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ANALYSIS OF WATER AREA IN CAOFEIDIAN WETLAND IN 1984~2013 BASED ON REMOTE SENSING IMAGE DATA

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Abstract

As one of the largest coastal wetlands in northern China, the ecological function of Caofeidian wetland has gradually degraded due to the influence of climate and surrounding environment. In order to regulate and repair the water area of the wetland, it is necessary to study and analyse the historical changes and influencing factors of the water area of Caofeidian wetland This paper extracts the water area of Caofeidian Wetland in 1984~2013 from the images collected by Landsat satellites using the normalized difference water index (NDWI), and analyzes the causes of water area variation in the wetland according to the climate data of Caofeidian Meteorological Station and the Tangshan Statistical Yearbook. The main conclusions are as follows: (1) the water area of Caofeidian wetland had been fluctuating in 1984~2013, showing a slow upward trend. (2) Considering the water area variation and the climate data of Caofeidian Meteorological Station, it is concluded that the mean precipitation of Caofeidian Wetland showed a slight decrease while the annual mean temperature exhibited a slow increase. The correlation analysis reveals that the water area variation is not highly correlated with annual precipitation or annual mean temperature. Thus, the natural factors have a slight impact on the water area variation in Caofeidian Wetland. (3) Based on the water area variation and the data in the Tangshan Statistical Yearbook, the author discovered a prominent growth in resident population in Caofeidian District, and a huge increase in the local aquaculture area. The correlation analysis shows that the water area variation in the wetland is highly correlated with the resident population and strongly correlated with aquaculture area. Because Caofeidian wetland is located in the underdeveloped areas of industry and economy, local people have built a large number of breeding ponds in the wetland, so the main influencing factor of the wetland water area is the breeding area, followed by the permanent population.

Key words: Caofeidian wetland, climate factors, human activities, remote sensing data

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1. Introduction

The wetland, dubbed as the "Kidney of the Earth" is a major ecosystem in the world alongside the forest and the ocean. Despite the various types, wide distribution and diverse features, the wetlands have noticeable similarities in water, soil and vegetation (Cui and Yang, 2006; Wei et al., 2018). Out of the three distinct features of the wetland, the water factor is taken as the research target in this paper. For a wetland, the water level varies by year and season due to natural factors like the alternation of wet and dry periods and human factors like fish pond digging, reservoir construction and other utilizations of water resources (Goswami et al., 2017).

The Caofeidian Wetland is one of the largest coastal wetlands in northern China. However, there is not yet a unified, clear and scientific database for the research on the change law and influencing factors of the water area in this wetland, which calls for an in-depth study on the wetland via scientific means and analysis.

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Fortunately, the popularity of remote sensing satellite images has greatly facilitated the protection and monitoring of ecological environment. Such images have been adopted for long-term dynamic monitoring of the water area of lakes (Chen et al., 2015; Devi, 2018; Elbeltagy et al., 2018; Jaafari et al., 2017; Panigrahi and Gupta, 2018; Xu et al., 2018; Yan and Zhen, 2014; Cai et al., 2013; Liu et al., 2018; Hui et al., 2008). In addition, Wang and Yi (2007) created a multi-index model to extract the water from the Dongting Lake, and then monitored the eutrophication of that lake. Nevertheless, the existing studies mainly focus on the landscape change (Zhang et al., 2010; Dan et al., 2014; Reis and Yilmaz, 2008), failing to tackle the causes of historical evolution.

Using the data collected by Landsat satellites, this paper dynamically monitors the water area variation of Caofeidian wetland from 1984 to 2013, and further analyzes the influencing factors of the variation in light of the climate data on the wetland and the *Tangshan Statistical Yearbook*, laying the data basis for the water protection of Caofeidian wetland.

2. Research area overview

Lying in the southwest of Caofeidian District, Tangshan, northern China's Hebei Province, Caofeidian Wetland (39°08'30''~39°16'10''N, 118°15'30''~118°24'54''E) is at the confluence of freshwater and seawater in the center of Bohai Bay, making it a golden node in the circum-Bijing-Tianjin leisure tourism belt (Fig. 1).

The wetland boasts the largest wetland hot spring center in northern China, and a holiday resort integrating bird protection, wetland sightseeing, popular science education and ecological living (Zhang et al., 2015). With a total area of 540km^2, Caofeidian Wetland covers a 110km^2 provincial level wetland and bird protection area. Being one of the largest coastal wetlands in northern China, Caofeidian Wetland is home to more than 1,200 species of wild animals and plants, including wild plants in 238 species, 164 genera and 63 families and birds in 208 species, 52 genera and 17 families. The birds migrating from Australia to Siberia treat this wetland as an important stopover site and habitat. The climate in Caofeidian Wetland belongs to the temperate monsoon area, featuring four distinct seasons. The weather is hot and rainy in summer and cold and dry in winter (Tangshan statistics bureau, 1991-2010). The annual mean temperature falls between 9℃ and 12℃, the extreme maximum temperature reaches 29.7°C, and the extreme minimum temperature stands at - 9.1°C. The annual sunshine hours total 2,051~2,719h, and the annual precipitation is about 304~1,059 mm.

3. Data extraction and methods

3.1. Data source and pre-processing

Our research targets the data between 1984 and 2013, spanning 30 years. The remote sensing image data in 12 periods were selected from the 30-year data. To ensure the comparability between the water area data extracted from these periods, the remote sensing images taken in the dry season (September and October), where the variation in water area is relatively small, were adopted, such that the different periods have a similar amount of data. Here, the research data are collected by the Landsat 8 Operational Land Imager (OLI) and the Landsat 5 Thematic Mapper (TM). Specifically, the data in 1984~2009 were collected by Landsat 5-TM and those in 2013 were collected by Landsat 8-OLI. Considering the location of Caofeidian Wetland, the track number of both sensors was set to 122~33. The sensor data are detailed in Table 1 below.

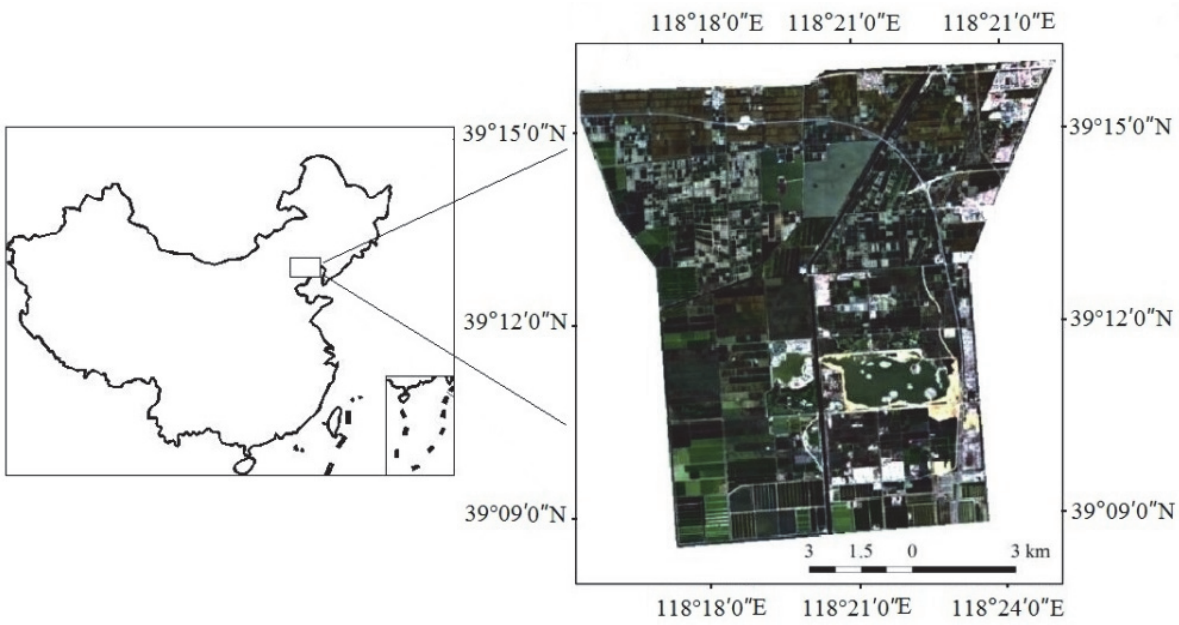

Fig. 1. Location of Caofeidian wetland

Table 1. Remote sensing image information of Caofeidian Wetland

Time	*Sensor type*	*Track number*	*Date*	*Resolution/m*
1984	Landsat5-TM	122-33	1984-09-10	30
1986	Landsat5-TM	122-33	1986-10-18	30
1989	Landsat5-TM	122-33	1989-09-01	30
1991	Landsat5-TM	122-33	1991-09-30	30
1994	Landsat5-TM	122-33	1994-10-24	30
1997	Landsat5-TM	122-33	1997-09-30	30
2000	Landsat5-TM	122-33	2000-09-06	30
2003	Landsat5-TM	122-33	2003-10-17	30
2005	Landsat5-TM	122-33	2005-09-04	30
2007	Landsat5-TM	122-33	2007-09-10	30
2009	Landsat5-TM	122-33	2009-10-17	30
2013	Landsat8-OLI	122-33	2013-09-26	30

The image data of the said 12 periods were subjected to radiometric calibration, atmospheric correction, and research area cropping. Note that the image data of 1997 were registered, those of some years were de-clouded, and the background of the data in each period was masked. In this way, the remote sensing image data of the wetland in the 12 periods were obtained for further analysis.

3.2. Water area extraction and estimation

Currently, the water area is mainly extracted by different water indices, such as the normalized difference water index (NDWI) and the modified different water index (MDWI) (Ma et al., 2017). This paper employs the NDWI to extract and estimate the water area of Caofeidian Wetland. The NDWI method computes the normalized difference between the specific bands, i.e. the green band (Green) and near-infrared band (NIR), in the remote sensing images, thus highlighting the water information in the images. The NDWI can be calculated by dividing the difference between the Green reflectance and the NIR reflectance with the sum between the two reflectances (Mcfeeters, 1996) (Eq. 1):

$$NDWI = \frac{\rho Green - \rho NIR}{\rho Green + \rho NIR} \quad (1)$$

where: $\rho Green$ and ρNIR are the reflectances of the Green and the NIR, respectively. The two bands each correspond to bands 2 and 4 for Landsat 5-TM and bands 3 and 5 for Landsat 8-OLI.

Next, a reasonable threshold was set according to the DNWI and the water features in the images, aiming to ensure effective extraction of the water area. The extracted data were then outputted as a vector file, which was further refined and corrected to make the results accurate (Zheng and Huang, 2015).

3.3. Model validation

In order to ensure the accuracy and feasibility of the extraction results of this water area, the extraction effect of Caofei west lake and Caofei lake of landsat8-OLI data in October 2013 was displayed, as shown in Fig. 2. The image map in Fig. 2 is standard color synthetic image of landsat-8-OLI, and the water area boundary of Caofei Lake and Caofei West Lake extracted by this research method is indicated by red line. The actual water area of Caofei West Lake is 51.5331hm^2. The actual water area of Caofei Lake is 280.1096hm^2. Fig. 2 and the statistical data show that the water area extraction method adopted in this study has high accuracy and the method can accurately extract and identify the water area.

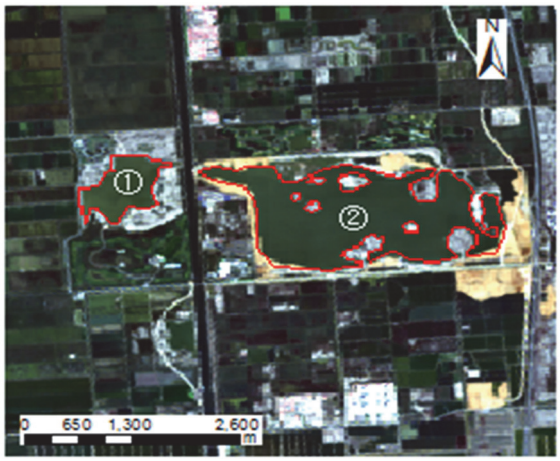

Fig. 2. Extracting effect of Caofei west lake and Caofei lake based on LandSat8-OLI
①Caofei west lake ②Caofei lake

4. Results analysis

The water area distribution map of Caofeidian Wetland in the 12 periods was plotted through the NDWI-based water area extraction from the corrected and registered images. Then, the subgraphs were compared to disclose the change in water area of the wetland. Meanwhile, the main external factors affecting the water area variation were analyzed in view of the relevant data on the wetland, as well as the local climate, population and human activities.

4.1. Analysis on water area change

The water area distribution map of Caofeidian Wetland in the 12 periods is presented as Fig. 3. The statistics on the water area of Caofeidian Wetland in

these periods are given in Fig. 4. The water area distribution map (Fig. 3) shows that the water area was mainly distributed in the north and south of the wetland from 1984 to 2003, with no large area of water in the central region. From 2005 to 2013, however, the water area gradually expanded towards the center from the north and south directions. As shown in Fig. 4, the water area of Caofeidian Wetland had been fluctuating in a wide range. The water area reached the minimum value of 9.51km^2 in 1997 and the maximum value of 42.27km^2 in 2007. In the first five years (1984~1989), the water area increased steadily by 6.67km^2, from 18.13km^2 to 24.80km^2. In the following eight years (1989~1997), the water area declined by 15.29km^2, from 24.80km^2 to 9.51km^2. The decreasing trend was reversed between 2000 and 2007, when the water area grew drastically by 31km^2 in seven years. Then, the water area plunged by 16.77km^2 in the two years from 2007 to 2009. From 2009 to 2013, the water area remained stable with little changes. In general, the water area of Caofeidian Wetland exhibited a slight upward trend in the 30 years.

Fig. 3. Water area distribution of Caofeidian Wetland in 1984~2013 (the water area is in blue):
(a) 1984; (b) 1986; (c) 1989; (d) 1991; (e) 1994; (f) 1997; (g) 2000;(h) 2003; (i) 2005; (j) 2007; (k) 2009; (l) 2013

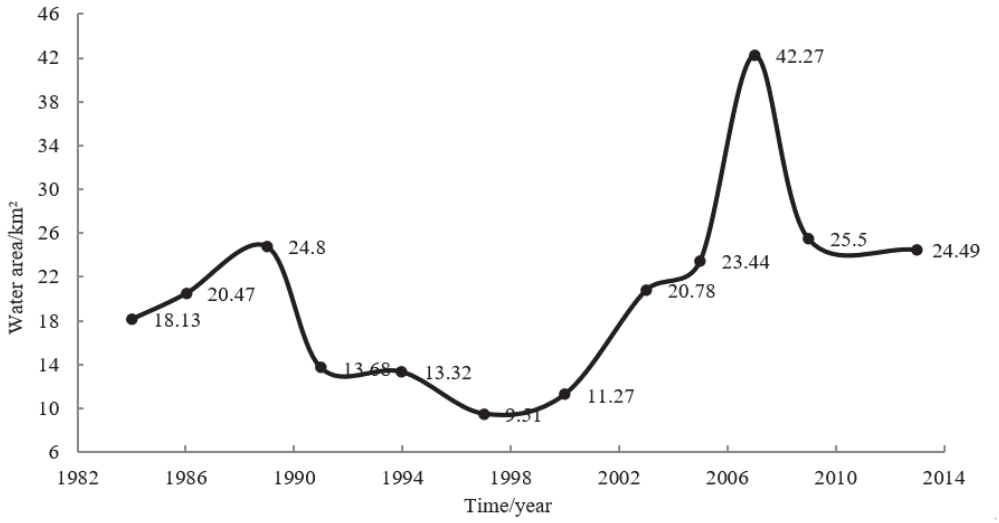

Fig. 4. Water area variation of Caofeidian Wetland in 1984~2013

Fig. 5 illustrates the distribution of water area change in Caofeidian Wetland from 1984 to 2013. It can be seen that, over the 30 years, the reduction of water area mostly occurred in the northern part of the wetland, while the growth was observed widely across the wetland.

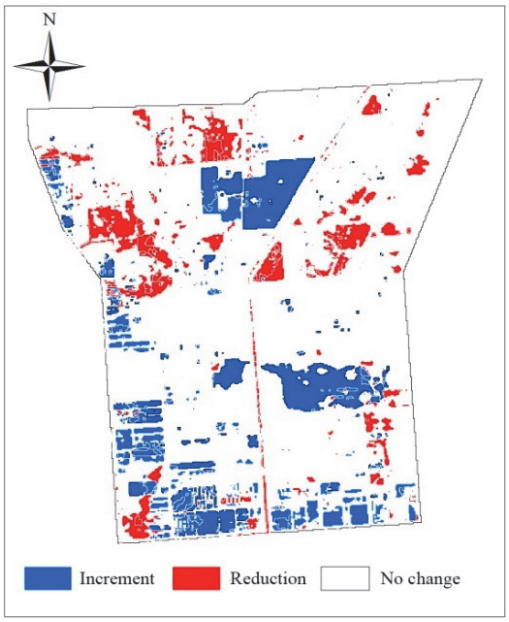

Fig. 5. Distribution of water area change in Caofeidian Wetland in 1984~2013

4.2. Analysis of influencing factors on water area change

The above data analysis shows that the water area of Caofeidian Wetland had undergone some changes in the 30 years from 1984 to 2013. Thus, this subsection examines how the water area change is affected by natural factors and human factors. To begin with, the annual precipitation and annual mean temperature data in 1984~2013 were collected from Caofeidian Meteorological Station, while the resident population and aquaculture area of Caofeidian District were acquired from the *Tangshan Statistical Yearbook*.

4.2.1. Analysis on the effect of climate factors on water area variation

If there is no or little human activity, the water area in wetland mainly changes with climate factors. The precipitation, a major source of water replenishment to wetland, directly bears on the increase/decrease of wetland water area. Another key influencer of wetland water area is annual temperature, because the temperature has an impact on the water evaporation. Fig. 6 and 7 show the relationship between annual precipitation and water area of Caofeidian Wetland and that between annual mean temperature and the latter in 1984~2013, respectively.

Fig. 6 shows a weak reduction in the annual precipitation and an increase in water area of Caofeidian Wetland. Through correlation analysis, the correlation coefficient of the annual precipitation and water area was determined as less than 0.01, revealing an extremely weak correlation. In some years (e.g. 2004 and 2007), the water area increased with the annual precipitation; in some years (e.g. 2009), the water area decreased with the annual precipitation; in some other years (e.g. 1991), the water area grew with the drop in annual precipitation. Hence, annual precipitation has a minor effect on the water area variation in Caofeidian Wetland.

As shown in Fig. 7, the annual mean temperature of Caofeidian Wetland showed a slow upward trend, so did the water area. Through correlation analysis, the correlation coefficient between the annual mean temperature and the water area was calculated as 0.48, indicating a low correlation. Overall, the annual mean temperature of the wetland increased rapidly in 1985~1989 and 1996~1999, but decreased to a certain extent in 2009~2013. In some years (e.g. 1986 and 1989), the water area of the wetland increased with the

temperature; in some years (e.g. 2009 and 2013), the water area decreased with the temperature; in some other years (e.g. 1991 and 1994), the water area declined with the rising temperature. Thus, there is no significant correlation between the water area variation and the annual mean temperature in Caofeidian Wetland.

4.2.2. Analysis on the effect of human activities on water area variation

The rapid population growth and the widening scope of human activities are bound to influence the ecological environment. Since the aquaculture is the main human activity in Caofeidian Wetland, this paper examines the effects of human activities on water area in the wetland using such two factors as resident population and aquaculture area. Fig. 8 and 9 depict the relationship between resident population and water area of Caofeidian Wetland and that between aquaculture area and the latter in 1984~2013, respectively.

It can be seen from Fig. 8 that the resident population of Caofeidian District was on the rise in the research period. The growing trend can be divided into three phases: the slow increase phase in 1991~1997, the stable phase in 1998~2004, and the rapid increase phase in 2005~2013. The resident population and water area in Caofeidian Wetland had a high correlation, as evidenced by the correlation coefficient of 0.62 obtained through correlation analysis. In 1991~1997, the water area shrunk with the growth in resident population.

By contrast, the water area grew with resident population in 2005~2007. Therefore, there is no strictly negative or positive correlation between water area and resident population, despite the high correlation between the two factors. As can be seen from Fig. 9, aquaculture area of Caofeidian Wetland exhibited an obvious upward trend in the research period, albeit significant declines in two periods (i.e. 1991~1996 and 2006~2009). The correlation analysis puts the correlation coefficient between water area change and aquaculture area at 0.91, indicating a significant correlation. The variation in water area always mirrored that in aquaculture area in the 17 years from 1996 to 2013. For instance, the water area surged up with the aquaculture area in 2005~2007, and dropped rapidly with the latter in 2007~2009. To sum up, the water area of Caofeidian Wetland was strongly correlated with the aquaculture area.

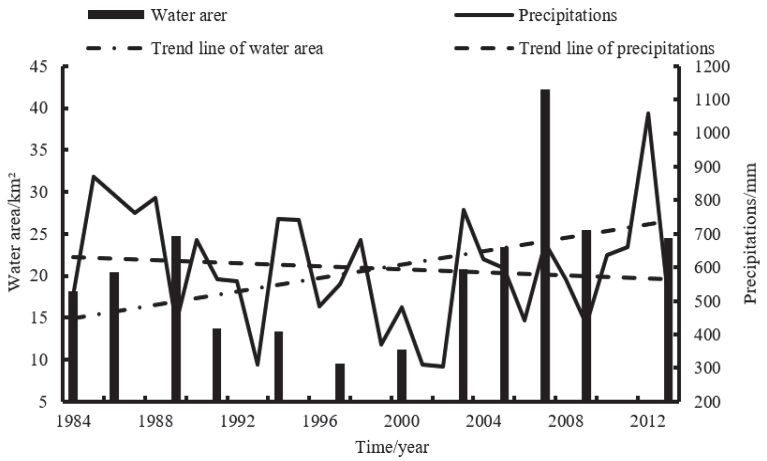

Fig. 6. Variation of water area with annual precipitations of Caofeidian Wetland in 1984~2013

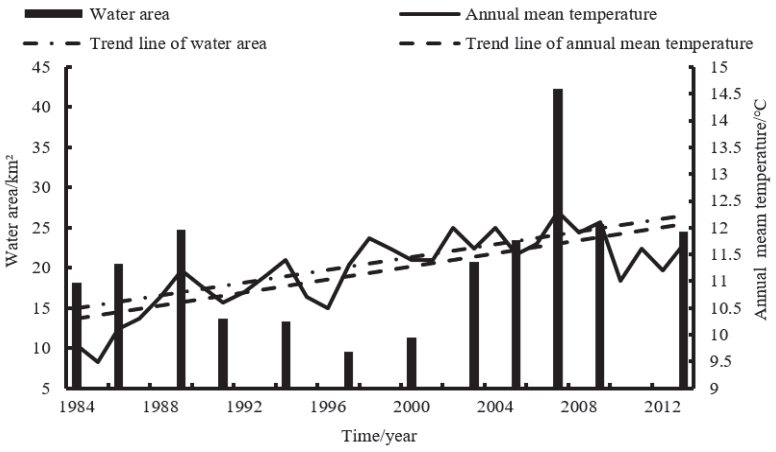

Fig. 7. Variation of water area with annual mean temperatures of Caofeidian Wetland in 1984~2013

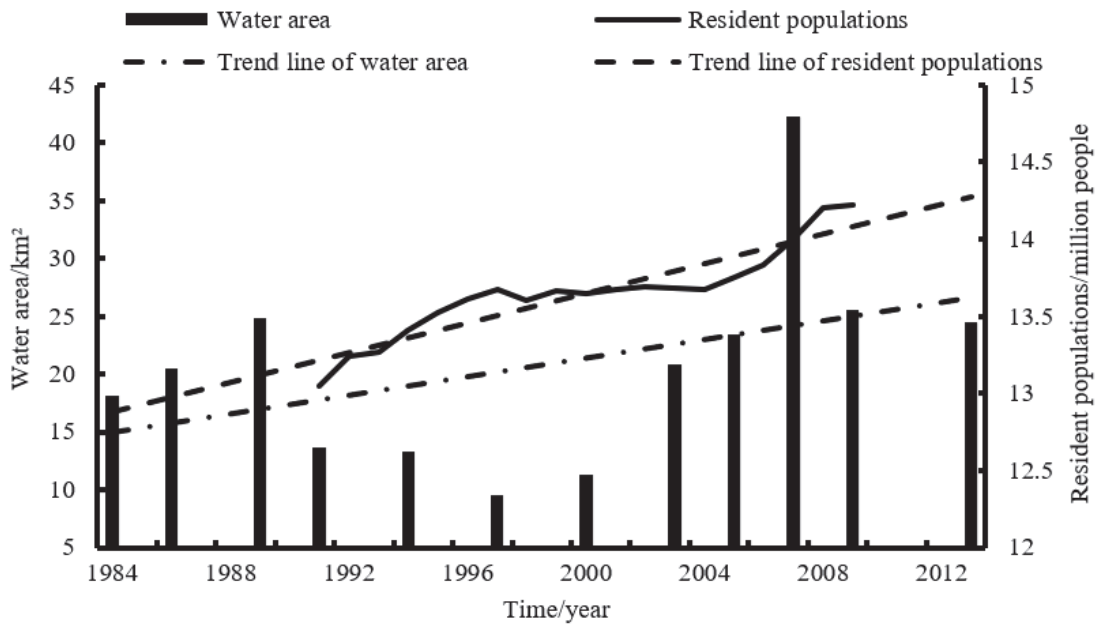

Fig. 8. Variation of water area with resident populations of Caofeidian Wetland in 1984~2013

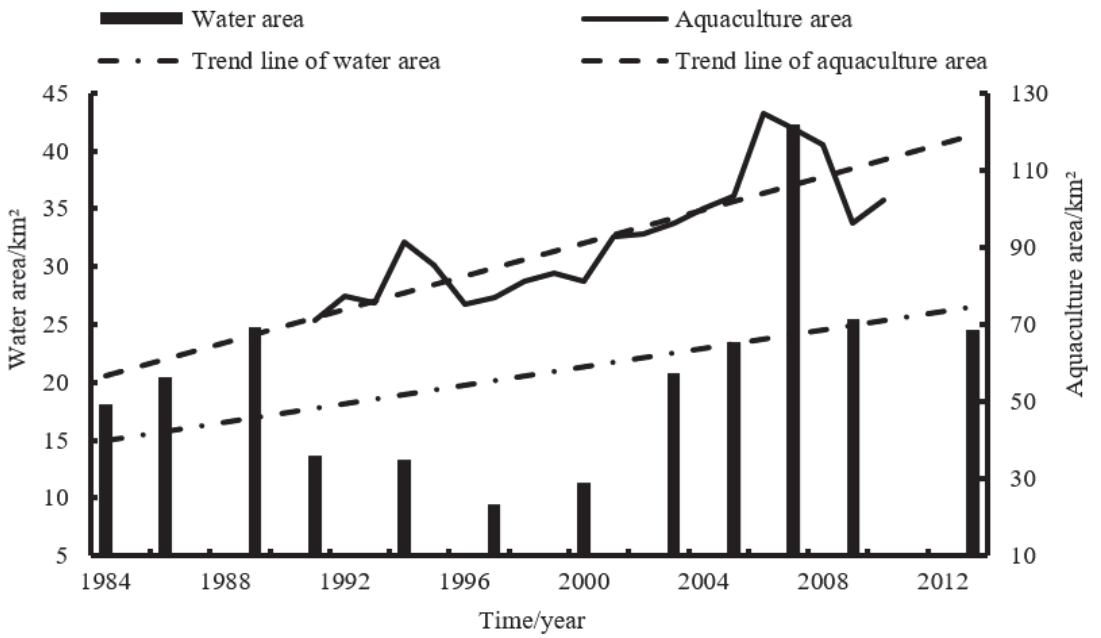

Fig. 9. Variation of water area with aquaculture areas of Caofeidian Wetland in 1984~2013

The natural environment will inevitably change with human factors like population growth and variation in the scope of human activities.

The above analysis shows that the water area variation in Caofeidian Wetland is mainly attributed to population change and the scope change of human activities, especially the variation in aquaculture area. Compared with human factors, natural factors have an insignificant impact on the change of water area in Caofeidian Wetland. In general, aquaculture is the leading human activities affecting water area variation in Caofeidian Wetland.

4.3. Discussion

Through research, this paper found that the most influencing factor on the water area of the Caofeidian wetland is local breeding area, followed by the resident population, and the water area of the wetland was less correlated with natural factors such as rainfall. The author has made many times further investigations on the Caofeidian wetland and found that the Caofeidian wetland is located in an underdeveloped area with relatively backward industry and service industry. Most of the residents around the wetland make a living by aquaculture, and

the natural waters formed by the wetland are transformed into breeding pond.

Due to the fact that the local residents will clean and dry the pond after 2-3 years of continuous cultivation, the water area of the wetland will fluctuate irregularly.

This is also the reason why the correlation coefficient between water area and aquaculture area is the largest. Because Caofeidian wetland is greatly affected by human factors, the correlation coefficient between the water area and natural factors is small, which is different from the results of other studies.

5. Conclusions

Based on the remote sensing image data collected by Landsat satellites, this paper dynamically monitors the water area variation of Caofeidian wetland in 12 periods from 1984 to 2013, and analyzes the influencing factors of the variation. The following conclusions were drawn from the monitoring and analysis:

(1) The water area of Caofeidian wetland increased by 6.36km^2 in the 30-year research period, up from 18.13km^2 in 1984 to 24.49km^2 in 2013, reached the minimum of 9.51km^2 in 1997 and peaked at 42.27km^2 in 2007; the water area had been fluctuating throughout the 12 periods.

(2) Considering the water area variation and the climate data of Caofeidian Meteorological Station, the correlation between water area variation and climate data were discussed, revealing that the variation is slightly affected by climate factors like annual precipitation and mean annual temperature.

(3) The correlation analysis between water area variation and resident population/aquaculture area shows that the variation is highly correlated with resident population and strongly correlated with aquaculture area; the aquaculture area is the main influencing factor of the water area in Caofeidian Wetland.

In summary, the water area in Caofeidian Wetland, one of the largest coastal wetlands in northern China, was mainly affected by human factors in the 30-year research period, especially aquaculture. In fact, the People's Government of Hebei Province made Caofeidian Wetland a provincial-level natural reserve in 2005.

However, the wetland had been suffering from human factors like fish pond digging, due to historical reasons. These factors have a negative impact on the local ecological environment. With the rapid development of remote sensing technology, it is necessary to implement dynamic monitoring of Caofeidian Wetland by high-resolution satellite remote sensing technology, with the aim to improve the monitoring accuracy and frequency of water area, make timely detection of damaging behaviors to wetland water environment, optimize the ecological environment of Caofeidian Wetland, and ultimately achieve harmonic coexistence of man and nature.

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