetation coverage and high vegetation coverage accounted for 5.27%, 38.93%, 32.97% and 14.46% respectively of the total area.

| Covering level of vegetation | Condition description |
|-----------------------------|-----------------------|
| <0.2 | Bare land | Almost no vegetation, mainly water, impermeable surface, gravel, bare soil |
| 0.2~0.4 | Low cover | Vegetation is sparse with scattered shrubs, dead reeds or weeds |
| 0.4~0.6 | Medium cover | Vegetation are growing well, including nursery, herbs, farmland, etc. |
| 0.6~0.8 | Medium-high cover | Vegetation are growing very well, including more nursery, herbs, farmland, etc. |
| 0.8~1.0 | High cover | Lush vegetation, including a large number of herbs, shrubs or trees. |

Figure 1. The classification figure of NDVI in 2019.
4.2. Analysis of inter-annual variations of vegetation

Aiming at inter-year variation characteristics of vegetation cover in the Liaodong Bay, NDVI of 1990, 1995, 2000, 2005, 2010, 2015 and 2019 were selected for analysis. From 1990 to 2019, 2010 was the turning point of vegetation cover change, which showing a trend of first increasing, then decreasing and then increasing. The total area of vegetation cover has less change, but the areas of the middle-high vegetation coverage and high vegetation coverage increased significantly, which were mainly distributed in the nature reserve on the east bank of the Liaohe estuary and the large reed farms on the west side of the Liaohe estuary (show in Figure 1 to Figure 7). From 1990 to 2019, the bare land and low cover changing is destined on opposition direction of the medium cover and medium-high cover. The transformation results of different vegetation coverages levels at the three periods are as follows (show in Table 2):

- 1) From 1990 to 2005, the vegetation coverage of Liaodong Bay increased steadily. The proportion of bare land and low vegetation coverage decreased from 12.94% and 43.63% in 1990 to 9.50% and 23.30% in 2005. However, the proportion of medium and medium-high vegetation coverage increased from 40.65% and 2.78% in 1990 to 60.47% and 15.07% in 2005.

- 2) From 2005 to 2010, the vegetation coverage of Liaodong Bay decreases obviously. The proportion of bare land and low vegetation coverage increased from 10.13% and 14.43% in 2005 to 31.68% and 40.53% in 2010. Instead, the proportion of medium and medium-high vegetation coverage decreased from 60.47% and 15.07% in 2005 to 24.36% and 3.42% in 2010.

- 3) From 2010 to 2019, the vegetation coverage of Liaodong Bay has shown a little recovery. The proportion of bare land and low vegetation coverage decreased from 31.68% and 40.53% in 2010 to 8.37% and 14.46% in 2019. While, the proportion of medium and medium-high vegetation coverage increased from 24.36% and 3.42% in 2010 to 32.97% and 38.93% in 2019.

Table 2. Statistics on vegetation coverage classification area from 1990 to 2019

| Year | Bare land | Low cover | Medium cover | Medium-high cover | High cover | Bare land | Low cover | Medium cover | Medium-high cover | High cover |
|------|-----------|-----------|--------------|-------------------|-----------|-----------|-----------|--------------|-------------------|-----------|
| 1990 | 1057.75   | 3566.08   | 3322.55      | 227.54            | 0.17      | 12.940%   | 43.627%   | 40.647%      | 2.784%            | 0.002%    |
| 1995 | 1625.65   | 3012.75   | 3031.67      | 607.19            | 0.06      | 19.640%   | 36.398%   | 36.626%      | 7.336%            | 0.001%    |
| 2000 | 763.78    | 1872.58   | 4565.59      | 836.30            | 0.06      | 9.502%    | 23.296%   | 56.798%      | 10.404%           | 0.001%    |
| 2005 | 816.70    | 1163.35   | 4866.46      | 1214.56           | 0.01      | 10.131%   | 14.432%   | 60.370%      | 15.067%           | 0.000%    |
| 2010 | 2572.76   | 3292.01   | 1978.20      | 277.98            | 0.21      | 31.680%   | 40.536%   | 24.359%      | 3.423%            | 0.003%    |
| 2015 | 923.48    | 1813.65   | 3261.06      | 2155.84           | 0.21      | 11.202%   | 22.001%   | 39.559%      | 26.152%           | 1.086%    |
| 2019 | 684.91    | 1182.80   | 2697.77      | 3185.28           | 0.4310    | 8.371%    | 14.456%   | 32.973%      | 38.931%           | 5.268%    |
5. Discussion and Conclusion
Liaodong Bay is located at the interface zone of land and sea, the change of vegetation coverage is closely related to the development and utilization of coastal resources. From 1990 to 2005, the rate of
economic development is relatively low in the coastal zone of Liaodong Bay, the man and land contradiction were not prominent, the development intensity was relatively weaker, vegetation coverage has increased steadily. The area of the natural vegetation and field crop are ever-increasing with the tidal flat sedimentation, and increased area of the vegetation coverage is mainly distributed on the both side of the Liaohe estuary. Around the year 2010, the center of human economic activity was shifted from land to sea, urban construction and industrial construction were take up a lot of vegetation covering areas, and the vegetation, beaches and other coastal resources over exploitation in the Liaodong Bay to a dramatic decrease in vegetation coverage. Therefore, the vegetation coverage was decreases in a certain extent from both sides of Liaohe estuary to the urban construction area. From 2015 to 2019, with the gradual implementation of the coastal repair in the Bohai Rim, the ecological environment in some parts of the region has improved. In this period, some key protection areas and ecological protection red line have been designated, which were impose stricter policies of ecological protection. With the gradual restoration of local ecological environment, the area of high vegetation coverage increased significantly from 2015 to 2019, such as the Red Beach reserve in the northeast and southeast of the Liaohe estuary. In addition, the natural vegetation such as hyacinth and reed growing in the tidal shoal zone has been restored or protected, these areas were transformed from bare land to low vegetation coverage.

The GEE platform greatly improves the efficiency of multi-temporal and large-scale remote sensing applications. Taking Liaodong Bay as an example, the time spent on data download of traditional methods needs to be measured by day. Loading a large number of data at once, that not only results in significantly slower running speed, but also may cause the software to crash or jam. In contrast, GEE cloud platform does not need to download and store data, which has more obvious advantages than the professional software. Based on the reference data and the data in this paper, by comparing GEE platform with traditional methods in aspects of data download, preprocessing and operational analysis, the overall efficiency of GEE cloud platform has improved by more than 90%.

Vegetation cover is not only closely related to the economics culture, but also directly affected by temperature, precipitation and other natural factors, there is a complex coupling relationship between land cover change and social economy and ecological environment, which has great significance for further understanding the man-land relationship. With the help of huge remote sensing data and strong data analysis ability of the GEE platform, it is able to achieve refined land cover mapping and carry out change detection, which will provide convenient data and efficient technology for the study the pattern and process coupling models at different scales. In this paper, due to the lack of statistical data such as social economy, population, temperature, precipitation, etc., an in-depth analysis on this issue has not been conducted. In the later study, a comprehensive analysis will be carried out based on the multiple type statistical data and multi-source remote sensing images.

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