Project: Historical Water Management and Environmental transition in Ningbo

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Abstract：

Ningbo was a city that heavily relies on waterway transportation. This has been documented in *Yinxian Tongzi* published during 1930s (here after referred as *Tongzi*): the transportation as a function has been recorded in many water channels in the area and the waterbus schedule listed depicted a complex public transportation network operated at weekly and daily bases.

However, in Ningbo today, the water transportation seem to only be limited on the three main river as well as the coastal. A transition from waterway dominant transportation style to a landline dominant transportation as it is now has not been clearly documented and analyzed.

This report takes the first step applying GIS spatial analytical techniques on one of the earliest surveyed maps in *Tongzi* to evaluate the spatial relationship between waterways and land transportation in a small and plain area close to Chenpodu in east part of Ningbo. The analytical results, together with the narratives in the contemporary documents, reveal the spatial interaction between the waterways and land roads during the time. This can serve a snapshot of the transition from waterway transportation to land transportation in 1930s.

It appears that most of the land roads were developed parallel to the waterways. The distances between the waterways and the adjacent land roads are relatively close. Based on this preliminary observation, it is considered during the period, the functions of waterways such as travelers' transportation and some goods transportation may be gradually taken over by land road. It is likely the speed and capacity of the vehicles moving on land become compatible to that of the vehicles traveling on water during the period. Further, the dense water network during the time may have become an inconvenient barrier for a larger scale of land development. Quite a few water channels reportedly were filled to either become land roads or served as public spaces such as a local marketplace. The waterways transportation was indeed gradually fell out of favour in the area.

Overall, the study piloted an approaching in analyzing historical transportation using tools and methods of spatial analyses as well as statistical analyses. This demonstrate the application of mixed method research in the area of digital humanities.

Extended Summer Research Report

Analysis of Spatial Relation between Rivers and Roads in Yin County, Ningbo in 1935

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1 Introduction

Yin County (Yinzhou, 鄞州), located on the southeast Chinese coastline, was a hinterland of Ningbo in history. It was one of the well-known water towns and trading ports in Zhejiang Province (Tang et al., 2016). The humid monsoon climate and plain terrain jointly contribute to dense natural river channels across the settlement. Based on these natural rivers, the people of Yin County built a sophisticated water network for transport and irrigation purposes. These tessellated channels then link the county effectively. In the view of a local history, 'Rivers are the city's bones, and water is its blood' (Zhou, 2008, p.55). Consequently, Yin County has gradually developed as a regional business centre because of transport convenience and agricultural harvest, brought by the knitted water network.

In 1844, Ningbo was opened to the western world as a treaty port due to the *Nanjing Treaty*. This might facilitate the entry of foreign companies, which brought a series of changes to local society. New transport technologies were introduced to Ningbo, such as steamships, trains, and automobiles (Ding, 2007). These new vehicles not only significantly improved transport efficiency, but also gradually changed urban infrastructure (Zou & Yang, 2003; Ding, 2007; Sun, 2010). This report will take a closer look into the transition between the waterway and land road system. It will analyse the spatial relation between river channels and roads in south-eastern Yinzhou, based on an ancient chorography *Yinxian Tongzhi* (鄞縣通志, hereafter named as *Tongzhi*) and attached maps that were firstly published in 1935.

2 Literature Review

2.1 Functions of Waterways

Firstly, it is important to understand the functions that river channels served in a city. Wu (1991) summarized rivers' functions into three major categories, namely daily production, disaster prevention and environmental recreation. In accordance with *Yinxian Tongzhi*, the water channel functions in 1935's Yin County mainly fall into the first two categories. The environmental improvement (e.g., water purification and entertainment function) was rarely mentioned in the *Tongzhi*. At the time, public awareness of the modern concept of water quality has not yet been established. Moreover, the recreational water gardens might be reserved for the literates and social elites, mostly in the city centre. The examples are the gardens or some semi-open theatres on the waterfront and small artificial islands on Moon Lake, Ningbo. In other words, water channels primarily supported daily activities (cultivation, transportation and domestic water supply), and disaster protection (flood and drought prevention) in Yin County in the early 20th century (Hong & Zhou, 2014; Zhang, 2016; Tang et al., 2018).

Regarding transportation function in the first category of daily production, the rivers mainly worked as connections between villages and towns. Shipping companies scheduled sailboats and steamboats for business and public navigation (*Yinxian Tongzhi*, 1935). At the same time, family private boats existed for smaller-scale transport and private outing (Zhou, 2011). Overall, in the 1930s, water carriage and shuttles were widely available and popular transport choice in County dwellers' daily life.

2.2 Development and Replacement of Land Roads in Yinzhou

However, water transport in Yin County was gradually replaced by roads due to the introduction of land-travel automobiles. It is recorded in the *Tongzhi* that Yinzhou had invested great efforts into road construction from approximately 1929 to 1935. Government agencies, street committees and local groups covered up the existing channels and filled up abandoned ones to build new land roads or expand the old city roads for cars (*Yinxian Tongzhi*, 1935). For example, in 1929, the city government filled up the Yuemiaoxi River (岳廟西河) to pave a 0.5 kilometres long, 5.7 metres wide stone street called Chejiao Street (車轎街), literary translated as a street for car and sedan transport. Such a change in infrastructure reconstruction and the name of the street reflects the transport transition from waterways to land-roads in the early 20th century Yinzhou.

The reasons for land-based transportation development mainly lie in three perspectives. Firstly, accelerating urbanization resulted in land-use transition. A large scale of farmland changed into construction areas, which possibly elicits a decline in irrigation demand (Chen et al., 2007). Secondly, river channels could be silted up easily due to rich sedimentation in the downstream estuary, where Yinzhou was located (*Yinxian Tongzhi*, 1935; Yan et al., 2018). Thirdly, land borne transport competed out waterways in velocity, which could be a vital factor in the fresh food business and military defence (Ding, 2007; Sun, 2010; Yan et al., 2018). Therefore, it seemed inevitable that roads and automobiles would take over the water transport.

2.3 Former Study on the Transition of Transportation

Overall, current studies have provided a general understanding of transportation evolution in the Republican Era of middle east coastal China. In general, they mainly focused on the introduction to new development of transportation (Ding, 2007; Liu, 2015; Sun, 2010; Zhou, 2011), reasons for transport transition (Ding, 2007; Yan et al., 2018; Zhang, 2016), urban river network change (Liu & Han, 2014; Yan et al., 2018; Zhou, 2011) and data analysis on road and river's length change (Chen et al., 2007).

However, the available literature barely discussed the river-road spatial relation in the early 20th century. Zhang (2016) investigated into this topic, but the research focus was on the urban areas in Nanjing in 2010, rather than traditional counties or villages in the last century. It is believed that further study of the river-road relation can provide a new and unique perspective of urban transport transition research. Moreover, as it is relatively difficult to find academic evidential support for river-road spatial analysis in the Republican era Ningbo, this research report aims at providing a primary map-based investigation and some evidence base for further study on this topic. Also, considering the way how transport technology evolves, this study could inspire the urban planners on a future vision of transport infrastructure designs.

3 Methods

3.1 Research Area

The target area of this research is in the southeast Yin County during the 1930s. It is in the east of Fenghua River, and the west of Dongqian Lake (shown in Figure 1). It covers an area of approximately 43.1 km^2. Five villages/towns were included, which were Jiangshan (姜山), Dingqiao (定橋), Jiacun (甲村), Xudongdai (徐東埭) and Shiqiao (石橋). The base map of this study is obtained from the Yi Map (乙圖, the map two) among a map collection of Yin County area, which was drawn in July 1935, published together with *Tongzhi*.

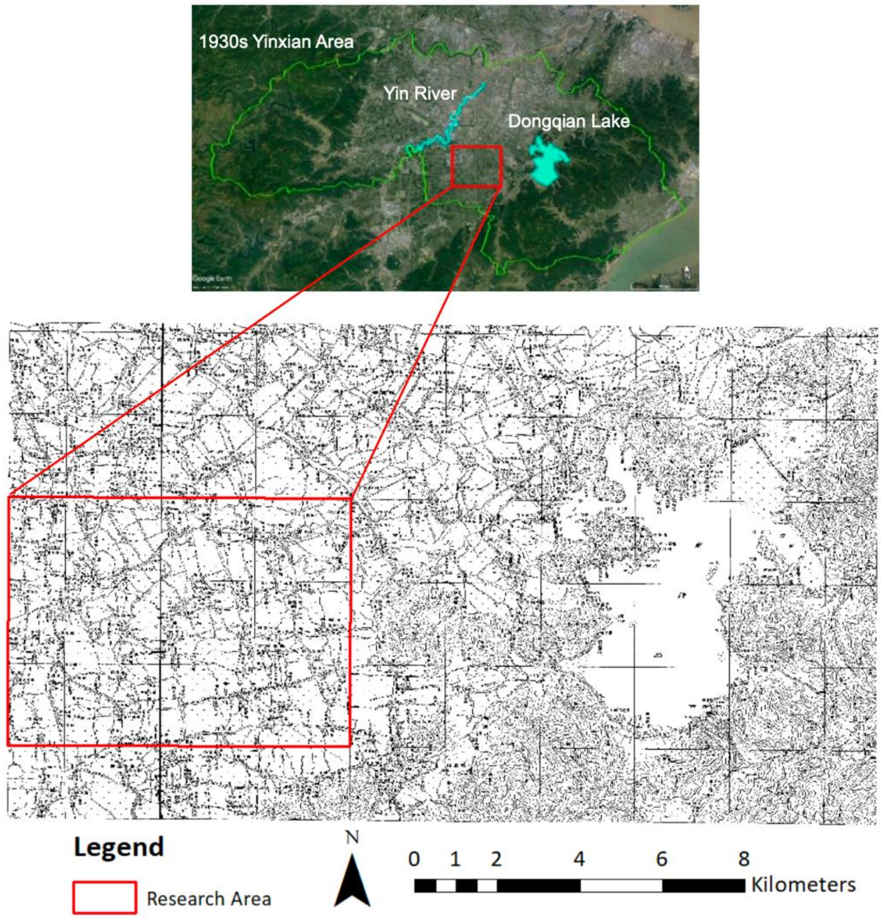

Figure 1. The research area.

The reasons for choosing this research area were primarily three folds. First, this area was selected from the focus fields of UNNC Library's Digital Humanity Project, to which this study is belonged and shared the data resource. Second, the channel networks and roads were relatively condensed in this area, providing a comparatively considerable spatial analysis resource for the study. Third, the terrain of this area was mainly flat plain, and the land-use types were primarily agricultural and residential zones at the time of this study analyse (*Yinxian Tongzhi*, 1935). These characteristics mainly represented the major land use types where human activities primarily took place in the early 20th century, and the results may suitably represent a larger area in Yinzhou or the Ningbo city at the same time.

3.2 Water Channels and Road Selection

The selection of channels and roads analysed was mainly based on the text recording in the *Yinxian Tongzhi*. The channels were referred to the Table of Eastern County River Channels (東鄉河渠表) in the River Channel Chapter (from page 144 to 148). The roads were referred to the Table of Total County Roads (全縣道路表) in the Transportation Chapter (from page 1380 to 1382). Only the rivers and roads that were recorded in the texts and on the attached maps were then included in the analysis out of data reliability.

3.3 Spatial Analysis

The spatial analysis was mainly conducted in ArcMap 10.8. Firstly, to form a river-land network map layer on the Yi Map, river channels were digitized using polygons, and roads were digitized as polylines. Secondly, the Buffer function was adopted to create riverain zones; three buffer areas were extended from the river polygons, with a distance radius of 100, 200 and 500 metres. To measure and visually check the distance and spatial interaction of road to river, the Intersect function was applied to each buffer area with the road polylines to generate three riverain roads layers (within 100-, 200- and 500-metre radius distance). Next, generate the lengths and the percentages of roads in each buffer ring to the total road length. This completed the digitization and standardization of the river-road spatial relationship. The attribute data of roads were then exported to statistical software for further analysis.

3.4 Data Analysis

To further verify the results obtained from the visual examination and quantify the significance, ANOVA was conducted to examine whether the proportions of the land road (both residual lengths and percentage to the overall length of each road) located within 100-, 200- and 500-metre buffer areas significantly different from each other (at significant level of 0.05). This analysis may aid in double-checking whether the perception of the road and waterway relationship based on visual presentation was generated by one or two long roads dominating the selected area. The reason for analysing the residuals (road lengths within each buffer) was to avoid double counting that may occur in the accumulative road lengths analysis.

In the case that ANOVA indicated the significance, the *post hoc* test was conducted to identify the source of significance. In this way, we can determine within which distant range of buffer areas, the roads are located most frequently.

4 Results

4.1 Spatial Distribution of Water Channels and Land Roads

Overall, the water channels in the research area were relatively straight and located in a reticular manner (Figure 2a). Only one meandering channel that seemed like a natural river was in the northeast corner of this area. Another characteristic of these channels was rich bifurcation. Instead of tributaries joining the mainstream, many tributaries here were derived from the main course to connect building blocks and farmlands. Moreover, it could be discovered in Figure 2b that the recorded and digitized water channels were only part of the total channels on the map.

The land roads were evenly distributed in a checkerboard pattern (Figure 2a). The recorded roads were mainly in north-south or east-west direction, and they were generally in line with or close to the water channels from visual observation. In Figure 2b, the roads in the west and north areas were more parallel to the water channel, but the roads in the southeast area seemed to be more separated from the river channels.

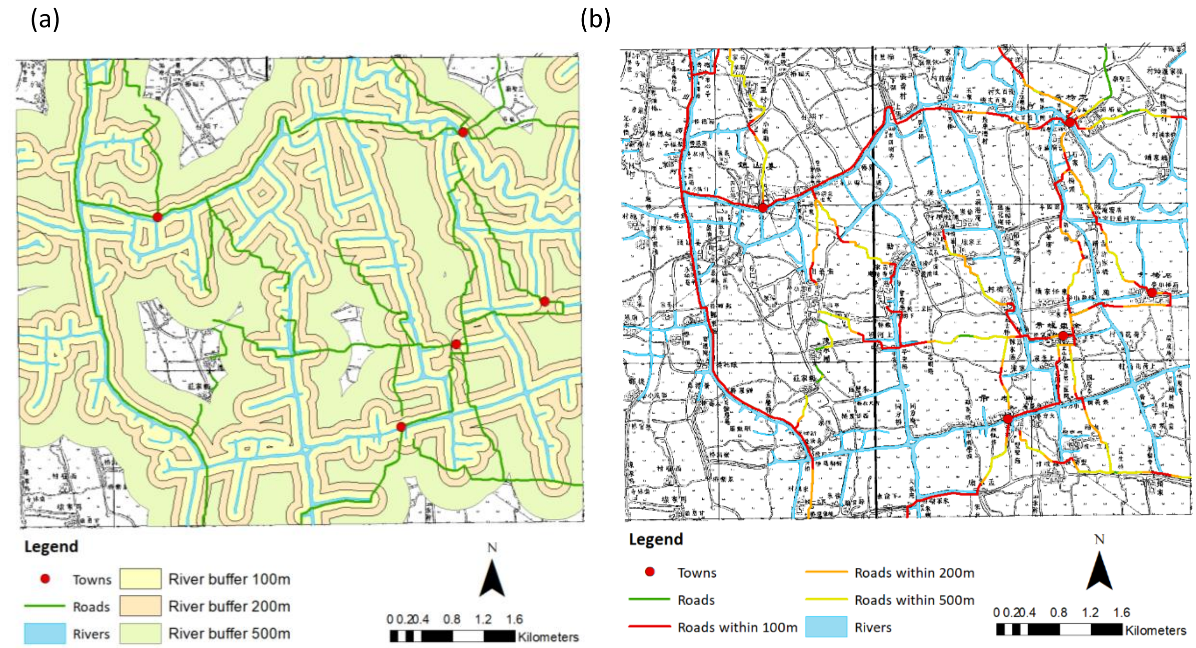

Figure 2. (a) Map of digitized roads and river channels with three buffer areas. (b) Map of three categories of roads within the distance of 100, 200 and 500 meters to the river channels.

For buffered areas (Figure 2a), the 500-metre buffer layer covered almost the whole research area. That is, most of the water channels were no less than 1000 metres far away from each other. In the central research area, the 100- and 200-metre buffer layers partly overlapped due to intensive channels distribution. Regarding the land roads distribution, the roads in the 100-metre buffer zone were mostly located in the north and west areas, or close to the villages and towns (Figure 2b). For the roads in 200- and 500-metre buffer zones, they were more dominantly in the southeast region, and some of them cut through the farmlands. Overall, the road length in the 100-metre buffer area seen to be longer than that of the other two buffer areas via visual examination.

4.2 Length Distribution of Land Roads

In total, 24 recorded roads were digitized in this research, and the total length was 47025.81 metres. Figure 3a illustrates the distribution of road lengths within three buffers and overall research areas, from which it could demonstrate that the lengths were quite close to normal distribution. Next, the percentages of residual road lengths in the three buffer zones are presented in Figure 3b. It illustrates that 52% of a total road were within 100 metre of a river, followed by 21% in 100-200 metre buffer and 23% in 200-500 metre buffer areas.

(a) (b)

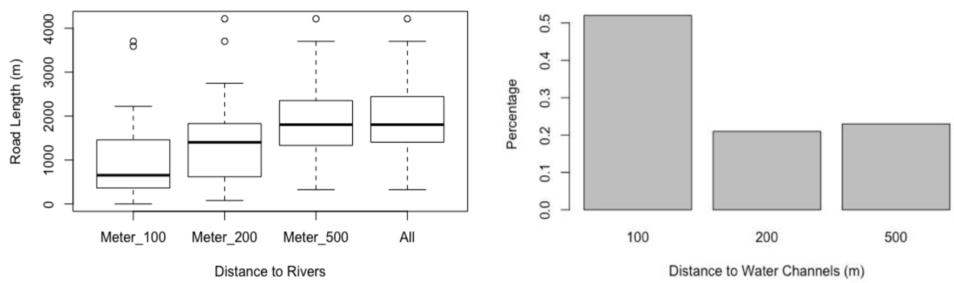

Figure 3. Distribution of 24 road lengths within three buffer areas: (a) Boxplot of road lengths (metre). (b) Bar chart of percentages of road lengths.

The buffer distribution percentages of each digitized land road were in Figure 4. Among the 24 roads, No.1-8 and No.17 were identified as major roads (described as 枝路 *zhilu* in the *Tongzhi*, since the primary road, 幹路 *ganlu*, was not located in the study area), and the other 13 roads were minor branches derived from the major ones. It is observed that the major roads had more 100-metre buffer length percentages than the minor branches, while the branches generally had larger 200 and 500-metre buffer length percentages. Four roads were fully located within the 100-metre buffer zone (No.1, 2, 8 and 16), of which three were major roads. Moreover, No.14 was the only road that had no course within the 100-metre buffer ring.

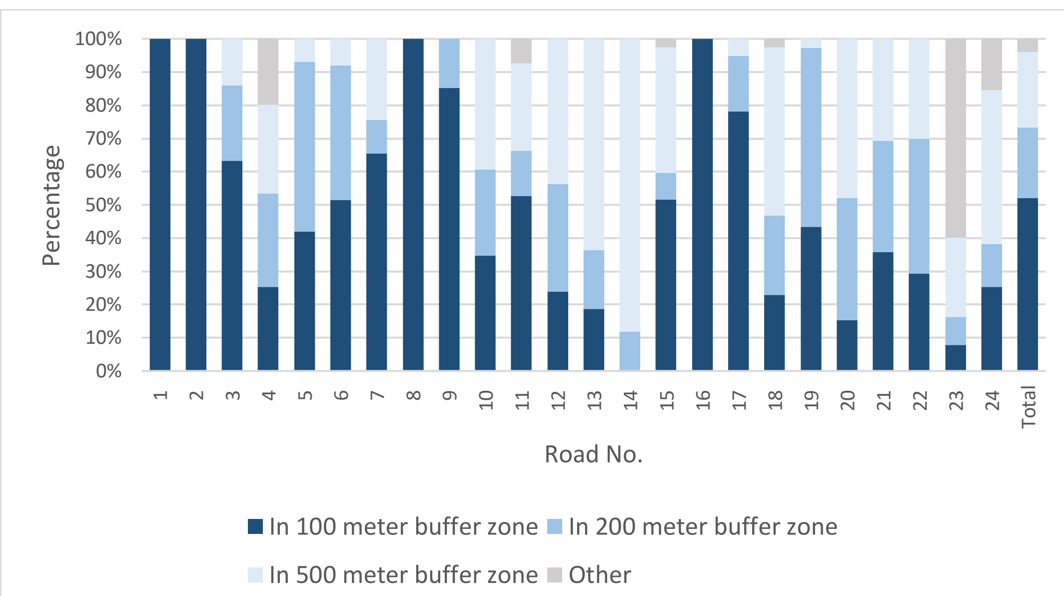

Figure 4. Bar plot of length distribution of studied roads in each buffer zones.

4.3 Road Lengths among Buffer Areas

The ANOVA test results for both actual number residual and percentage analysis are presented in Table 1. Both tests showed significant differences between group means, indicating the road lengths would change significantly when their distance to the watercourses changed. In the *pos hoc* test result (Table 2), four out of six group means were significantly different from each other, except for the group means between 200-metre and 500-metre buffer zones. This illustrated that the relevance of the location of roads to the watercourses might decrease when they were further away from the channels. In general, the result of ANOVA tests could reject the null hypothesis that the length of roads would not change with the distance to the rivers, and the post hoc test indicates the roads distributed within 100 metre buffer zone are significantly longer and in higher proportions.

Table 1. ANOVA table of the residual road lengths in actual measures (metre) and percentage.

		df	Sum Sq	Mean Sq	F value	*p* value
Actual Measures	distance	3	37444969	12481656	23.907	<0.000
	residuals	92	48033190	522100		
Percentage	distance	2	1.062	0.531	8.929	<0.000
	residuals	69	4.103	0.059		

Table 2. Post Hoc table of the residual road lengths in actual measures and percentages. Where r1, r2 and r5 were referred to as the residual groups in 100m, 200m, and 500m buffer areas respectively.

		diff	*p* value
Actual Measures	r2-r1	-598.867	<0.050
	r5-r1	-574.762	<0.050
	r5-r2	24.104	0.999
Percentage	r2-r1	-0.278	<0.001
	r5-r1	-0.231	<0.005
	r5-r2	0.0471	0.782

5 Discussion

5.1 Distribution and Functions of Water Channels

As presented in the Results section, the dense water channels formed a chessboard-like network. Except for one possible natural meandering river (Jiuqü River, 九曲河) in the northeast area (Figure 2a), most of the watercourses were relatively straight. Most of the time, two channels joined at right angles; the land shapes surrounded by them therefore were rectangular. These rectangle landforms could seldom be formed and maintained through natural processes (Knighton, 2014), indicating the water channels were mainly constructed and maintained artificially.

Such artificial watercourses and landforms were shaped out of transport and irrigation purposes (Wu, 1991; Zhou, 2008). On the map, the villages and towns are usually located at the conjunctions of channels. In *Tongzhi* (1935), there was an individual section specifically recording the steamboat timetables on the major water channels within the Yin County and to the nearby towns, claiming the traffic importance of waterways. Also, other than residential areas, farmland was the second major type of land use within the study region. The waterways flew across the farmland, bringing water to cultivate the crops. In short, the water channels were the links between living areas, and they provided water resources to local agriculture in southeast Yin County in the 1930s.

5.2 Development of Land Roads and Competition with Channels

However, land-based transportation was quickly growing and started to replace water transportation during the 1930s (Ding, 2007). Although from visual observation, the density of roads recorded in *Tongzhi* and digitized in the study area was not as high as the water network. More than half of the land roads were located within a 100-metre distance to the rivers, and the road length percentage reached 97% when the distance increased to 500 metres. The results of ANOVA and *pos hoc* tests are also in favour of that the road lengths would change significantly with the distances to the river courses changed, especially when the distance changed from 500 metres to 100 metres. From the visually examination, the roads, especially for those within 100-metre buffer zone, are usually parallel to channels nearby. Thus, the land roads at the time also connect the living areas in spatial patterns that are quite similar to the water network, implying a competition of traffic load between water and land road transportation.

The shift could be further examined from specific river-road examples. Along the Jiangshanxi River (姜山西河) in the west and Jiangshan River (姜山河) in the north area of this study, two major roads parallel to them closely followed through the entire course within the research area, with a comparatively much shorter distance than 100 meters (Figure 2a). It is notable that, the Jiangshanxi River linked the Yin County with the Fenghua County (奉化縣) to the south, and the road close to the Jiangshanxi River was also recorded as the County Road (縣道). According to the *Tongzhi*, the County Road was an official regional road connecting to other counties. In this case, placing such a regional roadway near to the water channel indicates that the government would probably like to shift at least some of the regional traffic function from rivers to roads.

Other than the major roads, higher proportion of minor roads (the branches of recorded roads in *Yinxian Tongzhi*) were located in the 200- and 500-metre buffer zones from the water channels. It seems that they were not as close to the river as the major ones. In contrast, from the map, some minor roads were indeed near minor or shorter water channels that were not recorded in the *Tongzhi.* For instance, minor road No.14 (Figure 4) had no length within the 100-metre buffer zone but largely in the 500-metre zone. It was a short branch between two small villages, located in the northeast research area. In fact, on the map, it was close to water channels, which were however too trivial to be recorded. Therefore, generally both major and minor roads were spatially linked to watercourses.

Moreover, it is noteworthy that some roads would cut across the rectangular farmland blocks, reducing the travel distance between residential areas. Such phenomenon could be discovered especially when the roads were linking larger towns, such as the road between Dingqiao City (定橋市) and Shiqiao City (石橋市) in the northeast study area. The road length between these two towns was 2.35 km, while the watercourse length connecting the two was approximately 3.04 km. It is another indicator of river-land transport shift, since the land roads were taking short-cuts to connect residential blocks to improve the commuting efficiency, competing out the inflexible waterways. This might have been somewhat facilitated by the reduced need for farmland in the areas.

Additionally, there was also specific evidence in *Yinxian Tongzhi* showing that the government was an essential pushing force to the transition of transport infrastructure. It is written that, since the 16th year of the Republic of China (1927), the county government started to fill in the river channels and build land-based roads (Yinxian Tongzhi, 1935). Then, between 1931 and 1935, a 'City River Committee (城河委員會)' was established to be responsible for such reconstruction. They mainly focused on the channels that were silted and expanded the original roads to fit the horse carriages and automobiles. This is another important factor that physically helped the land-based roads took over the water transport.

Overall, from spatial and statistical analyses, historical records, as well as reviewed literature, the river-road spatial relationship reflects the two transport systems were competing, and it seems the roads were gradually replacing the water-based network in southeast Yin County in the 1930s. The evolution of traffic technology, combined with the changing need for land use, had significantly impacted the county's infrastructure pattern in Yin County, possibly and progressively influencing the spatial development plans and implementation of the county.

5.3 Limitations

This research has three major limitations, including the chorography recording, area limitation and analytical methods.

Firstly, the key reference, *Yinxian Tongzhi,* did not fully record all the water channels and land roads in Yin County, nor on its own maps. Generally, the maps recorded more land roads and river channels than the texts. This resulted in issues in matching features in the text and map records. Therefore, considering that the text might record essential and dominant roads and waterways, only the roads and waterways that were both recorded in the maps and texts were chosen due to data reliability and interpretation.

Secondly, the research area is relatively small to reach a universal conclusion on river-road spatial relation in the whole administration area of Yin County. In total, the old map in *Yinxian Tongzhi* covered an area of approximately 1345 km^2. The focused region in this report was only 43.1 km^2, roughly 3.2% of the total map coverage. Thus, this study can be considered a pilot study. It is suggested that future studies could expand the focus area to get a more valid summary and universal conclusion.

In addition, the spatial analysis method could be improved in future research. Only buffering analysis, ANOVA and *pos hoc* were involved in this research, which was relatively straightforward. Not only the distance, but also other possible factors should be considered in the methods. For example, future research can investigate specific road-river intersect patterns, such as bridge distribution. Steamboat and bus timetables in the *Tongzhi* can be researched to identify how busy would the traffic be in each water channel; this can be an additional indicator regarding the importance of the waterways to the transportation during the 1930s.

6 Conclusion

In conclusion, this report investigated the spatial relation between water channels and land-based roads in the 1930s southeast Yinzhou. The waterways and roads were all recorded in the chorography in *Yinxian Tongzhi*, and they were analyzed by digitized map observation and statistical analysis. The road lengths were significantly longer closer to the water channels, claiming that these two features were closely related in the 1930s Yinzhou. This could be regarded as one of the representations of how transport technology evolution impacts the city's land use and infrastructure planning.

Future studies can expand such a spatial analysis to larger areas of present or historic maps, or further investigate specific land-water transport infrastructure interactions. The transport facility distribution can be important and inspiring to urban planning specialists. Especially taking forward the result of our study in the interactions between waterways and land roads, future studies can address how an emerging transport choice or pattern can gradually interact with the urban and rural land-use patterns.

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