Water Environment Evolution along the China Grand Canal

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Abstract: The China Grand Canal is one of the earliest canals in the world, having lasted for nearly 3000 years. Even its section canals have a rich history, such as the North-South Grand Canal that was established during the Sui Dynasty, whereas the Beijing-Hangzhou Canal was excavated during the Yuan Dynasty and the east line of the South-to-North Water Diversion. As one of the longest in the world, the China Grand Canal’s total length is over 3500 kilometers. This length includes the navigable, unnavigable, and underground sections. Making the best use of situations and according to local conditions, the Chinese people harmoniously constructed the Beijing-Hangzhou Canal with nature. Tens of millions of workers took nearly 3000 years to complete the great shipping system. Navigable sections still exist for up to 900 kilometers and the volume of freight traffic is approximately 300 million tons. The canal remains the main logistical channel of the North-to-South Coal Transportation, South-to-North Water Diversion, and resources circulation. To date, China is promoting the success of heritage application. Part of these efforts is the declaration of the China Grand Canal as a World Cultural Heritage by 2014. In addition, the east route of the South-to-North Water Transfer project is planned to be navigable by 2016. The ancient Beijing-Hangzhou Grand Canal will usher in the new ecological civilization and cultural revival along the canal. This paper presents technical methods of water environment evolution research on the river system, river, and water quality along the Beijing-Hangzhou Canal through the integration of historical literature and modern remote sensing image data. The study carried out water environment investigation and analysis along the Beijing-Hangzhou canal by using ETM, SPOT image data, and GPS measurement data. Spatial and temporal evolution characteristics and regulations of the Beijing-Hangzhou Grand Canal regional water environment in the span of 3000 years were obtained. As a key national cultural relic, candidate of the world cultural heritage, and route of the South-to-North Water Diversion, the China Great Canal is a worthy subject of a study. Results presented in this paper therefore have high realistic significance.

1. Introduction
The China Grand Canal is a huge hydraulic engineering through North and South China, which was established by the people of ancient China. In its establishment, the people took advantage of natural rivers and lakes. The canal was a major shipping artery of the ancient Chinese, and was also responsible for water diversion, flood control, and irrigation. Fourteen hundred years of waterways

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development have passed since the Sui Dynasty. Hydraulic engineering facilities, river systems, maritime engineering facilities, ancient canal facilities, management institutions, and canal water quality have continued to evolve along with the changing dynasties. However, the Water Transport was stopped in the late Qing Dynasty, and the Grand Canal once declined. After the founding of New China, the Grand Canal was governed through several initiatives, such as digging the new watercourses and broadening channels, among others. As a result, the river canals south of Jining restored its shipping function. Until now, the east route of South-to-North Water Transfer project based on the Grand Canal is under construction, and the first stage of the project will be completed by the end of 2013. In the meantime, the northern section could be used for flood control, drainage, or irrigation. The water supply of Qingdao and Jiaozhou of Shandong is still unfinished, as the second stage will be completed in 2016. Then, the Grand Canal would achieve an all-line run-through. This means that the Grand Canal would reach 3000 years old.

Therefore, determining the water environment and its evolution, river channels changes, water conservancy facilities, and ecological environment along the Grand Canal are not only the attention of human social development in the past. This has gained important practical significance for the ecological environment protection along the Grand Canal. Apart from promoting economic and social development, the Grand Canal is undoubtedly a beautiful Chinese construction.

2. Remote Sensing Extraction of the Watercourse and Water Conservancy Facilities of the China Grand Canal

The remote sensing extraction of the watercourses and water conservancy facilities of the China Grand Canal is a prerequisite for monitoring the canal and researching water environment evolution. This paper adopts the normalized difference vegetation index (NDVI) threshold method to extract the China Grand Canal river information. The template matching method is used to extract the water conservancy facilities and outbuildings of the China Grand Canal.

This paper aims to monitor and extract the riverways and water conservancy facilities along the China Grand Canal. Data collection included 22 scenes of Landsat TM remote sensing data, 45 scenes of SPOT5, and the Quickbird data of 18 cities along the canal. At the same time, for the convenience of image correction, 400 all-line topographic maps were obtained at a scale of 1:1000, 000. Figure 1 shows the distribution of TM and SPOT remote sensing data along the Grand Canal.

![Figure 1. The TM and SPOT data distribution along the China Grand Canal](image)

2.1 The remote sensing extraction of the watercourses of the canal

This paper obtained the remote sensing automatic extraction of the watercourses along the canal by selecting the SPOT remote sensing data and using 1:10,000 topographic map data for geometric precision correction, which has a calibration accuracy within 0.5 pixels. Then, we completed the mosaic of remote sensing images after the geometric precision correction. The NDVI calculation method was used to extract the watercourses of the canal. The data process frame is shown in Figure 2.
Atmospheric correction for SPOT remote sensing data was performed to eliminate the impacts of fog and haze and to improve the accuracy of riverways extraction. This paper processed data using 6S atmospheric model. The correction parameters mainly include six, namely, solar altitude, solar azimuth, satellite elevation angle, azimuth, visibility, and elevation. Afterwards, NDVI was extracted to further obtain watercourses information.

NDVI is calculated by using the following equation:

$$\text{NDVI} = \frac{\text{Band}_4 - \text{Band}_3}{\text{Band}_4 + \text{Band}_3}$$

In Equation (1), Band3 and Band4 are the third and fourth bands of SPOT data, respectively. For NDVI data, the threshold value is set to extract the corresponding watercourses.

2.2 Remote sensing automatic extraction of canal water conservancy facilities

Comprising an important part of the China Canal, the canal water conservancy facilities refer to the bridges, sluices, dams, and other artificial constructions. These facilities serve an important role in the normal operations of the canal and their number is high. As such, this study adopts the template matching method for extraction. First, bridges, sluices, and dams were selected as samples based on field survey data and prior knowledge. These areas are already identified based on the remote sensing images. Pixel values were extracted in the different bands as a spectral template of water conservancy facilities. Then, the template matching method was used to finish matching calculation in the other regions of images. The threshold was set to extract a possible water conservancy facilities area. Other restrictions were likewise introduced in order to avoid extraction errors and errors caused by environmental factors. For example, sluices are generally located in watercourses, whereas roads are found on both sides of bridges. These facilities are close to the canal to constrain extracted results and remove incorrect information. The extraction result of the Shushan Lake embankment is shown in Figure 2.

![Figure 2. Remote Sensing Extraction of the Shushan Lake Dams](image)

3. GPS Precision Measurement along the China Grand Canal

In order to investigate the water environmental status of the Grand Canal, determine the evolution of the Grand Canal water environment, and seek the Heritage property of the Grand Canal, launching the Grand Canal protection planning and implementing its utilization protection become urgent. In addition, conducting accurate positioning measurements for water conservancy heritage is necessary. This includes ancient and modern watercourses, water sources, water conservancy facilities, shipping engineering facilities, ancient canals facilities, as well as remains of the governing organizations and ancient remains that are referred to by canal records. For this purpose, GPS measurements for the full length of the Grand Canal from July 2008 to January 2009 were generated.
During the measurement process, the following data were collected: watercourses noumenon, canal sluices, dams, weirs, embankments, water diversion culverts, shipping engineering facilities, as well as the ancient canal management agencies (such as Linqing Chao Guan, the governor of water transport).

GPS measurements along the canal employ the WGS-84 coordinate system as a reference. The local coordinate systems employ the Xi'an 80 coordinate system, and the elevation systems use the 1985 state height data. With Z-Max, a product of the Thales Navigation Company, this measurement system is a high-precision global positioning system that is designed specifically for the field of topography and architecture with superior RTK performance. Its innovative design and complete application software enable the Z-Max to meet various needs of precision positioning. Figure 3 shows the measured ancient pier sites of the Dezhou Canal.

Figure 3. The measured diagram of GPS in Dezhou ancient Canal

Figure 4. The final shape of the China Grand Canal

4. The Study of the Evolution of Water Environment of the China Grand Canal

4.1 The River System Changes along the China Grand Canal

Along the Grand Canal, from South to North, five large rivers undergo natural river changes. In particular, the Huaihe and Yellow Rivers change the most. Since the 12th century, the Yellow River has begun history by taking Huai River to the Yellow Sea for nearly seven hundred years.

In 1194, the southern end of the Yellow River took the Sishui and Huaihe Rivers to sea, disrupting the original stable Huaihe River system. Sishui was the downstream section of the Yellow River from the north of Xuzhou to Qingkou. Huaihe River below Qingkou was likewise along the tail section of the Yellow River. The lower reaches of the Huaihe River and the Yellow River combined. The Yellow River water potential is high, and significant sediment siltation continued. Thus, water from the upper reaches of the Huaihe River strongly flowed downstream. The northeastern area around the Xuyi County of Anhui is a low-lying area, and the river accumulated to create the Hongze Lake. Depressions of Sishui in Shandong Province and small surrounding lakes gradually formed Nansi Lake (Weishan Lake, Zhaoyang Lake, Dushan Lake, and Nanyang Lake). The connection point of Sishui and Yishui also gradually formed Luoma Lake. The old course of the downstream Huaihe River gradually silted and became the Ground River. In 1851, Huaihe River reached the sea via the Yangtze River, and not directly. In 1855, the Yellow River changed its way in Tongwaxing, Lanyang, and Henan. The Lower Yellow River swung back to the north, and ended the history of taking Huai into the sea. The Yellow River thus flowed north into the Bohai Sea.

Established during the Yuan Dynasty, the China Grand Canal is located through this area. Therefore, the changes of the Yellow and the Huaihe Rivers produced the largest effects on the canal.
4.2 Channels Evolution of China Grand Canal

The China Grand Canal was the lifeline of the ancient regime in the Yuan Dynasty. The rulers spared no effort in governing and maintaining river channels. Meanwhile, the river changes mainly occurred in the watershed hub of Nan Wang of Huitong River, the governance of Qingkou of the Huaiyang Canal, and in the separation of the Yellow River and the Canal. Finally, the Grand Canal was shaped.

1) Watershed hub of Nan Wang of Huitong River

The highest point of the Shandong terrain is located in Nan Wang of Wenshang (now East Dongping Lake). During the Yuan Dynasty, Huitong River was excavated, and a dam was built in Wen River. Wenhuai flowed into Huangshui, into Ji Ning, and then separated into North-South. Nan Wang, at a higher position, was located in the north of Ji Ning. Thus, the water encountered difficulties in flowing north, and the canal was not smooth. The Ming dynasty solved this problem by building Daicun dam on Wenhe. Wenshui flowed into Nan Wang and the watershed hub of Nan Wang was built. In Nan Wang, the Wenshui split into North-South. Then, sluices were built on the river from Ji Ning to Lin Qing to regulate water volume. Water tanks were likewise built along the river.

2) Governance of Qingkou of the Huaiyang Canal

Huaiyang canal connected the Huaihe and the Yangtze Rivers. After the Yellow River captured Huai, the Ming dynasty re-built Qingjiangpu in order to reduce the risk of the Yellow River shipping, according to the old road of Shahe of Song Dynasty. The dynasty also extended the northern end of the Huaiyang Canal to Qingkou, which was the connection of the Canal, the Yellow River, and Huai River. This also became a conflict region of the China Grand Canal. Governments of the Ming and Qing dynasties exerted efforts to clear sands with converging flows and brushing the Yellow River by storing clear water to construct the Hongze Lake – Qingkou water hub for the protection of shipping.

3) The separation of the Yellow River and the Canal

The China Grand Canal, from Huaiyin to Xuzhou segments, uses natural river channels of the Yellow River. Specifically, the Yellow River went southward and changed its way to encroach on the original Huaihe and Sishui. Numerous incidences of flooding in the Yellow River occurred. The canal water transport was often interrupted due to the intrusion of the Yellow River. During the Ming Jiajing period, the Nanyang New River was excavated. The Canal of Shandong Yutai County, from Nanyang to Liucheng (now Weishan Lake), changed from the west low-lying Zhaoyang Lake to east. In the time of the Ming Dynasty, Jia River was built, starting from the east coast of Weishan Lake to Zhihekou, Peixian province (now Zaohe west of west Luoma Lake). This strategy prevented the risk of Zhihekou inversing the Yellow River to reach Xuzhou. Nanyang New River and Yunjia River served as the prelude to the separation of the Yellow River and the Canal. During Kangxi, Qing, Jinfu built the middle Canal in the old course of the Yellow River, parallel to the eastern side. From Suqian into Huaiyin, the Canal flowed into the Yellow River. Here, the name was changed from “borrowing the Yellow River for shipping” to “outside the Yellow River for shipping.” At the same time, this symbolized the eventual shaping of the China Grand Canal.

The China Grand Canal is divided into seven parts, namely, Tonghui, North Canal, South Canal, Huitong River, Middle Canal (including Jia River, Zhonghe), Huaiyang Canal, and Jiangnan Canal. Figure 4 shows the final shape of the China Grand Canal.

4.3 Changes in Water Quality of the China Grand Canal

With the ensuing industrial development, the impact of residential water affected the water quality of the China Grand Canal. The water cycle has both self-regulation and renewal capacity; thus, little change in water quality is expected. However, after the founding of New China, along with China's industrial revitalization, urbanization led to several negative effects and caused problems for the China Grand Canal water quality. Increasing population, domestic wastewater, overexploitation, irrational use of resources, and industrial wastewater became the water pollution sources in the canal. The water quality classification grade of the China Grand Canal is shown in Table 1.
Table 1. Water quality classification of the China Grand Canal

| Water System Name Of Each Canal Segment | Percentage Of Various Types Of Water Quality |
|-----------------------------------------|---------------------------------------------|
|                                         | I  | II | III | IV | V | Lower than V |
| Beijing                                 | 0  | 0  | 0   | 0  | 7 | 93             |
| Tianjin                                 | 0  | 0  | 8   | 0  | <1| 99             |
| Hebei                                   | 0  | 0  | 0   | 0  | <1| 99             |
| Shandong                                | 0  | 0  | 0   | 0  | 30| 70             |
| Jiangsu                                 | 0  | 0  | 25  | 37.5| 37.5|
| Zhejiang                                | 0  | 0  | 47.6| 21.7| 30.7|

China Grand Canal is located across the Haihe, Yellow, Huaihe, Yangtze, and Qiantang Rivers. Its water quality is not only related to the quality of water resources, but also affected by the water quality in the middle and lower reaches as well as tributaries of the five river systems. Therefore, improving and protecting the China Grand Canal water quality is extremely important.

5. Characteristics and Laws of Temporal and Spatial Evolution of the Water Environment of the China Grand Canal

The water environment temporal and spatial evolution has numerous features: This environment is a successful example of the exploitation of wetlands and the use of lakes in big plains of eastern China; It is a landmark project of the farming civilization era; It is also the main link of political, economic, and cultural facets that ensures the unity of the north and south of China since the Sui and Tang dynasties; It is the main artery of the development of Chinese history; It is the embodiment of great ecological civilization engineering. About 3500 kilometers long, the Grand Canal was established by conforming to the natural environment and the water system pattern plains micro-geomorphological conditions; It is the great water transport system that the Chinese people, for 3000 years, labored to complete in stages. Through the efforts of thousands and thousands of workers, the China Grand Canal was finally accomplished according to the trends and local conditions. Approximately 900 kilometers remain to be used for normal navigable shipping, and cargo volume is about 300 million tons per year; It is the main route of the eastern route of the South-to-North Water Transfer project and the transportation of resources along the Canal; Moreover, it still serves as the channel of the North-to-South coal transport, South-to-North Water Diversion, and resources circulation logistics. The Grand Canal is an organic heritage site, and one that still plays a significant role of regulating north and south sites.

The temporal and spatial evolution law of the Canal are mainly presented in two aspects. First, the Canal evolves along with changes in the natural environment. This is because many of the Canal realize navigation by making use of natural water systems and by connecting with the surrounding water networks. This, in turn, is affected by the rising and drying up of natural water systems. For example, the Grand Canal is impacted by the water level of Yellow River and Huaihe River. Second, the canal varies with the country's political and economic evolution. If the nation is unified and prosperous, the Grand Canal is unblocked. If the nation is separated and corrupted, the Grand Canal is blocked. Literally and figuratively, the China Grand Canal changes along with the nation.

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