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GEOMORPHOLOGICAL CHARACTERISTICS OF A TRANSECT FROM THE YELLOW RIVER TO THE IRON PAGODA IN KAIFENG CITY, CHINA

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Abstract: The downstream area of the Yellow River is a suspended river and has constantly threatened the security of Kaifeng city. The Yellow River is one of the main forces driving the geomorphological characteristics evolution of Kaifeng city. Recent developments in unmanned aerial vehicle remote sensing system (UAVRSS) technology mean that research can now include both macroscopic and microscopic remotely sensed data. This paper utilized a digital elevation model (DEM) obtained using UAVRSS technology and evaluated the DEM and digital orthophoto map (DOM) of a given transect to analyze the geomorphological characteristics from the macroscopic and microscopic perspectives. Results of this research show that: the surface elevation near the Iron Pagoda is 88.44 m, the spire elevation is 143.618 m and the height is 55.183 m. The downstream area of the Yellow River in the Kaifeng city area is a typical suspended river. The surface elevation rises from 88.44m in Kaifeng city to 105 m near the Yellow River levee, while the elevation of the Yellow River is 92.25 m. The Yellow River is about 4 m above Kaifeng city and the river embankment is 16.56 m above the city. On a macro level, the transect elevation gradually decreases from north to south, which exhibits a stepwise pattern called the Four Typical Ladders. On a micro level, the most geomorphological changes were seen in the North Wall, the city-protection dike and the embankment. Those drastic changes were mainly influenced by the Yellow River floods, three major defense projects, and other human activities. The Yellow River remains the major of safety hazard to Kaifeng's steady and healthy development. Communities in Kaifeng city need to take a more active role in safeguarding their security and continuously aiding in flood control by recognizing the importance of major local defense projects.

Keywords: UAVRSS; Transect; DEM; Geomorphology; Yellow River; Kaifeng

1. INTRODUCTION

According to over 4000-years of historical records, the Yellow River has flooded in Kaifeng over a hundred times (Chen & Syvitski 2012). The Yellow River has become one of the main forces driving the development and prosperity or desolation of Kaifeng. The geographical position of Kaifeng close to the Yellow River has not changed, meaning that the risk of floodwaters breaching the embankment still exists. Under the combined impacts from human activities and climate change during the 20th century, the Lower Yellow River channel accumulated an average of 3-5 cm of silt each year and has recently increased to accumulating about 10 cm each year (Luo et al., 1997). The sedimentation velocity shows an increasing trend during the 21th century. The elevation of the Lower Yellow River channel is several meters above Kaifeng, which is typical of an "overhanging river"(the riverbed is raised above the surface by river channel sedimentation). Some simulations suggest that the area inundated by the next major flood event will exceed 13,000 km^2 (Jerolmack & Mohrig, 2007; Ma et al., 2007). Because of the large inhabited area that could potentially be flooded, it is both theoretically and practically necessary to have a better understanding of the geomorphological characteristics and other factors in Kaifeng that contribute to the flooding.

Geomorphology focuses on the origin, distribution and evolution of the landforms of the earth which bears the production and life of human beings, and it is also the research object of ecological environment construction and rational utilization of resources, which has attracted extensive attention from scholars. There is both theoretical and empirical research on the geomorphological features of the Lower Yellow River. On the theoretical side, scholars have studied the river bed and deposition changes (Guo et al., 2013), flood prediction (Zhao et al., 2007), simulated and analyzed the embankment breaching process (Ma et al., 2007), and analyzed the historical evolution of changes in the Yellow River channel as the result of flooding disasters and the government's social governance countermeasures (Hoffmann et al., 2010; Zhang et al., 2012). There has been a great deal of empirical research on the geomorphological features (Su et al., 2016; Liu et al., 2017). In addition, Du et al., (2017) quantified the distribution information of sand dune structures in Horqin, and quantitatively described the characteristics and morphology of dune patterns; Li et al., (2017) discussed the volcanic features of the Darino volcano group in Inner Mongolia; Huang et al., (2016) analyzed the geomorphology, morphological characteristics and formation of weathering pits on Miaowan Island, Guangdong, China; and Wu et al., (2016) studied changes in scour and deposition patterns in the Yangtze River estuary.

Past literature has mainly focused on flood control characteristics of the lower Yellow River (Jiang et al., 2010; Chen et al., 2014) as well as geomorphological features of the coast and seabed (Zhang et al., 2013; Gong et al., 2016; Wu & Nian., 2017). Currently, academic research on the geomorphology between the Yellow River and Kaifeng is mostly based on a small number of point elevation data (Li, 1988; Liu, 2011), with very limited precision. In this study, the geomorphological characteristics, trend evolution, and potential causes of certain geomorphology are discussed from both macroscopic and microscopic perspectives. In addition, this research explores the geomorphological characteristics of the "hanging river" in the lower Yellow River in Kaifeng at high-precision scales for the first time.

Today, remote sensing has become an indispensable technology for obtaining regional or even global information about the changing geographical environment (Li, 2008; Li et al., 2010). Unmanned aerial vehicle remote sensing systems (UAVRSS) are a technology which integrates current internet, remote sensing and inertial navigation methodologies in a rapidly developing holistic. Remote sensing and photogrammetry systems from unmanned aerial vehicle with various imaging and non-imaging sensors as the main load can obtain the video and image data (Li & Li, 2014). Compared with UAVRSS, it is more difficult to observe areas in complex environments using traditional satellite remote sensing (Zhang, 2011). With its simple structure, low cost, good security, low risk, flexible mobility and real-time performance, UAVRSS is becoming an effective replacement for Satellite Remote Sensing, Airborne Remote Sensing and Terrestrial Remote Sensing (Jaakkola et al., 2010; Li et al., 2012). In recent years, the development of UAV remote sensing technology has made it feasible to grasp regional geomorphological features from both macro and micro perspectives. Using these advances, this paper relies on UAV remote sensing technology to obtain high resolution Digital Elevation Models (DEM) and Digital Orthophoto Maps (DOM) of the study area. While the traditional method of studying regional geomorphological features uses only a few discrete points, in this paper, we study the geomorphological characteristics of an entire transect and determine the main factors influencing it using high resolution DEM with both macro and micro perspectives. The vertical relationship between the Yellow River and Kaifeng was also compared to provide a theoretical basis for further scientific research surrounding potential flood routes, timing, and scope in this region. Finally, this study assists government departments as they improve urban safety strategies and implement management measures that improve the science surrounding and public awareness of the "hanging river" in Kaifeng.

2. STUDY AREA

This research focuses on the geomorphological characteristics in the "Yellow River-Tower" transect (Fig. 1) located between Kaifeng city and The Yellow River. The Yellow River-Tower transect has a total length (N to S) of about 15 km and a width of 500 m (E to W), with a total area of 8 km^2. The micro-geomorphology of the study area is formed by human economic activities and long-term erosion by wind and water as a result of Yellow River flooding, siltation, and erosion. The geomorphology of transect is developed on the Yellow River flood deposition layer. Most sand dunes are formed by the transportation and piling of sand particles by the wind within a short distance, combined the effect of human and nature, resulting in the interphase distribution of positive and negative geomorphology.

Selection of the study location was based on the following three considerations: (1) the transect is located in the vicinity of the extraordinary flood in the 21st year of the Qing dynasty (1841 AD) (Wu et al., 2014), which caused a major change in the river's geomorphology and pattern; (2) the Yellow River embankment located near the penstock of Liuyuankou protrudes into the center of the riverway, and is responsible for an enormous amount of flood control; and (3) with the goal of comparing the elevations of the Iron Pagoda and The Yellow River. Depositions from the Yellow River's flooding have reformed the geomorphology of Kaifeng. Dunes, sand, and depressions are widely distributed, including dunes in northwestern Kaifeng that extend for dozens of kilometers. Due to the prevalence of northeast winds in winter and spring, dunes are generally oriented northwest-southeast and northeast-southwest (Feng, 1926). As a whole, Kaifeng has large areas of wilderness and plains, as well as dunes. However, its positive-negative terrain with few undulations is widely distributed and not far away from each other in local. Micro- geomorphology was formed over time through the long-term impacts from human activities, wind power, and water from several previous floods, erosion, and siltation events (Si & Ma, 1958). Depressions are widely scattered across the transect, which generally presented as a strip or sporadic pattern in the transect. The depressions are from built up sediment and siltation that was used as an engineered defense around suburbs areas to protect against floods, as well as excavated soil caused by the construction of the Yellow River levee.

3. DATA AND METHODS

3.1 Data collection and processing

3.1.1 UAV remote sensing platform

The Avain-P fixed wing UAV was used to collect data, a system which is produced in Taiwan. The length of the UAV is 1.03 m, with a

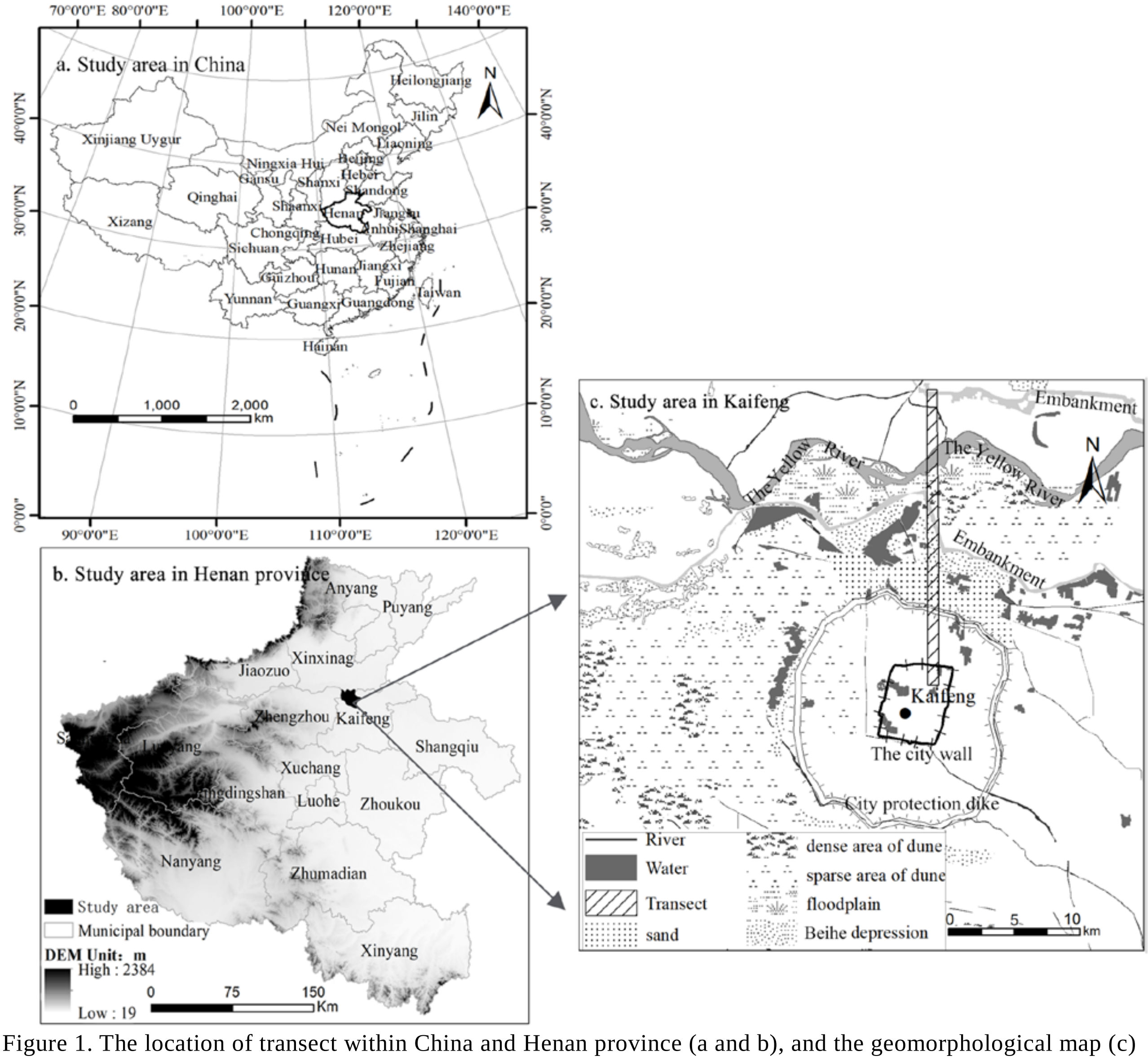

Figure 1. The location of transect within China and Henan province (a and b), and the geomorphological map (c)

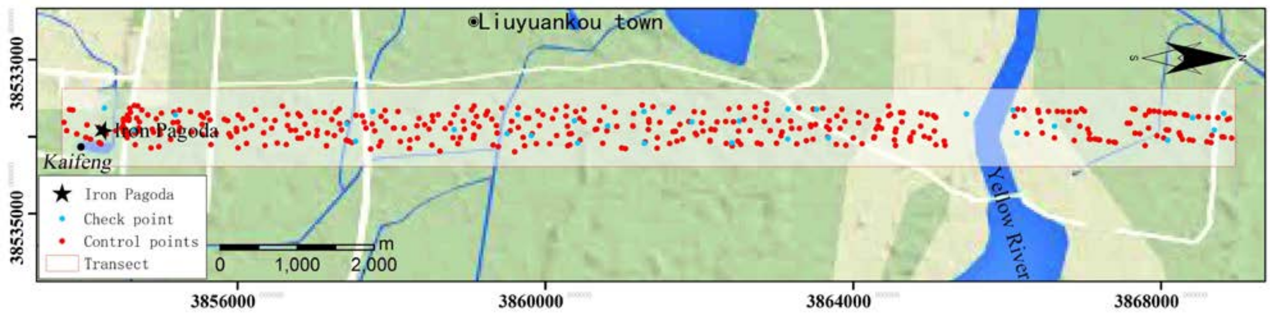

Figure 2. Distribution of control points and check points in the transect

wingspan of 1.6 m, a height of 0.35 m and has a maximum take-off weight of 4.3 Kg. The UAV uses a projectile take-off mode, and achieves a relatively high flight elevation of 280 m. The flight platform was equipped with a SONY A7r non-measuring digital camera, pixel resolution size: 0.0048 mm * 0.0048 mm, with a camera focal length of 35.5841 mm.

3.1.2 Aerial photography parameters

Three aerial routes were planned that traversed north to south, with course and side overlap of 82% and 57%, respectively. Images were taken every 2s for a total of 1200 effective images (per image includes the instantaneous flight altitude information), with a spatial resolution better than 5 cm. As it was difficult for radio signals to cover the whole area of the transect (a total length of about 15 km), the transect was divided into three sections, and each adjacent segment presupposes 500 m overlaps to meet the requirements of creating the mosaic image.

3.1.3 Control point establishment

The original control points and checkpoints were taken from the WGS-1984 geographic coordinate system, and the elevation was based on the 1985 national elevation datum. However, the points used for photogrammetry needed to be represented in the plane projection coordinate system. In this research, we converted the WGS-1984 geographic coordinate system into Xi'an 1980 Gaussian projection coordinate system according to the position and range of the transect. The total number of control points and check points arranged in the study area are 418 and 32, respectively (Fig. 2).

3.1.4 Image data processing

The UAV image processing methods based on the digital photogrammetry system are accomplished in three stages: data preparation, aerial triangulation encryption, and DEM/DOM production (Fig. 3). In addition, other important processing steps include: image quality inspection, image distortion correction, elevation point and line collection, DEM data editing and precision verification, digital differential correction, unifier ray and coloring of the image, and image clip and mosaic.

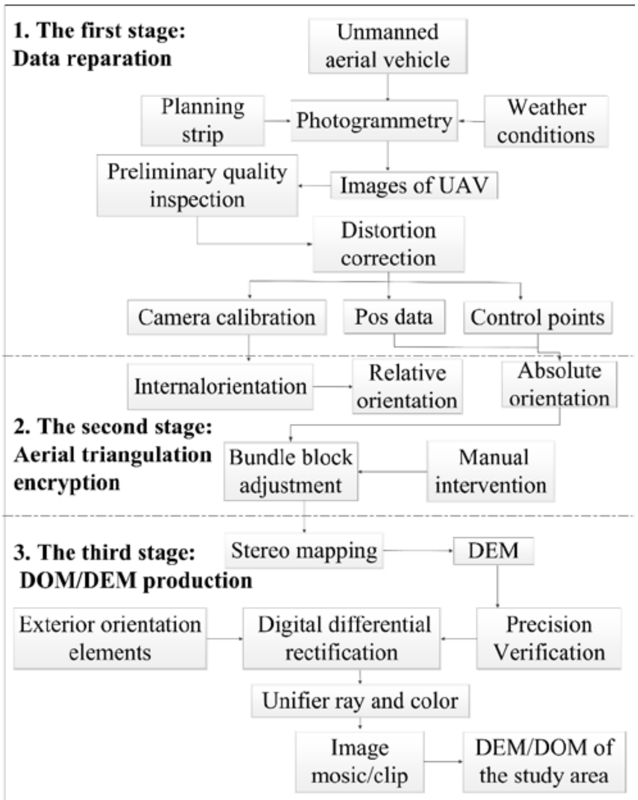

Figure 3. Processing flow of UAV data

The detailed data processing process of images are as follows: ① Image distortion correction: the UAV platform is equipped with a non-measurement digital camera, and the image should be corrected for both image distortion and displacement of the main point; ② Aerial triangulation encryption: using the DataMatrix software, create strip, rotate the images, automatically create connection points, and add thrust control points in the 3D view environment. Following that, conduct multiple loops to eliminate

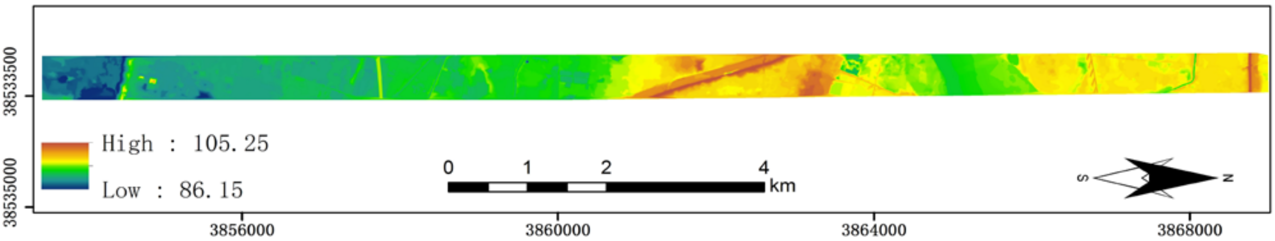

Figure 4. Digital elevation model of transect

Figure 5. Digital orthophoto of transect

a. Transect southern edge (south gate of Minglun campus of Henan university); b. Iron Pagoda park; c. North city wall; d. city protection embankment; e. Yellow River irrigation canal; f. The Yellow River levee; g. Floodplains and watercourse

error overrun, until the precision meets the specification requirements; ③ Stereo Mapping: based on the results of the aerial triangulation encryption, collect geomorphological feature points and lines and interpolate them to generate a DEM (Fig. 4); ④ The digital differential correction: performed by integrating the DEM with the image foreign element; ⑤ The DOM (Fig. 5) is obtained after applying the unifier ray and coloring, creating a mosaic, and clipping the image.

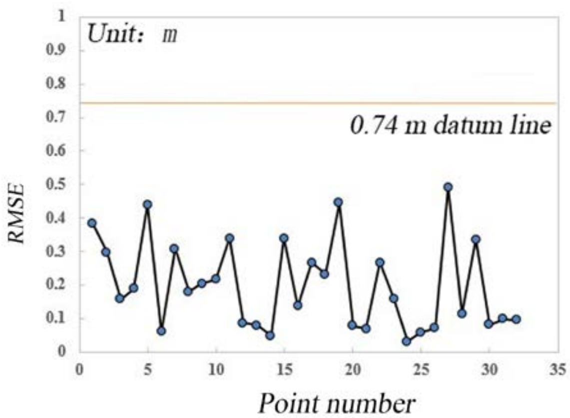

Figure 6. Distribution of the checkpoint residual value

3.2 Data evaluation methods

All data should be evaluated for its accuracy and quality before being used in research and decision-making. The evaluation methods for the verification of the accuracy of regional DEM data mainly include the checkpoint method, profile method and contour method (Jia et al., 2011). The check point method is the most representative and commonly used method. In this paper, the checkpoint method is used to check the accuracy of DEM data.

4. Results and Discussion

4.1 DEM assessment

Precision evaluation of the DEM is based on the GH/T 9008.2-2010 standard, as shown in Table 1. The RMSE accuracy of the 3rd-level digital elevation model at the scale of 1:1000 was lower than 0.37 m, and the maximum error of the checkpoint was within twice the RMSE (0.74 m). Figure 6 shows that the residuals of 32 checkpoints were lower than 0.74 m, indicating that the residual accuracy of checkpoints was in line with the requirements (Fig. 6).

Table 1. Precision index of the digital elevation model

Scale	Terrain categories	RMSE(m)
1:1000	Flat	0.37
	Hilly land	1.05
	Mountain land	1.50
	alpine land	3.00

4.2. Vertical changes in the geomorphology

The process of formation and evolution of geomorphological characteristics in the transect between the Yellow River and Iron Pagoda are closely related to the Yellow River. If the Yellow River embankments broke, Kaifeng city would be a disaster area, or could be totally destroyed. The Yellow River has a great influence on the formation and evolution of the geomorphology in the region. The geomorphology is also affected by the construction of three major defense projects (city wall, city protection dike, and the Yellow river embankment) and various human activities. Figure 7 is the geomorphological characteristics map nearby the three major defense projects. This paper will discuss the relevant factors one by one.

There are many kinds of alluvial micro-geomorphology types in the suburb of Kaifeng. Figure 7a shows that the micro-geomorphological characteristics on both sides of the embankment that protects the city shows a significant gradient. The surface elevation of the protection embankment in the north area of the city is generally higher by 1-1.5 m than it is in the south, as the function of the embankment in the historical period was to intercept, decelerate and divert flooding, as well as to carry the sediment from the flood outside the dike. Between the embankment that protects the city and the Lian-huo expressway (G20), the ground elevation is lower than south of the city protection embankment and north of the expressway. This phenomenon is because the Lian-Huo expressway was constructed using borrowed soil. The embankment in the intersection of the city protection embankment and the Zheng Xu high-speed rail was destroyed, and the ruins of the defense engineering can be glimpsed here.

In Figure 7b, the geomorphological characteristics that changed in both sides of the city wall are apparent, where the elevation in the outer surface of the wall is significantly higher than the inside. With the city wall as the boundary, the elevation of surface from the north wall to the north was generally gentle, showing a decreasing trend, while the elevation change of the south area was abrupt, as the surface was relatively lower than north of city wall with widely distributed rivers and lakes. This phenomenon might be caused by the large amount of sediment in the Yellow River, which is blocked by the north city wall, and consequently reduces the flow rate. The sediment was deposited on the outside of the city wall, which protected the city from the silt from the flood.

Figure 7c shows that the difference of geomorphological characteristics on both sides of the south embankment of the Yellow River are remarkable. The south embankment has an elevation of 104.6 m, which is about 17 m higher than the central city of Kaifeng. Meanwhile, the surface elevation decreases by 5-6 m between the Yellow River Beach and the Beihe depression. This phenomenon is caused in part by the silt brought by the Yellow River accumulating and causing the river bed and beach area to rise. In addition, the embankment is also constantly reinforced by people adding soil on the outside, which increases the geomorphology change on the two sides of the embankment.

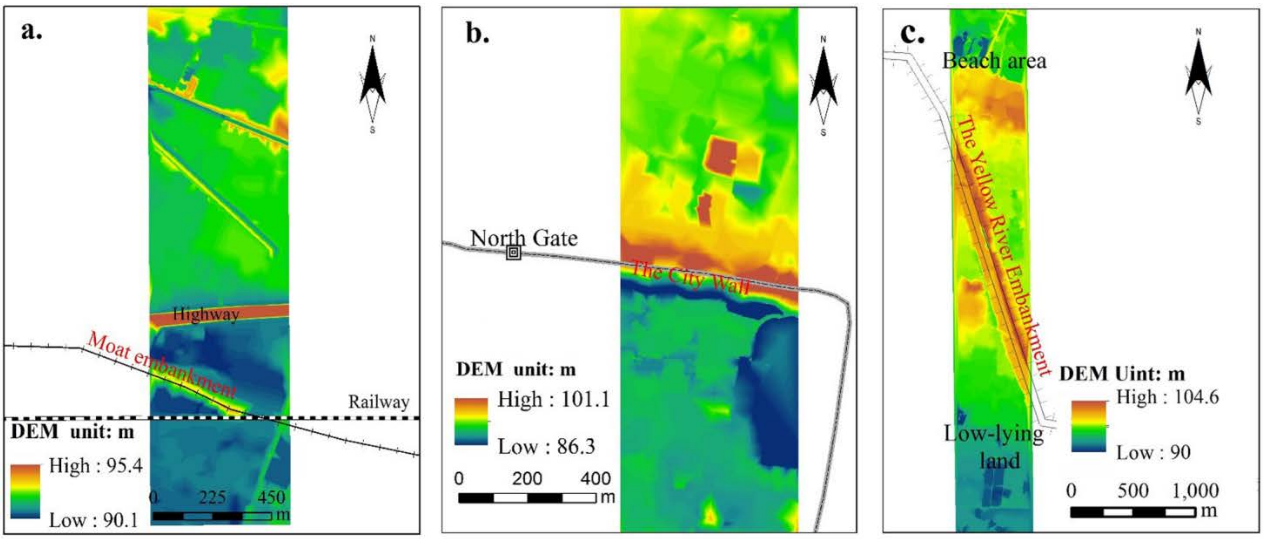

Figure 7. Terrain characteristics nearby the city protection dike (a), city wall (b) and Yellow River embankment (c)

For all these reasons, the elevation difference between both sides of the three flood protection projects is several meters, indicating that the flood defense projects effectively blocked and slowed the effects of the flood in Kaifeng city. These projects also show communities that they should pay attention to the important role of protective engineering in safeguarding urban security. Strengthening the Kaifeng city walls via repair and adding protection will allow them to continue to function in flood control and disaster reduction.

4.3. Horizontal changes in the geomorphology

The terrain profile of the transect was obtained using the GIS section segmentation method (Fig. 8) based on the DEM collected via UAV remote sensing technology. The transect traverses the urban area, the city wall, the outskirts, the city protection embankment, the Beihe depression, the Yellow River embankment, the Yellow River beach, the Yellow River channel and other areas that typify the terrain.

① The geomorphology of the transect showed obvious spatial gradient changes at the macro level. The four typical regions between the Yellow River and Kaifeng include the Yellow River floodplain, the Beihe depression, suburban areas, and Kaifeng city proper. The surface elevation gradually decreased, with the transect elevation decreasing from north to south.

② The surface elevation of the transition zone between the four typical regions is drastic at the micro level, and each shares a commonality. In each transition zone, there is a man-made flood defense project between each region (the Yellow River embankment, the city protection embankment, the north city wall), all of the defense projects significantly impact flood and sediment deposition. The typical geomorphological characteristics in the transect were the result of the comprehensive effects from the Yellow River, flood defense engineering, and human activities. At the same time, this phenomenon confirmed the important role of the Yellow River in the geomorphology evolution of the region.

③ The south bank of the Yellow River floodplain was the worst affected by the flood, as the slope of the bank was close to 90°, and the beach and distance to the water was very short with a significant drop in elevation. However, the slope of the north bank of the floodplain was relatively flat (about 60°), meaning that silt was deposited there all year, increasing the average elevation of the north bank beach. This differential occurred because of the Coriolis force causing the river to flow against the right bank, and because the river bank was directly affected by upstream water, making the south bank of the Yellow River in Kaifeng the key area to focus attention for disaster prevention.

④ The lower Yellow River is known as the "hanging river", which shows the obvious characteristics of water on the ground. The surface elevation of the transect in urban Kaifeng city was only 88.44 m and reached 105 m near the levee. The water level of the river was two to three meters higher than that in the Kaifeng suburbs, and it was about five meters above the urban surface, while the Iron Pagoda was about 50 meters higher than the water surface of the Yellow River. This observation was very different from the common saying that the Yellow River was more a dozen meters above the surface of Kaifeng city, or the same as the Iron Pagoda.

⑤ The elevation of the Yellow River water surface was 92.25 m, and the Iron Pagoda base was 88.44 m. This means that the surface of the river was 3.81 m higher than the base elevation of the Iron Pagoda. The Iron Pagoda spire was 143.618 m high, meaning that the Iron Pagoda was at 55.183 m. These results are somewhat different from the measurements of 55.88 m and 55.63 m obtained by other researchers, but the error was still within the limit range (0.74 m). The variability in flying

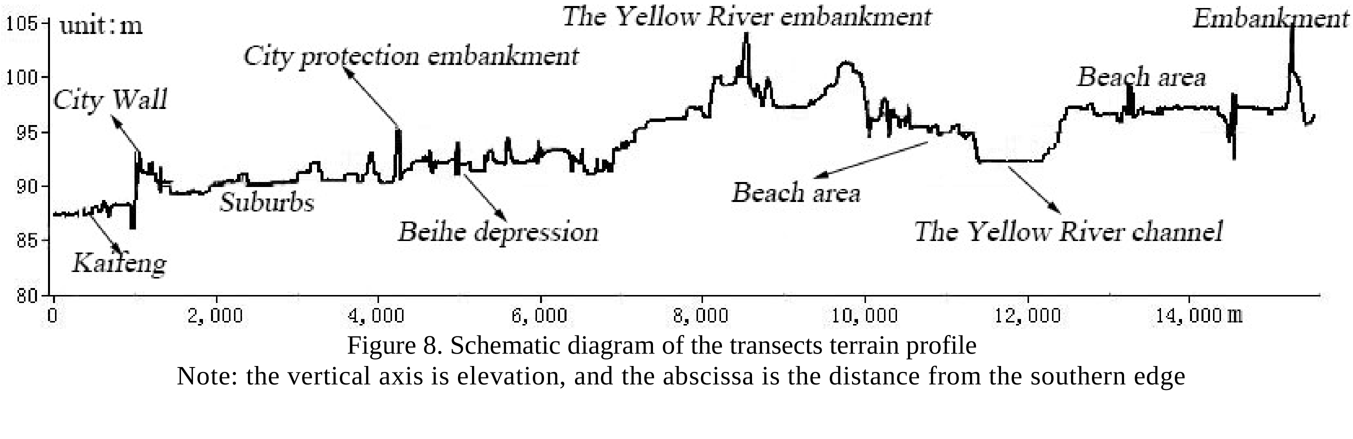

Figure 8. Schematic diagram of the transects terrain profile

Note: the vertical axis is elevation, and the abscissa is the distance from the southern edge height may have contributed to difficulties in measuring the distance of the lightning rod on the spire of the Iron Pagoda.

5. CONCLUSION

This paper investigated the geomorphological characteristics and evolution in the region from the Yellow River to the Iron Pagoda based on high-resolution DEM and DOM data. Based on these works, the relationship between geomorphological characteristics and floods of the Yellow River was analyzed. ArcGIS 10.4.1, ENVI 5.0 and other software was used to obtain the geomorphological change profile and to analyze the change characteristics and causes of geomorphology changes. The main conclusions of this study were as follows:

(1) The checkpoint method was used to verify the quality of the DEM and found that its accuracy satisfied the relevant specifications requirements (GH/T 9008.2-2010). The overall geomorphology changes of the transect is not large, the slope is relatively gentle, but there are still exist some complicated geomorphological characteristics. The elevation of the Iron Pagoda base was measured using UAVRSS as 88.44 m, and the spire as 143.618 m，thus the Iron Pagoda had a height of 55.183 m. In addition, the elevation of the Yellow River water surface was measured as 92.25 m. While the elevation of the Yellow River only accounts for 6.9% of the Iron Pagoda, this result corrects the expression that "the elevation of the Yellow River is highly consistent with the fourth floor of the Iron Pagoda"(Li et al., 2006).

(2) The sediment found in the lower Yellow River in Kaifeng is typical of that found in an "overhanging river". The overall surface elevation of the study area decreases gradually along the direction of N-S. The Yellow River channel is about 4 m above the downtown area of Kaifeng，and it is between two and three meters higher than the surrounding suburbs. The surface elevation increased from 88.44 m in urban areas to 105 m near the embankment, with an average slope of 0.11°. These findings provide a more scientific understanding of the phenomenon of an "overhanging river". On the other hand, the south bank of the Yellow River floodplain was the worst affected by the flood, as the slope of the bank was close to 90°. That warn people that the Yellow River remains the major safety hazard to Kaifeng's steady and healthy development.

(3) The four typical geomorphological regions in the transect show obvious differentiation in gradient at the micro level. With the floodplains of Yellow River, Beihe depression, suburban plain and Kaifeng city as benchmarks, the elevation showed the law of stepwise decline. The geomorphological characteristics of the embankment, city protection embankment, and north city wall changed drastically at the micro level due to the combined effects of flood and defense engineering. Lakes and ponds are widely distributed in Kaifeng city due to the low surface elevation. The geomorphological characteristics of the study area are obviously controlled by the Yellow River and human activities. Furthermore, it is not only possible to quickly obtain the high-resolution geomorphological characteristics of the study area, but also to analyze the distribution and evolution degree of different geomorphological types by using UAV remote sensing and GIS technologies.

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