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Downstream Channel Evolution and its Causes in the Yuan River during the Qing Dynasty

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ABSTRACT：

The determination of channel evolutions and the causes is important for reconstructing the evolutionary history of river landforms. This study aimed to elucidate the downstream channel evolution of the Yuan River in Hunan Province, China, during the Qing dynasty via Landsat 8 satellite image data and relevant literature. The objective was to establish the modes of channel evolution and discuss the significance of historical climate change. The downstream paleochannel of the Yuan River was identified in the late Ming dynasty and early Qing dynasty（1600–1644 AD），the Kangxi-Qianlong periods of the Qing dynasty (1661–1796 AD), the late Qing dynasty (1840–1912 AD), and World War II (1939–1945 AD), and three main modes of river evolution were determined. Using RS data and ancient books, the evolution characteristics of palaeochannel in the lower Yuanshui river can be analyzed and the palaeochannel distribution in typical historical periods can be comprehensively inverted. The findings reveal a strong correlation between channel evolution, flood events, and climate change. Numerous flood events that occurred from the Late Qing dynasty to World War II caused a high rate of channel evolution, demonstrating the combined effects of climate change and human activities. In order to adopt robust and resilient hydrological management methods in the changing climate of the future.

Key Words: Qing Dynasty, Downstream Yuan River, River Evolution, River Evolution Causes, Climate Change

1. INTRODUCTION

A paleochannel refers to the morphological body of an abandoned river channel, formed when the river channel undergoes changes, such as river capture or course diversion. It is influenced by natural factors including tectonic movement and climate change, as well as anthropogenic factors such as river blockage, and straight-cutting manual digging. Research on the location, form, and distribution patterns of paleochannels can provide not only basic geographic data for economic construction but also an important scientific basis for reconstructing ancient hydrological networks and determining the evolution of the geographical environment. Previous studies have shown that the watershed landform retains a large amount of information relating to changes in the earth’s surface environment (Li et al., 2001). The study of the landform in the river basin can reveal the evolution of the river, and then indicate the changes in the earth's surface environment. The evolution of the river and its channel changes often reflects climate and temperature conditions at a given time. For example, 11.5% of the annual runoff of the Hutu-wall River is derived from glacial melting water, and 66.5% from rain and snow precipitation. Increases in temperature and precipitation are conducive to elevations in river run-off (Zhang et al., 2020). Significant hydrological changes during floods and droughts can also have a significant impact on channel morphology. The Mann-Kendall test (MANN, 1945; KENDALL, 1975) and Sen's slope (SEN, 1968) use equations to calculate the annual average flow of river water and reveal the trend in the highest flood data series. The amount of water flow has a significant effect on river migration(Ijaz et al., 2020).

In addition, changes in the earth's surface environment have constrained political and economic development throughout history. The Shanxi Province and Shaanxi

Province in China beach case in the ancient literature show the dynamic connection between river evolution and the division of administrative boundaries. Historical literature, such as the collection of Chinese memorials to Yongzheng Emperor (1723–1735 AD), and the *Directory of Wetlands for New and Old Collapses in Yingtianzhuang* compiled by the municipal government of Zhaoyi County in Shanxi Province, records the channel changes of the Yellow River. The disputation over Jixin Beach between the two provinces of Shanxi and Shanxi reflects the human attachment to land, the Yellow River, and the environment. Jixin Beach is a landform formed by river evolution (HU., 2020).

The traditional approach to reconstructing river evolution not only requires a large amount of manual effort and material resources, but also takes a long time. Moreover, it damages the surface environment to some extent. With the development of science and technology, remote sensing image interpretation has been widely applied to river evolution and reconstruction, and has achieved good results(Choi et al., 2020). In 2020, analyzed the morphological changes of the internal channel of the Xitang River over the last 100 years, and revealed that local floods directly resulted in morphological changes in the estuary. The tightening flow scale was truncated, causing landform changes in the estuary-sea-river transition zone of the Xitang River, which revealed the causes of sediment loading in the estuary and facilitated the formulation of governance plans.

Previous studies have analyzed the evolution of paleochannels from different perspectives. River channel changes, as natural phenomena, record the changes of the past hydrological environment and climate characteristics. Such trends in human history are the basis for current and future predictions. The Yuan River, also known as the Yuanshui River, is the tributary of Tongting Lake in the Yangze River Basin, and flows through Guizhou and Hunan Provinces in China; it is one of the most important tributaries of the Yangtze River Basin. There is currently little research on the downstream paleochannel of the Yuan River. Based on satellite remote sensing images, this study identified the downstream paleochannel of the Yuan River, and determined the river channel change processes from the Qing dynasty based on historical records from the ancient literature. It summarizes the mechanisms and models of channel evolution in the region, and compares it with ancient climate data to reveal the climate evolutionary trend in the future.

2. RESEARCH AREA OVERVIEW

Yuan River originates from the Yunwu Mountain in Duyun County, Guizhou Province, and has a total length of 1,033 km. Regarding administrative divisions, there are three sections in the lower stream of the Yuan River (Fig 1); Taoyuan County in the western section, Dingcheng District and Wuling District in the middle section, and Hanshou County in the eastern section. The general terrain of the region is high in the southwest and low in the northeast, and there are varied landforms including mountains, hills, plains, and lakes. (Museum et al., 2016)Taoyuan County is rounded by hills in the north, west, and south sides. Its east side is open resembling a dustpan and the mountains in its southwestern side are relatively high. Tiger Summit, located at the southwest corner of the border with Yuanling County in Huaihua City and Anhua County in Yiyang City, is 1,130 m high. The Dingcheng and Wuling Districts in the middle section present the terrain features of Taoyuan County, showing a low saddle shape between the north and the south, with half of the area comprising plains, and the other half hills, sentries, plains, and lakes. Sun Mountain, Hefu Mountain, and De Mountain in Wuling District surround the ancient city of Changde. Hanshou County on the eastern section is categorized by Quaternary and Paleozoic stratigraphic structures, and is located in the transition zone from the stretching branches of Xuefeng Mountain to the Tongting Lake basin, generally presenting lakeside landforms.

As this terrain dramatically affects the climate zonation, Changde City has a unique landform diversity from lakes and plains to mountains, and a redistribution of temperature, light, and water also occurs in the area. Therefore, Changde City, located in the humid monsoon climate zone with a transition from a mid-subtropical climate to northern subtropical climate, benefits from a large annual rainfall, fertile soil, and abundant sunshine, which provides a desirable agro-ecological environment (Tang., 2020). The climate here is conducive to the growth of warm crops, such as rice and cotton. Simultaneously, the warm climate is prone to abundant rainfall, flooding, and droughts. Influenced by the varying temperature and precipitation, natural disaster events, such as seasonal droughts and extreme variable temperatures, have become a frequent occurrence (Zhang et al., 2020).

The Yuan River basin, as a central link connecting the southwest economic circle to the mid-downstream area of the Yangtze River, has historically formed a unique water transportation industry. The rate of urbanization in the Yuan River basin was the fastest in the Ming and Qing dynasties, compared to other periods. While anthropologist, Prof. Skinner pointed out that the population of this area was partly Sinicized in Qing and Ming dynasties, as is the case in the western Lingnan, Yunnan, and Guizhou Provinces, when explaining the intensive urban construction of the Yuan River basin during the late empire (Skinner., 2000). This indicates that the strongest driving force for urbanization is the development of regional economies instead of Sinicization. Actually, economic development downstream of the Yuan River was faster than that in the upper and middle reaches, due to the unique advantages of its geographical location. The northwestern part of Changde City, downstream of the Yuan River, is the low recess of the Wuling Mountains with stretching mountains in the southwest and the Tongting Lake plain in the east.

3. DATA SOURCES

3.1 Remote sensing data

The image data were acquired via the Landsat 8 satellite operational land imager sensor (Fig 2), which also includes a thermal infrared sensor. The operational land imager comprises all of the enhanced thematic mapper plusbands and eliminates the atmospheric absorption of some features, with a spatial score ratio of 30 m and a panchromatic band resolution of 15 m. Data from the Environment for Visualizing Images (ENVI®) v.5.3 software were utilized to complete pre-treatment work such as radiation calibration and atmospheric correction to minimize or eliminate errors caused by atmospheric factors, light differences, and sensor performance. In remote sensing image acquisition, the target image pixel gray-degrees vary within several gray-degree ranges. There is a weak contrast between the river channel and the background, making its visual interpretation difficult. The pixel contrast can be strengthened through histogram equalization, which helps identify the characteristics of ancient river channels, channel ruins, river azimuths, and general morphology, and thus facilitates the analysis of river channel evolution in the lower basin of the Yuan River.

A series of erosions and accumulations during river evolution form unique geomorphic structures such as serpentine, linear, intermittent linear, and sediment sequences, which differ from on land in their spectrum absorption and solar radiation reflection. This is indicated in remote sensing images by varied tonal characteristics and can be utilized for identification of paleochannels. For example, the water in the river interacts with the riverbed to form a thick sand body and the minerals inside it are mainly light-colored such as quartz feldspar with a high spectral reflectivity(Shi., 1983). The floodplain materials on both sides comprise mafic clay and subclay of relatively low reflectivity (Campbell., 2001). The paleochannel is usually characterized by central brightness and darker edges in remote sensing images, supplemented with some indirect indications, such as residential land and cultivated land, which are usually arranged along the river channel(Qin et al., 2008). Additionally, the paleochannel area is also distinguished from the surrounding vegetated areas(Gao et al., 2009). For instance, the groundwater level of the paleochannel is usually higher resulting in improved plant growth in the summer. The bushes or sandy vegetation growing intermittently along the river are shown as dark strips in the image. In contrast, the frozen overflow water in winter and the salt in the surface water after it has receded in some areas increases and accumulates in the saline-alkali land formed on the surface of the soil, which appears as bright areas in remote sensing images(Wang et al., 2019).

3.2 Ancient literature

Table 1 shows the ancient literature and related information utilized in the research, including: Tangting Lake Historical Change Atlas (Department., 2011); Ming

Jia Jing [Changde Fu Zhi] Proofreading (Chen., 2011), Ching Jiaqing [Changde Fu Zhi] Proofreading (Upper and Lower) (Tu., 2001); Introduction to the First Year of the Qing Dynasty [Wuling CountyZhi] Proofreading (Upper and Lower) (Chen., 2020); Qing Guan Xu [Tao Yuan CountyZhi] Proofreading (Liang., 2013); [Long Yang CountyZhi] Proofreading (Committee., 2020); Changde County Water Conservancy (Chang., 1982); Li Family Tree (Committee., 2016); Atlas of Chinese History (Tan., 1991); Changde City Xuan Zhi (Changde City., 1989); Ancient Atlas of China-Qing Dynasty 1644–1911 (Cao., 1997); Changde Comprehensive Hydrogeological Map (Survey., 1979); Military Secrets 50,000 points in China Changde 47, Military Secrets, East Asia 500,000 points, Tutsi, Tenth Line South, Fourth Paragraph, and General History of Chinese Administrative Divisions (Zhou., 2013); and Changde Regional Water Conservancy (City., 1992). The position of the Yuan River channel in different historical periods was acquired from this literature.

4. Results and Discussion

A significant amount of research on paleochannel evolution has been previously conducted. For example, the evolution of Egyptian paleochannels can be traced back thousands of years with remote sensing image technology. However, owing to the distinct climate differences in the present area, droughts and floods have occurred, causing frequent changes in river courses and ultimately forming multiple superpositions throughout the geological history. While the earliest remote sensing image data were collected from the aerial photography of the United States around 1950, due to limited technology, the reconstruction results were unreliable because of insufficient resolution. In addition, the relevant data were confidential and not freely available. To ensure reliability, Landsat 8 satellite remote sensing image data were utilized in this study. Given the complex hydrological environment, the downstream paleochannel of the Yuan River can only be traced back to the period of the Late Ming dynasty to the Qing dynasty.

4.1 Results

The evolution of the paleochannel corresponds to the distribution of the lower reaches of the Yuanshui River in historical periods. Based on the paleochannel records in ancient literature, its temporal and spatial distribution could be interpreted via remote sensing images, displaying the river channels in five historical periods (Fig 3). The distributions of the paleochannel in different periods were superimposed upon one another for subsequent discussion of its evolution during the Qing dynasty.

4.2 Discussion

4.2.1 Evolutionary history of the paleochannel

In the Late Ming and Early Qing dynasties, a well-developed river formed gradually in the area of Wuji Tsui in the southeast of Changde City. The water flow in the river increased dramatically in the Late Qing dynasty and the river channel was cut straight to present today's distribution. Meanwhile, the abandoned river gradually dried up, ultimately becoming a paleochannel. This change is well-documented in the ancient literature. It is clearly recorded in the Hanshou County Water Conservancy as follows "...flowing hundreds of miles, with the sight of vast water melting into the sky". Catastrophic floods occurred in 1931 and 1935 before World War II (1939–1945 AD).

The black box in Fig 4 indicates the ancient Luzhou Zhang of Dingcheng District on the lower reaches of the Yuan River. Its water conservancy developed as the imperial court encouraged reclamation and production after reunification in the Ming Dynasty. An embankment was built within the county during the Jiajing period of the Ming Dynasty (1522–1566 AD). At the same time, dikes were also constructed on the north bank of the Yangtze River and subsequently forced the water to move southward, resulting in the silting up of Dongting Lake and formation of abundant islets. Additionally, the area along the lake was gradually reclaimed. In the Wanli period of the Ming dynasty (1573–1620 AD), embankments were built in Luzhou, Yaojia, Papaya, and Guandi displaying a meandering river in the Ming Dynasty. "Each village was able to attack and retreat via the water from the land to the boat. Huangcheng village was surrounded by rivers and lakes in the east, west, and north."(Chen et al., 2015). It was the main stream of the Yuan River in the Song dynasty, where General Yang Si could enter the water when failing to combat opponents on land and return to land when failing to repel the opponents in the water.

The Yuan River has undergone changes in the county (Fig 5). According to the county annals in the first year of Tongzhi in the Qing dynasty (1862): "...its main stream passed through Jiajie, county government to Wangshan (now Deshan), with the Wangshui River on the south and Majiaji River on the northeast, dividing the Yuan River into east and north sections. The main stream flowed eastwards to Baishazhou. The Xinxing River flowed from the south, and it was divided into two branches to the east, with one branch flowing around Da Zhou and the other running to the northeast through Jngzhiwan to meet at Niubi Bay.” The floods frequently oscillated due to the abundant water in the river during the Ming and Qing dynasties. The flow direction of the Yuan River was also recorded here.

As the historical records indicate, dramatic changes occurred in the lower reaches of the Yuan River during World War II (1939–1945 AD). Firstly, the number of flooding events increased. Rainfall in the upper and middle reaches of the Yangtze River increased in 38 years around World War II (1939–1945 AD), causing floods once every 2 years on average. Particularly, there were massive foods in 1931, 1935, and 1949. Secondly, the channel of the Yangtze River altered dramatically. There were 10 bends in the section from Ouchikou to Chenglingji on the Yangtze River in the late Qing dynasty. Influenced by years of water flow, 10 meanders emerged in the passage between Ouchikou and Chenglingji in the Yangtze River in the Late Qing dynasty. Additionally, there were 14 meanders in the middle of the Republic of China. Furthermore, the river curvature was reduced and the meander range lengthened over a short period of time. The area around Dongting Lake was heavily silted.

4.2.2 Main modes of river evolution

The formation of the downstream paleochannel of the Yuan River was elucidated and its evolution determined using paleochannel changes documented in the ancient literature. The channel was extremely curved, and the surrounding terrains were mainly alluvial plains and small-scale hills. The distribution of the paleochannel was roughly consistent with the present river channel. However, there were still relatively large variations in some areas, such as Wuji Tsui in the southeast of Changde City, and Shenhu Temple and Wuling in the east. The curvature of the paleochannel showed sustained changes and moved horizontally over a large scale on the plains. It transitioned from a straight channel to a curved one, but reverted back to being straight again alongside the concurrence of floods in different periods. This cycle repeated.

Despite the stabilization of the river channel during its evolution, there were significant changes in some areas due to the effects of river erosion, as follows:

1. The extremely curved river channel was abandoned and dried up gradually to form the remaining oxbow lake. The bending channel, in the flood season, was cut straight to form a new flat river and continued to evolve. As shown in Fig 6b, a well-developed meander formed in the Late Ming and Early Qing dynasties in the Wuji Tsui area, southeast of Changde City. The river channel maintained a relatively stable morphology until the late Qing dynasty. The river was gradually cut straight and developed into the current straight river following a flood event in World War II (1938 AD).

2. The convex shore silt advanced, and the concave shore eroded and withdrew. The convex shore was washed away by the water flow and collapsed, and the sediment silted on the convex shore where water flow was slow. The river channel constantly bent to form a snake-bending shape. As is shown in Fig 6b, in the areas of the Shenhu Temple and Wuling in the east of Changde City, the original, almost straight channel protruded westward due to the impact of the river's dynamic geology, altering the channel with westward protrusion from the Late Ming and Early Qing dynasties to the years of Emperor Kangxi. In the late Qing, the river channel was diverted again to straighten out, forming a new oxbow lake. Nevertheless, with river erosion, the straight river channel continued to bend west over time, forming a new snake curve. A flood in the late Qing dynasty was also recorded in the ancient literature. The north-to-south channel around the Songjia Beach area in northeastern Hanshou County was almost straight without meanders in the Late Ming and Early Qing dynasties. Due to geological action, the river gradually bent westward. In the late Qing dynasty, a sharp

bend was formed. Meanders near Wujia Beach were generated owing to the continuous siltation of the river.

3. There was a connection with the main river channel in the east, and the low-lying and trough-like channel was formed only in the upstream of the river. The frequent swings of the river channel affected the water supply downstream. The channel diversion of the river occurred in the southern area of Hanshou County and resulted in the drying-up of the channel. The low-lying and belt-shaped channel formed previously enabled the downstream channel to maintain a certain amount of water owing to the intensive flood events in World War II (1939–1945 AD), which required manual irrigation and drainage technology to extract the rainwater that had accumulated in the channel. The remote sensing images clearly identify the old dry upstream channel and the wet downstream channel in southern Hanshou County (Fig 6c).

4.3 Significance of historical climate changes

According to the literature on historical climate (Ge., 2011), the Qing dynasty generally experienced the climate of the Little Ice Ages (1500–1850 AD), during which it was cold in the early period, relatively warmer in the early-mid period, and cold in the middle and late periods for a long period of time (Fig 7). From 1780 to the Late Qing dynasty, China's climate was relatively cold, especially in 1870. China's temperature has shown a rapid upward trend since then, which indicates an important turning point in the climate transition from cold to warm. It was much colder in central and eastern China with a greater fluctuation in temperature from the Late Ming and Early Qing dynasties. Additionally, the temperature in the period 1650–1770 AD increased the fastest at a rate of 0.2°C/decade. Temperate increased in the mid-to-late 18th century (1720–1770 AD) with little fluctuation in values. From the early period of the 19th century, there was another cold period lasting until the 20th century before the start of the Modern Warm Period. During the period from 1870–1910 AD, the temperature increased by 1.0°C, and the temperature change rate was 0.25°C/decade.

The rapid rise in temperature usually caused the melting of glaciers and an increase in water volume. The river was then cut straight. The old river channel was abandoned and a new one was formed.

From the changes in the river channel in the lower reaches of the Yuan River, there was a good correlation observed between the peak period of river diversion in the research areas and the flood events recorded in the historical literature. Furthermore, the historical climate literature suggests a dramatic increase in temperature, glacier melting, and water flow volume, which corresponds with the simultaneous frequent diversions of the river channel and flooding. Of note, the intensive floods from the Late Qing dynasty to World War II (1939–1945 AD) were correlated with population explosion, a transformation from mountains to cultivated land, and soil and water loss due to the destruction of vegetation. There are two speculations regarding the lack of recorded floods in the warm age in the early-to-mid Qing period. Firstly, some literature was missing during dynasty transition. Secondly, there had not been a large number of floods despite the suitable vegetation cover and rising temperatures.

5. CONCLUSION

Remote sensing image data can facilitate the interpretation and identification of the types and boundaries of paleochannels. In this study, the evolutionary characteristics of the Yuan River's channel were analyzed, and the presentation and distribution of the river channel over historical periods were comprehensively reflected via the ancient literature. In summary:

1. Comprehensive distributions of the downstream paleochannel of the Yuan River were reflected in the late Ming and early Qing dynasties, the Kangxi and Qianlong periods of the Qing dynasty, the late Qing dynasty, and World War II (1939–1945 AD).

2. The evolution of the downstream paleochannel of the Yuan River demonstrated three modes: oxbow lake, ridge-shaped channel with beach replacement, and low-lying and trough-shaped channel in diversion.

3. The peak periods of channel diversion in the research areas showed a strong correlation with the flood events recorded in historical literature. From the late Qing dynasty to World War II (1939–1945 AD), the river channel underwent frequent changes and a large number of floods occurred. In accordance with the historical climate data and ancient literature, it is believed that this occurrence of floods was the combined effect of climate change and human activities.

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TABLES

Table 1. Ancient literature on the lower reaches of the Yuanjiang River

Year (AD)	Literature	Related information
1522-1566	Ming Jia Jing [Changde Fu Zhi] Proofread-ing	Geography, temple worship
1760-1820	Ching Jiaqing [Changde Fu Zhi] Proofread-ing" (Upper and Lower)	Mountains, monuments, cities
1862-1875	Introduction to the First Year of the Qing Dynasty [Wuling CountyZhi]Proofreading" (Upper and Lower)	Public map, geographic geogra-phy, territory
1871-1908	Qing Guan Xu [Tao Yuan CountyZhi] Proofreading	Frontier domain, mountains, con-struction logs, embankments
1594-1875	[Long Yang CountyZhi] Proofreading	Public map, territory, mountain, river, embankment, construction
Year 37 of the Republic	Li Family Tree	Family boundaries
1820-1908	Atlas of Chinese History	Historical map
1644-1911	Atlas of China-Qing Dynasty 1644-1911	Historical map
1965-1978	Comprehensive Hydrogeological Map-Chang Deforma	geological map
Year 22 of the Republic	Military Secrets 50,000 points in China Changde 47	Military map
Year six Zhaohe	Military Secrets, East Asia 500,000 points, Tutsi, Tenth Line South, Fourth Paragraph.	Military map
1662-1911	Changde Country Regional Water Conserv-ancy	embankments, floods, droughts of various dynasties
1542-1873	Changde Regional Water Conservancy	Water conservancy, embankment
277 BC-1988 AD	Changde City Embankment Bulletin	embankments,
1644-1911	General History of Chinese Administrative Divisions	Provincial administrative agency

FIGURES

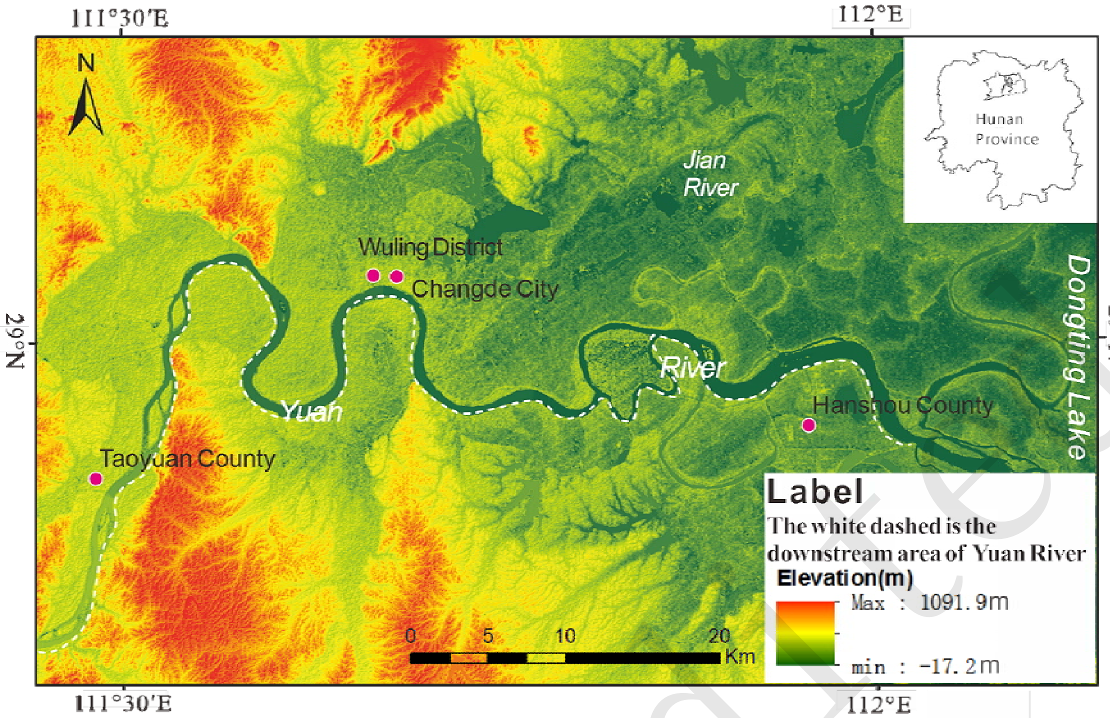

Figure 1. Topographic map of the downstream area of the Yuan River

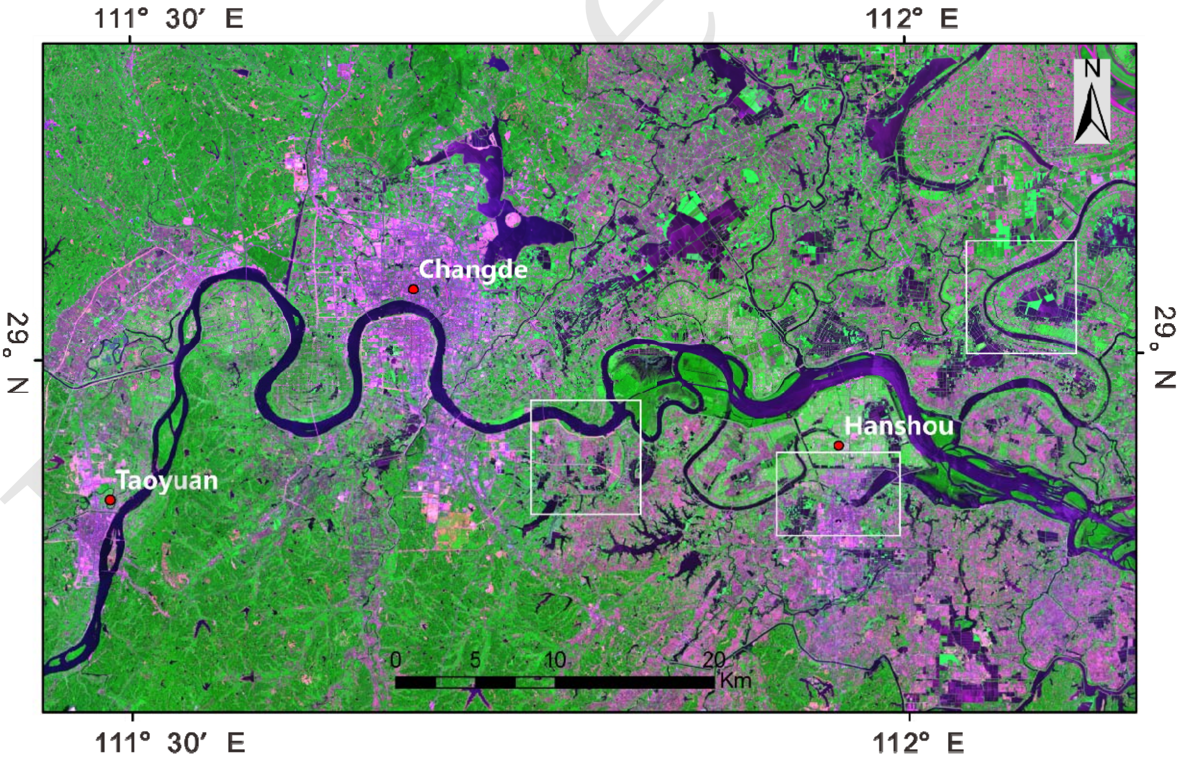

Figure 2. Fake color Landsat 8 remote sensing image in Yuan River downstream basin (combined by bands 4, 5, and 1)

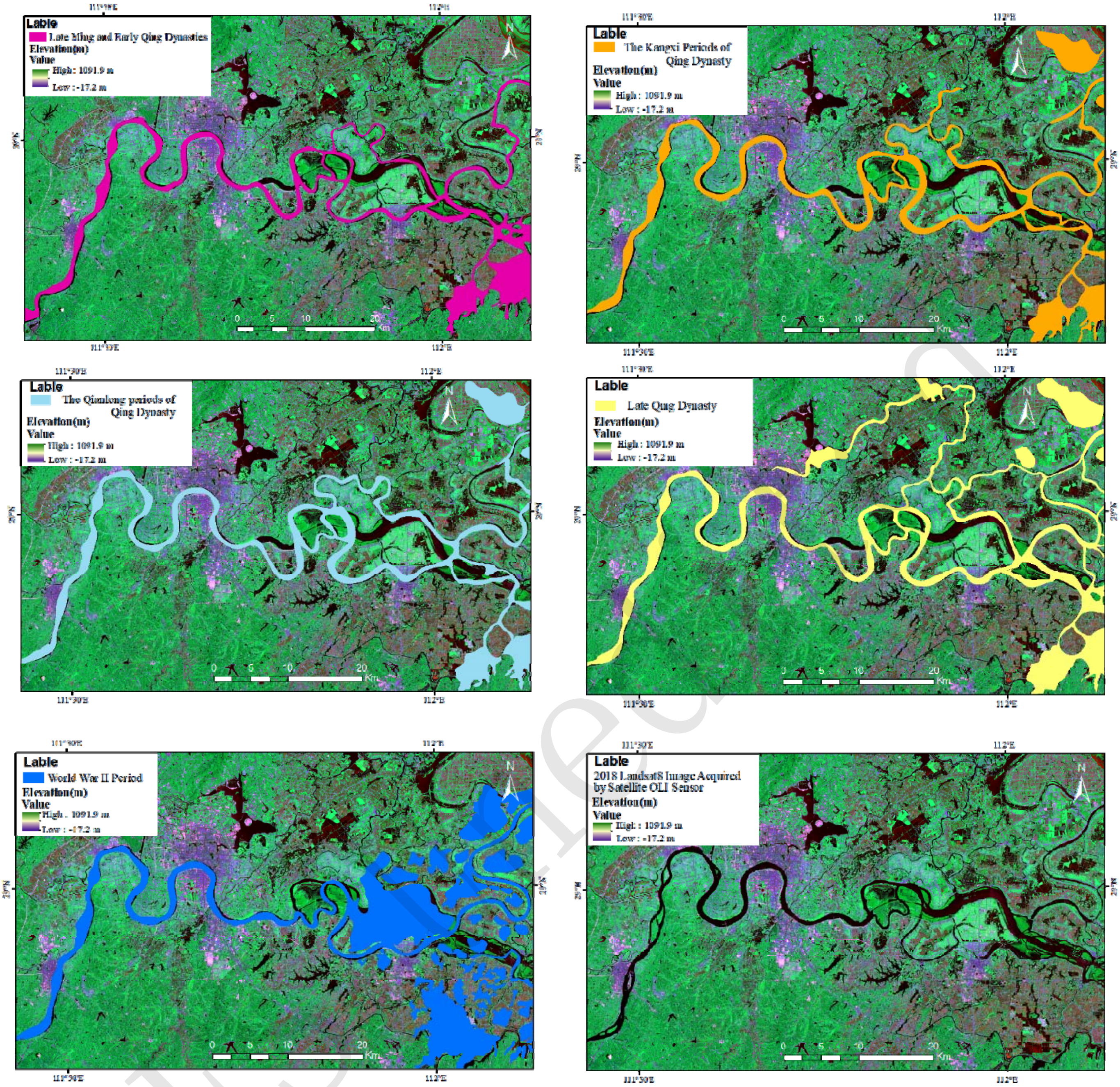

Figure 3. Historical reconstruction of downstream river channel changes in the Yuan River after the late Ming dynasty

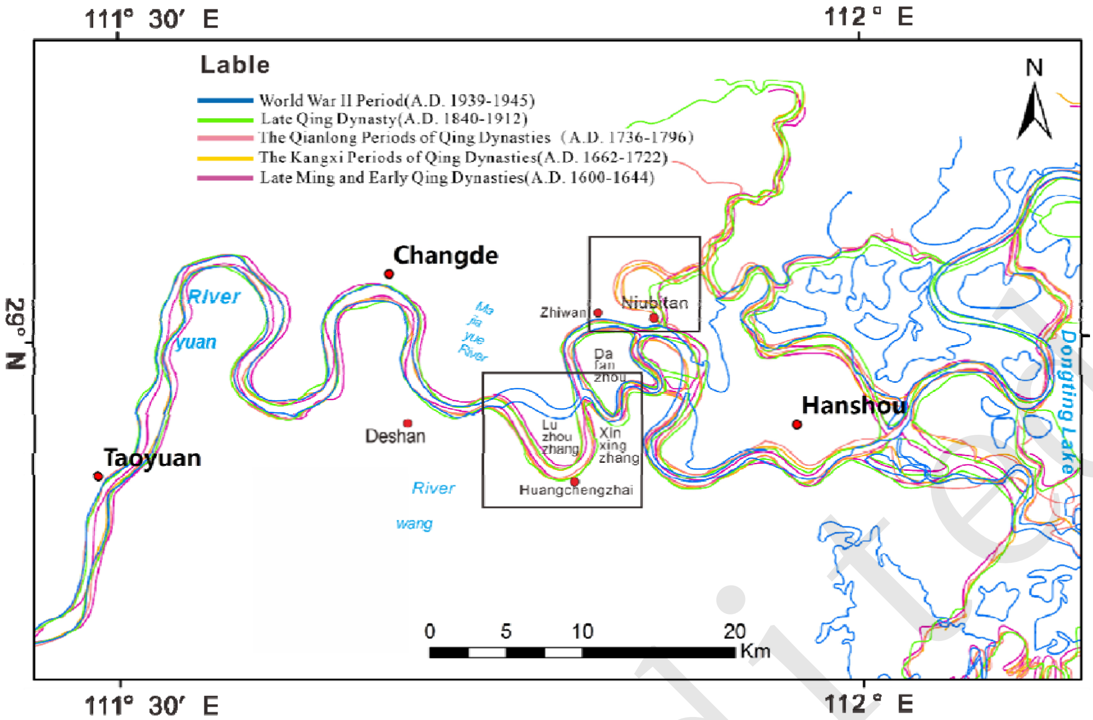

Figure 4. Summary of river changes in the lower reaches of the Yuan River form the late Ming dynasty to WWII

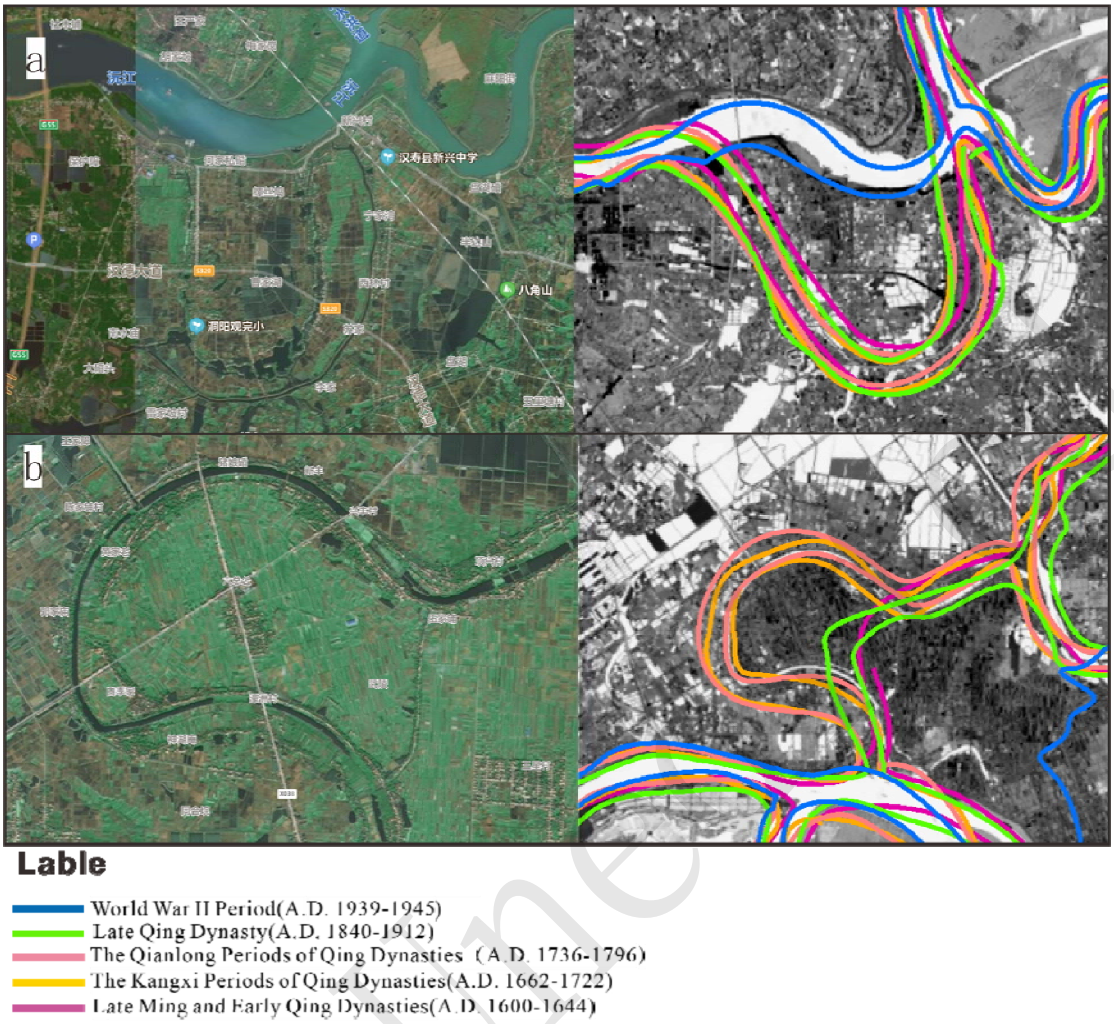

Figure 5. Evolution of downstream sections of the Yuan River (its location is indicated by black boxes)

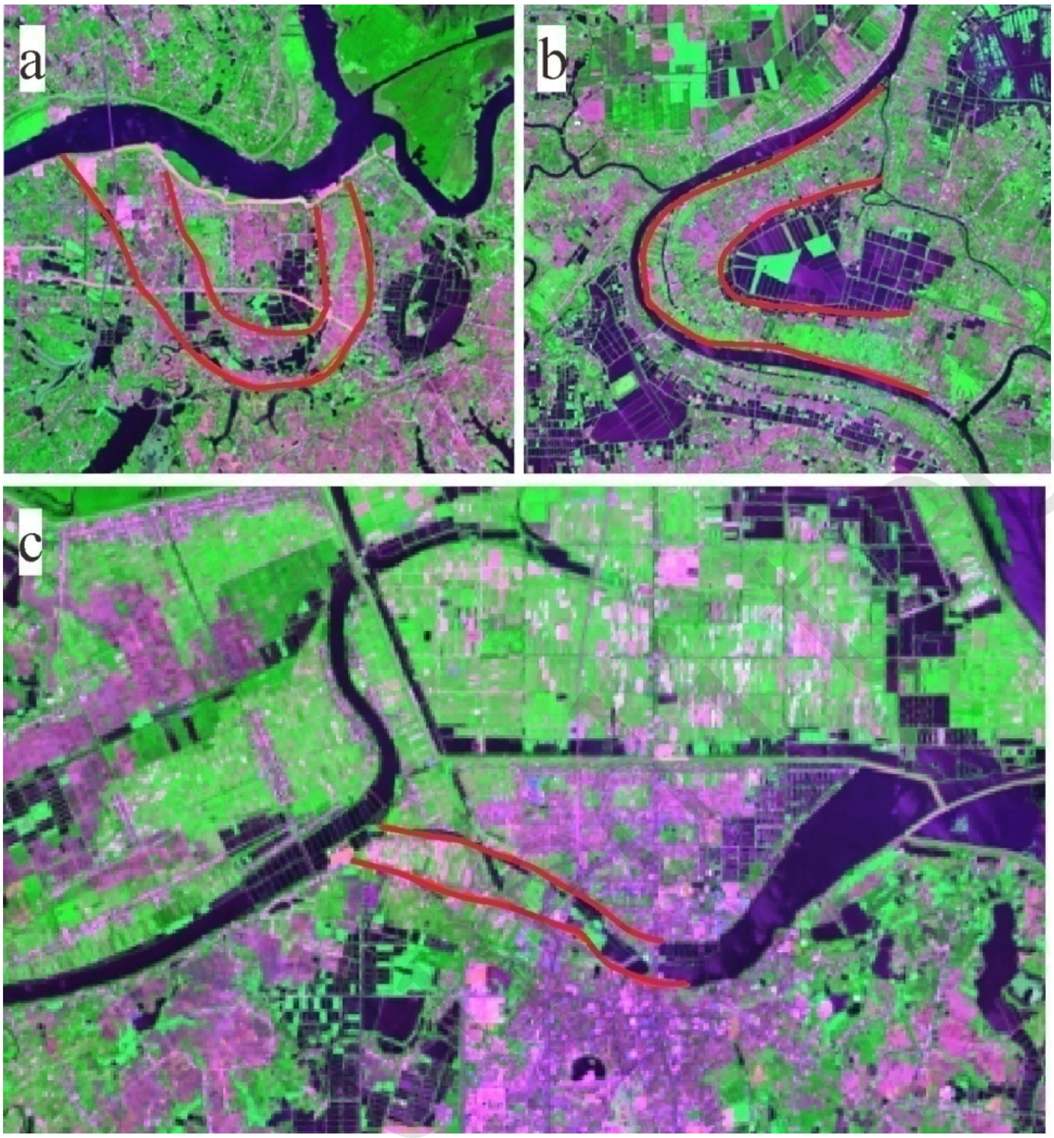

Figure 6. Partial details of ancient channel interpretation by remote sensing (all locations are shown in the white box in Figure 2; a. channel of the oxbow lake; b. channel of the beach plain displacement ridge; and c. modified low-lying river channel)

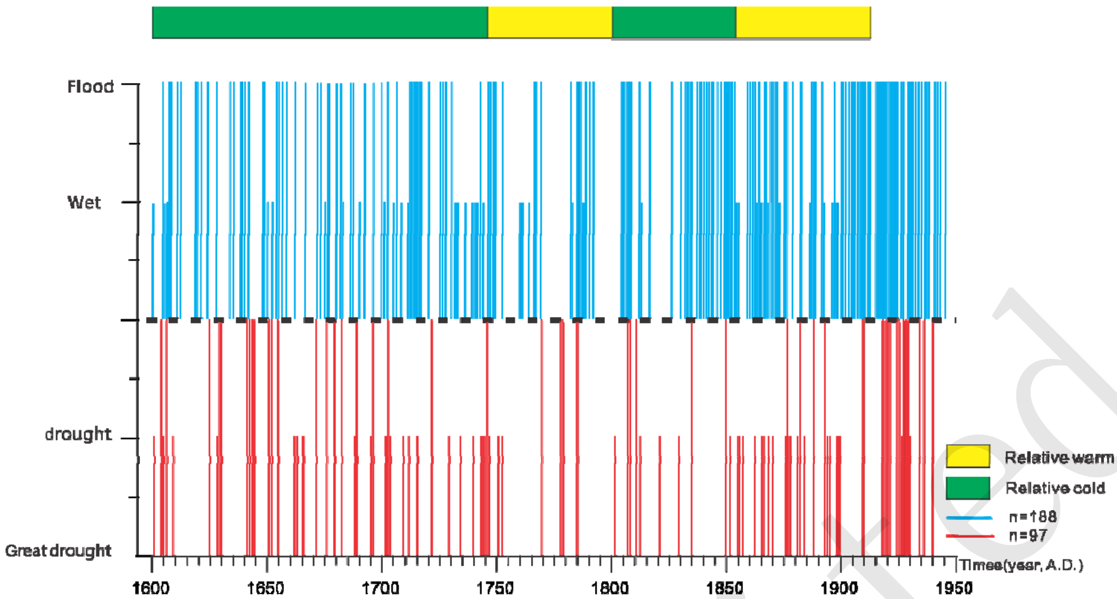

Figure 7. Records of drought and flood disasters, and historical climate change in the downstream Yuan River basin since 1600 AD

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