River Flood Risk Assessment of Jinan, China

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Abstract

In this project, I assessed the exposure and vulnerability of different communities of Jinan city to the possible flood hazard through spatial analysis and empirical analysis. The result can be a good reference for city council to improve their water management systems and preventive measures.

Problem Statement

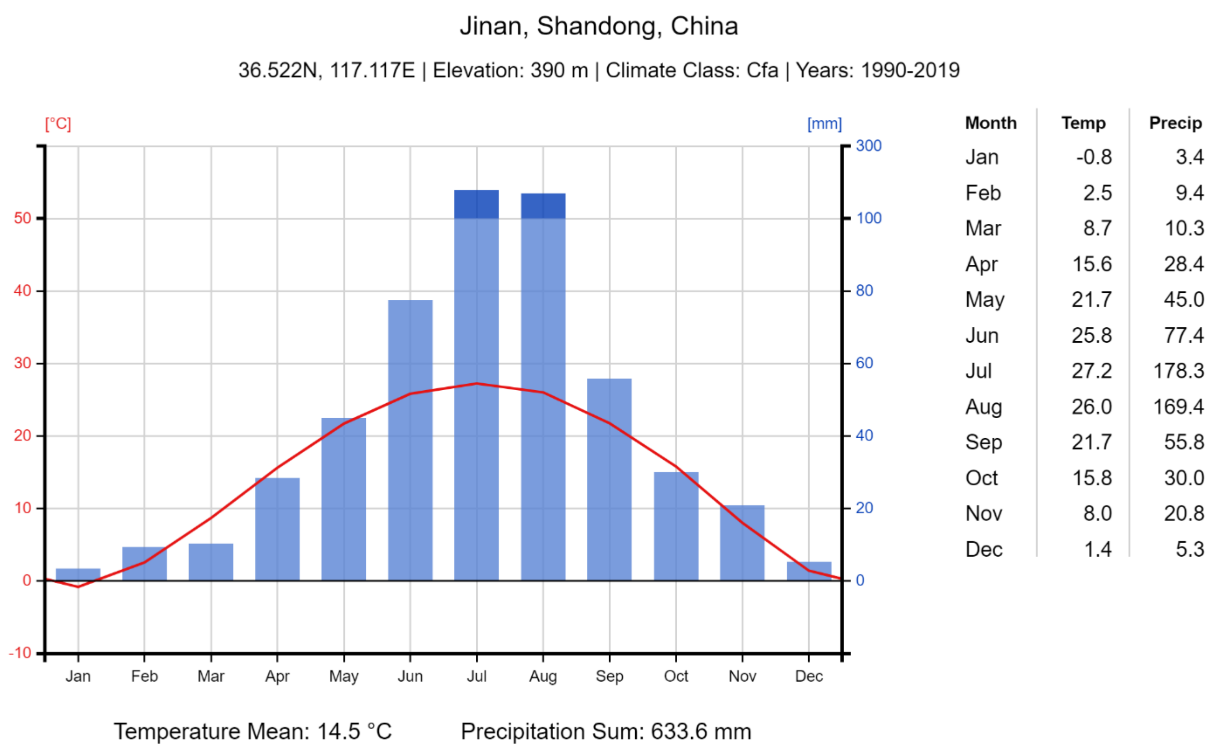
1. Research Problem

In 2007, a thunderstorm attacked Jinan, a city with of 5 million people in China. The city was built 5000 years ago, while the water management systems were introduced in the late 19th century and early 20th century. With rapid urban expansion in the last 50 years, the sewage pipes and drainage systems have been considered problematic for a long time.

Each year, wet monsoons bring a lot of precipitation into the city, usually in the form of thunderstorms. During the 2007 Thunderstorm, a lot of people were blocked in an underground shopping mall, and some of them were injured. After this thunderstorm were actions taken to repair and reconstruct the water management system easily flawed.

In the downtown area or the urban village, rainfall accumulates easily. Under this scenario, pedestrians, bicycles, and scooters are in danger of falling into the sewage well. Although, there were some measures taken to mitigate the effects of heavy precipitation, in 2021, an unexpected thunderstorm still made the Urban Transit Metro Line 2 stop their services for a couple of days.

Figure 1 The Paper News. Jinan: a road section became the "sea" every time storms hit! Citizens: living in the "sea view room" ~



Month	Temp	Precip
Jan	-0.8	3.4
Feb	2.5	9.4
Mar	8.7	10.3
Apr	15.6	28.4
May	21.7	45.0
Jun	25.8	77.4
Jul	27.2	178.3
Aug	26.0	169.4
Sep	21.7	55.8
Oct	15.8	30.0
Nov	8.0	20.8
Dec	1.4	5.3

Figure 2 Climatograph of Jinan. The precipitation is concentrated during summer. The heavy precipitation is one important factor of the possible flooding in the city. Data acquired from https://climatecharts.net

2. Research Question

Climate change has been influentially on the general weather patterns in China, especially during El Nino years and La Nina years. In some wet years, severe thunderstorms and typhoons are more impactful than normal. Jinan city has become more vulnerable to natural hazards.

However, I think the local government still has the responsibility to prevent hazards and lower losses as much as possible. In this project, I will examine and evaluate the exposure and vulnerability of different urban communities in Jinan city to possible flood hazard through spatial analysis and empirical analysis.

More specifically, I will explore the local spatial patterns of the regions that are exposed to flooding hazards. In this process, I will identify some key communities that are more vulnerable to flooding disasters and analyze how they correlated to the social and economic environments like education status, land price, population density, or land classification.
With data visualized in maps and charts, the result can be a good reference for the city council to improve their water management systems and preventive measures.

3. Literature Review

Currently, there are few studies done about the flooding risk assessments of Jinan City in English. However, there is a lot of research on other Chinese cities. For example, in an article about Guangzhou's flooding risk, the authors utilized spatial interpolation and spatial regression models to analyze the sensitive areas of all metro lines in Guangzhou. My research will bring similar methodologies to the case study of Jinan.

In addition, I will consider the social dynamics of flood risk in Jinan, drawing an existing scholarship to define some key natural concepts in my research, such as the ways to define flooding risks. Framing the flooding hazard into a big picture can also help me identify how the flooding evolves. There are many studies about how flooding disasters affect differently to different communities based on their income levels, ethnicities, education levels, and administrative divisions. Many of them focus on a complex economic-social aspect of long-lasting flood impacts. In conclusion, the existing scholarship has provided plentiful information, frameworks, and insights for me to conduct my research.

Table 1. Preparation Data

#	Requirement	Defined As	(Spatial) Data	Attribute Data	Dataset	Preparation
1	Administrative Regions	Raw input dataset from OSM	Polygons	Name, Location, Level of Administration	OSM Data	Import from QGIS Plugin
2	Water Bodies	Raw input dataset from OSM	Polygons and Multi-lines	None	OSM Data	Import from QGIS Plugin
3	Monitor Stations Data	Raw input dataset through Governmental Website	Point data	Warning Water Tables	Self-Generated	Organize and Import from table
4	Digital Elevation	Raw input dataset from Copernicus 30m resolution	Raster TIF	Altitude	OSM Data	Import from Copernicus

4. Data Preparation

I accessed and downloaded the digital elevation data, administrative boundary data, and water bodies of Jinan from Copernicus and Openstreetmap. Also, I made a table of the river monitor stations around the city, with their warning water levels according to the official data of hydrological bureau in Jinan City.

Input Data

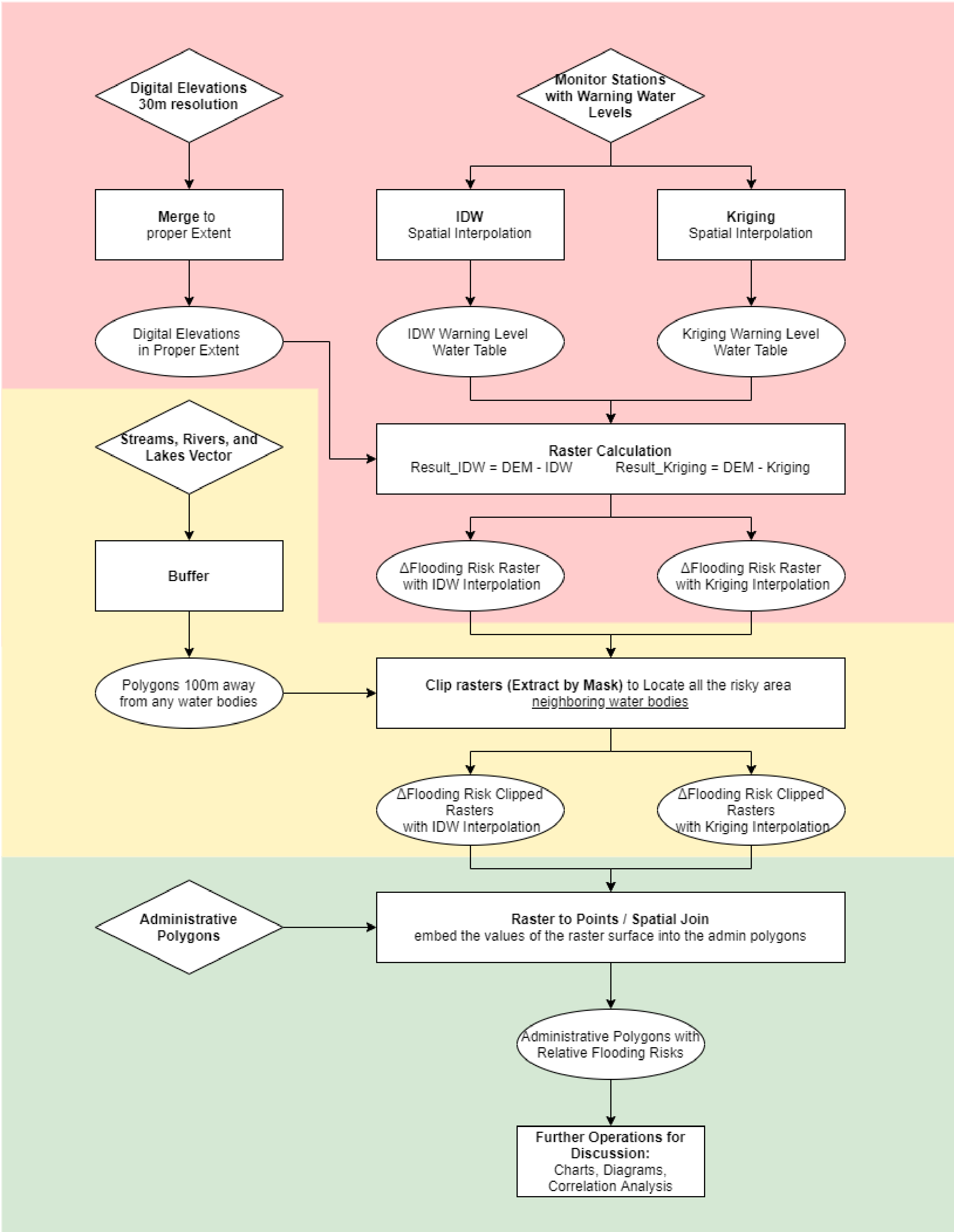
Table 2. Input Data

#	Title	Purpose in Analysis	Link to Source
1	Administrative Regions of Jinan	To frame the Flooding Risk data into each administrative communities of Jinan City, for analyzing the spatial pattern of the flooding area	Openstreetmap
2	Lakes, Streams, and Rivers in Jinan	To clip the raster data of flooding raster surface to those only closed to the water bodies, the source of the possible flooding	Openstreetmap
3	Monitor Stations Data of Rivers in Jinan	The warning water table of each monitor station is the main input data in this analysis. The warning water table is used to generate a raster table for the flooding risk.	Hydrology Bureau of Jinan
4	Digital Elevation	Major input data in this analysis. The elevation data is used to be subtracted by the warning water table to generate a raster table for the flooding risk.	Copernicus

Methods

The whole process can be divided into three parts, which are indicated with different colors in the diagram below.

Figure 3. Data flow diagram.



Part 1: Generate Raster Table of Flooding Risk

With the table of warning water levels, I used spatial interpolation tools to make a raster surface of the warning water tables in the city. Then, I used raster calculations to let the digital elevation subtract by the water tables to find which areas are in the flooding zone. Since the data is sensitive and DEM is in low resolution, the flooding zone is labeled with low risk, middle risk, and high risk. Please note that to get the most suitable results, I will use both deterministic data interpolation (IDW) and geostatistical method (Kriging) to generate the raster table.

For IDW method parameters, the p-value and the variable numbers are important factors to be considered. The p-value indicates how the distant things affect the interpolated values. A higher p-value means the distant things have little or no effects on the interpolated values, and a smaller p-value means the distant things have minor or even similar significant effects on the interpolated values. The default p-value is 2 in ArcGIS, which is what I used in this project. The optimization of p-values can be conducted if there are more sample points available. For the variable numbers, I decided to use a broader range, which includes all the sample points. The reason behind this choice is tied with tis hydrological nature. The water table is a continuous surface with smoothed changes over rivers, lakes, and other water bodies. It is known that a lack of sample points can result in a IDW raster surface with sharp edges and boundaries, so I chose the range to include all the sample points available to generate the IDW raster surface.

Figure 4. Surface Result of IDW Method.

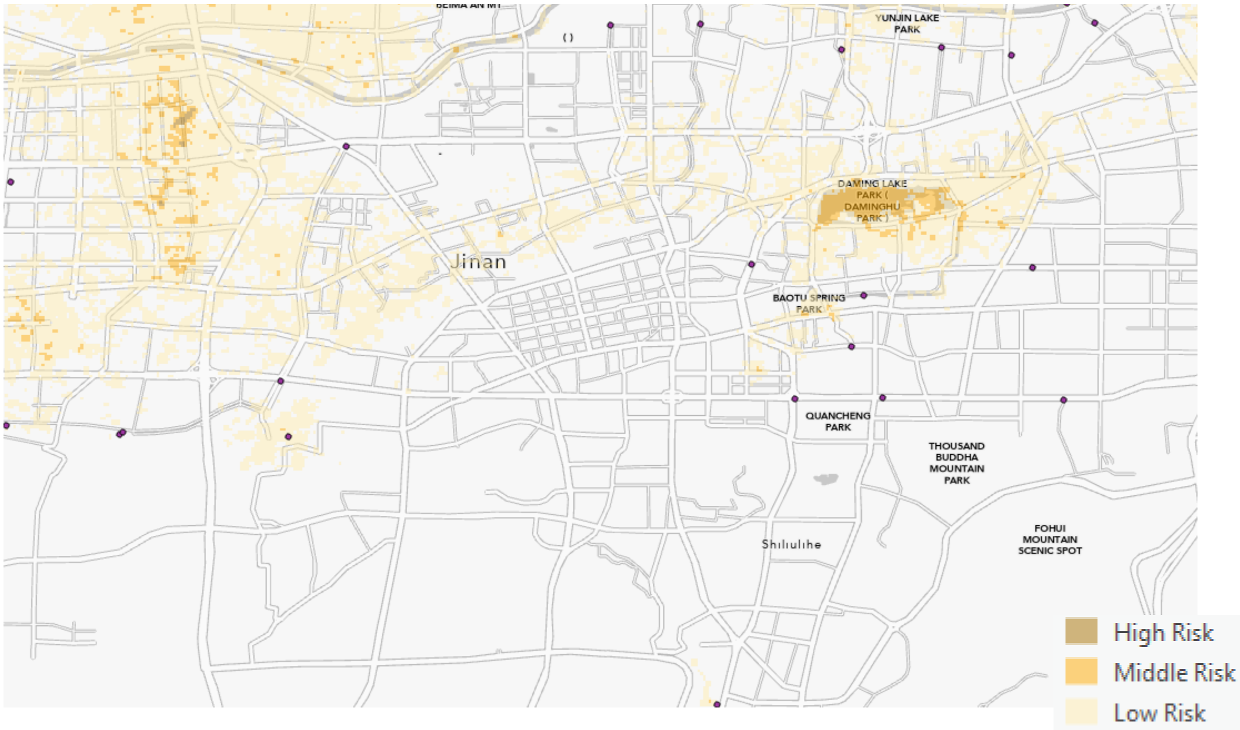
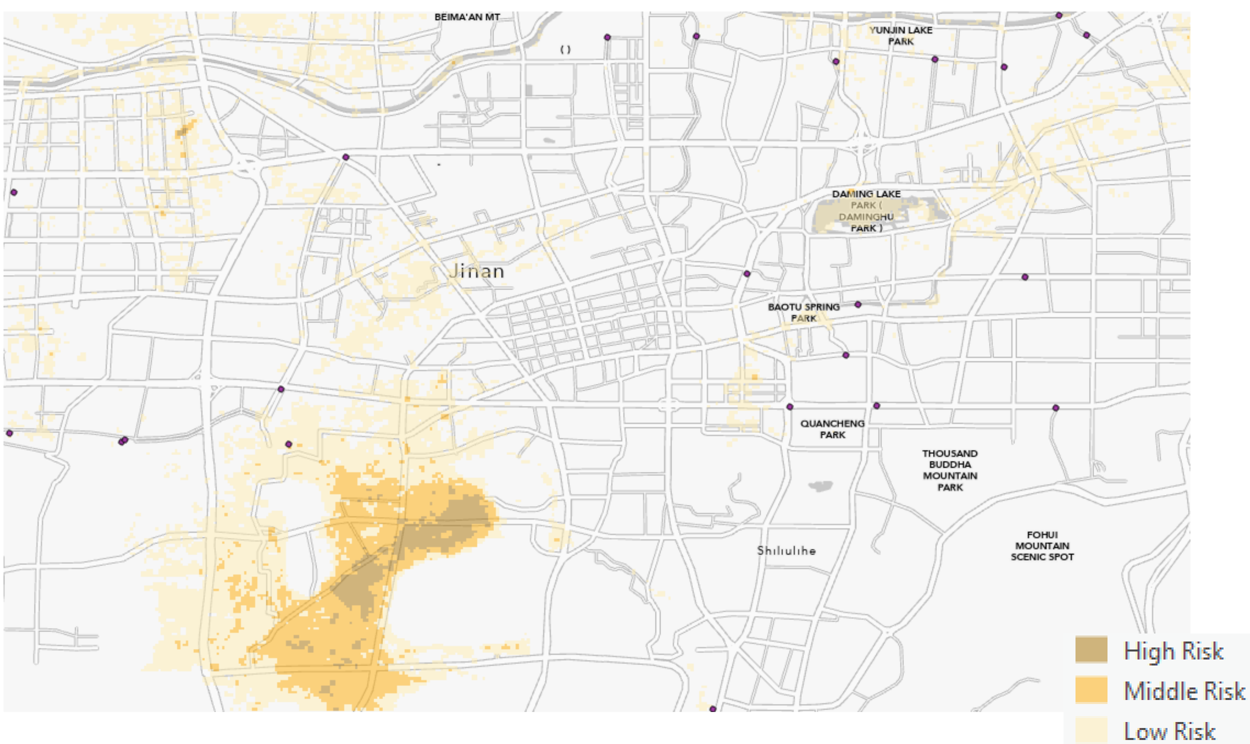


Figure 5. Surface Result of Kriging Method.



The Kriging interpolation, in turns, plots the variables to the interpolated points by values and distance. Then, a theoretical semi-variogram is generated to best conclude how the values change as the distance change. By overlapping the semi-variograms, I can generate an interpolated raster surface.

In this process, it is important to make sure what kind of distribution is suitable to make a semi-variogram. Without suitability analysis, I utilized the default spherical distribution in my Kriging interpolation. Also, to control the variable, I used the same number of variables that I used in the IDW interpolation into this Kriging interpolation.

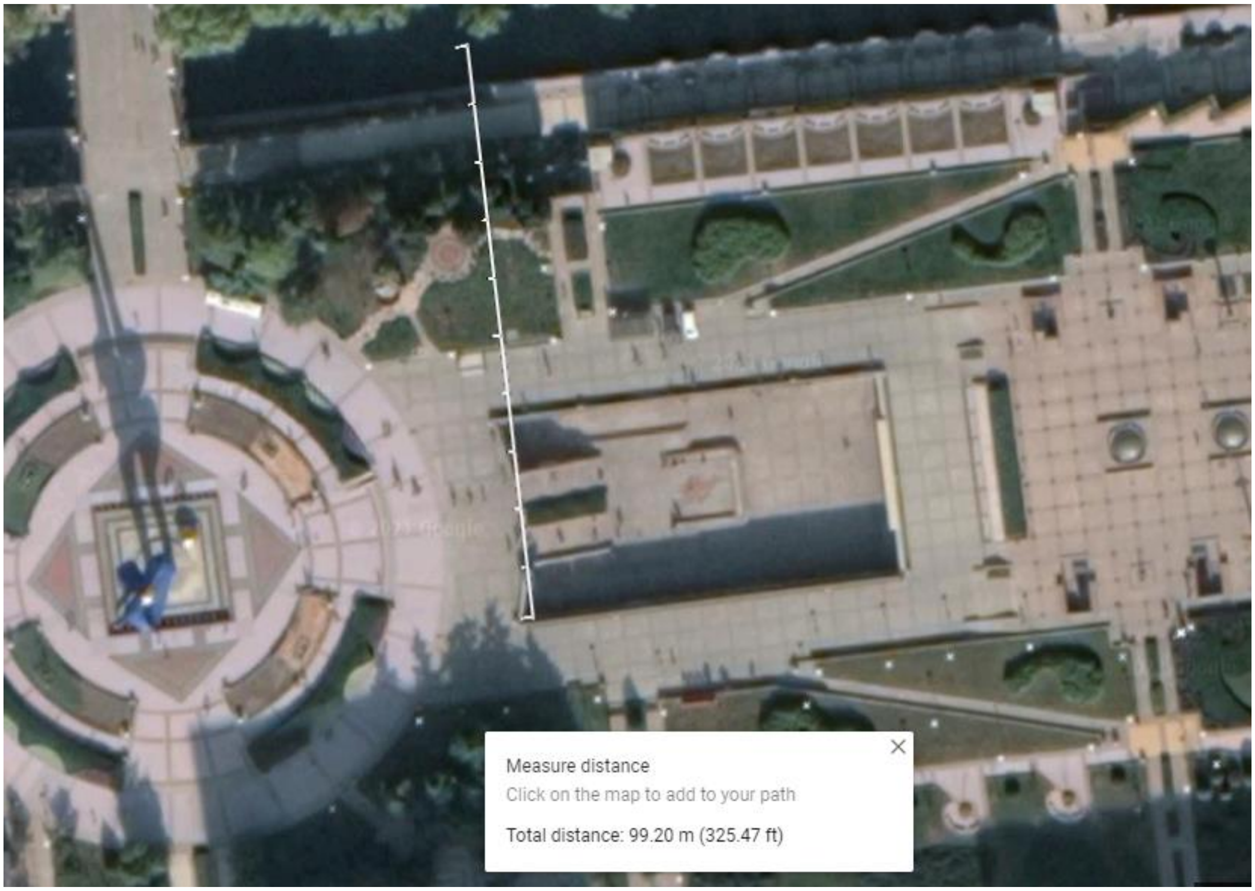
Part 2: Clip the Surface to be matched with the actual River Flow

There would not be any flooding risk if the place is not closed to any waterbodies nearby. Based on this logic, I used buffer tool to generate a set of polygons that are from the river. Then, I used these polygons to extract the raster data to identify the regions that are more sensitive to the flooding risk.

In the urban environment, the river flooding is only impactful on the road segments closed to the river. However, because I subtracted the DEM by the warning water level interpolated layer, some of the low elevation area without river flowing through might be considered as sensitive areas to flooding. Thus, I have to clip the high-risk area out if the area is distant from the rivers.

It is hard to make the constraints to define how far the area should be excluded, but we can find traces from the previous flooding disasters in Jinan. The 2007 Jinan Extraordinary Rainstorm was a very heavy rainstorm that hit the city of Jinan on the evening of July 18, 2007, from 5:00 pm to 8:00 pm (UTC+8). During these three hours, a rainfall of 180mm (7 inches) accumulated. The Ginza Underground Plaza was worst impacted regions at that time, and the Southern edge of the plaza is 100m away from the moat, where the water came from.

Figure 6. The distance between the moat and the southern edge of the plaza is 100m. Measured in Google Map.



Thus, I chose the 100 meters as the hard constraints of the flooding risk area that I wanted to clip. However, in the real life, the boundary that indicates how far the river flooding can impact is dynamic, determined by the elevation, surface materials, the efficiency of water management system, the weather, and the inherited properties of river water such as the speed, discharge, and the purity of the water.

Figure 7. Water Body Buffers.

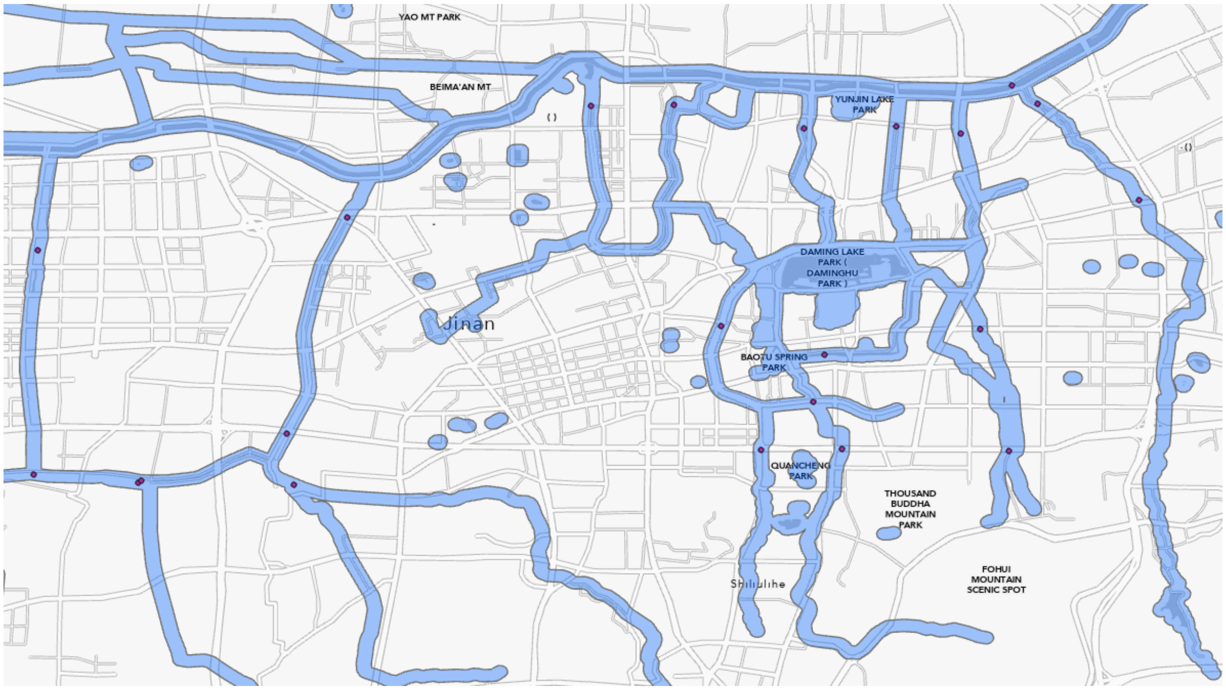


Figure 8. Extracted Result of IDW Method

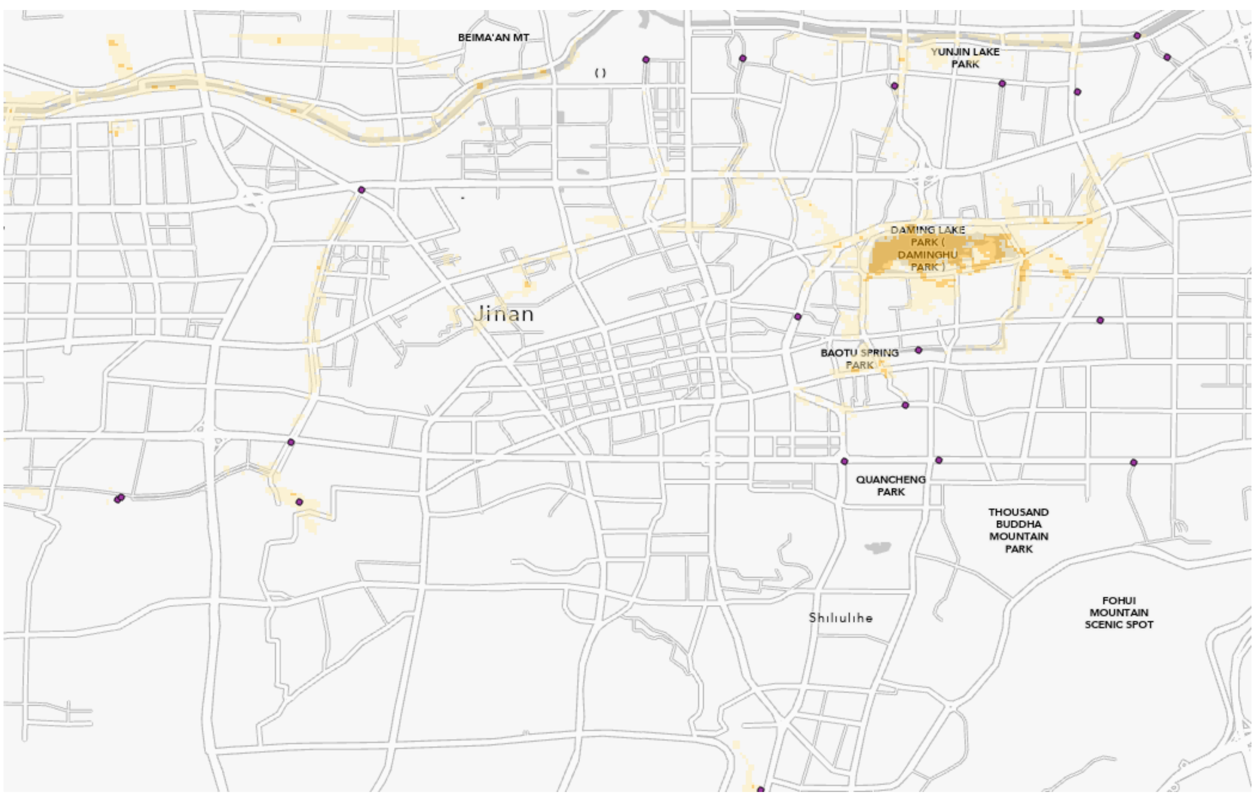
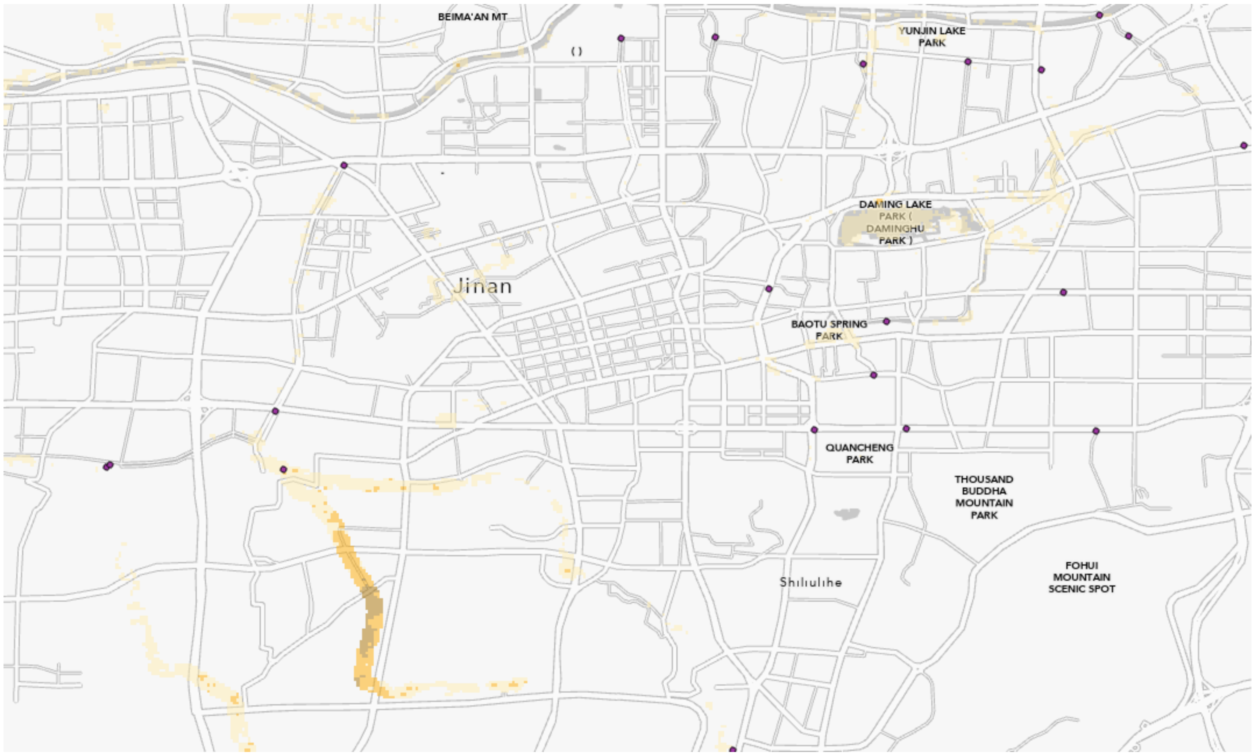
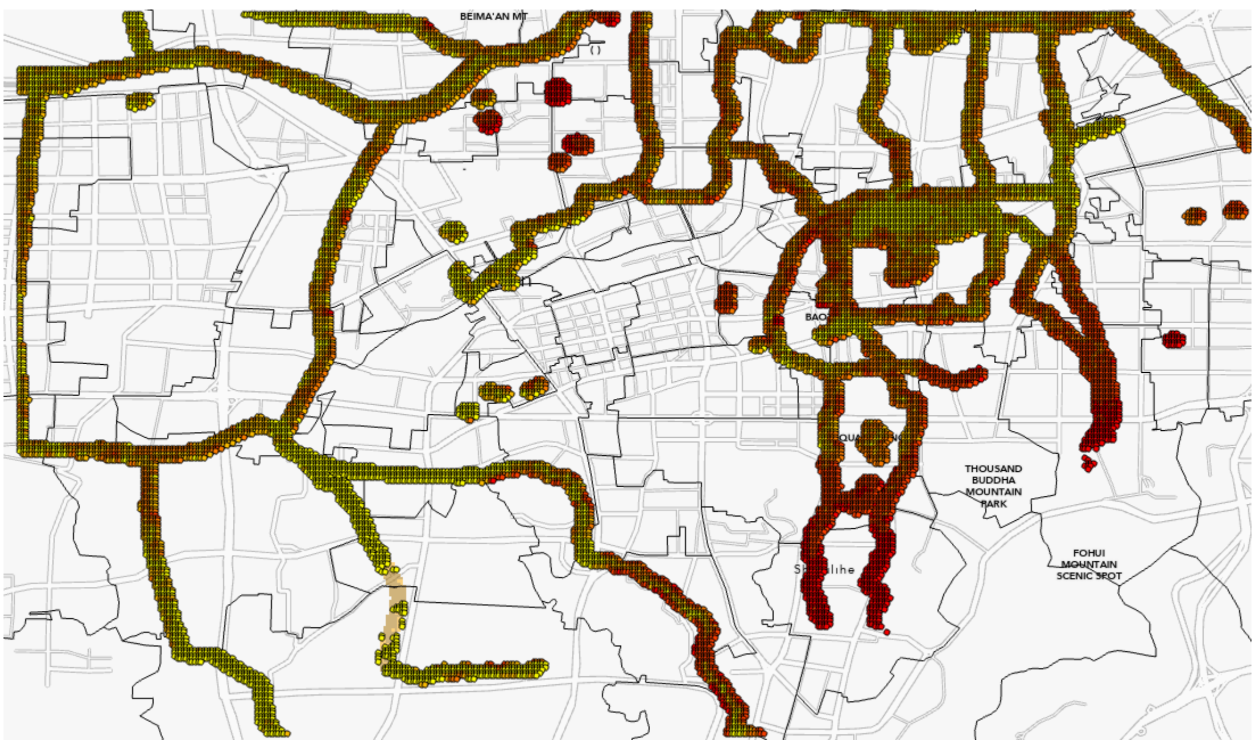


Figure 9. Extracted Result of Kriging Method



Part 3: Following-up data management and visualization

Figure 10. Raster Extraction into Vector Points



After finishing all the flooding risks data, I used two different functions, raster to points and spatial join, to embed the value of the raster into the administrative communities in Jinan. The results are two maps indicating the flooding risks of Jinan City by IDW and Kriging interpolations.

I classified all the communities into three different categories by using quantile method, which shows the relative flooding risks in the city effectively. I also labeled the district boundaries, which is helpful for the following discussions.

Results

Figure 10. The Result of the values of Flooding Risks embedded into each community, via IDW Interpolation

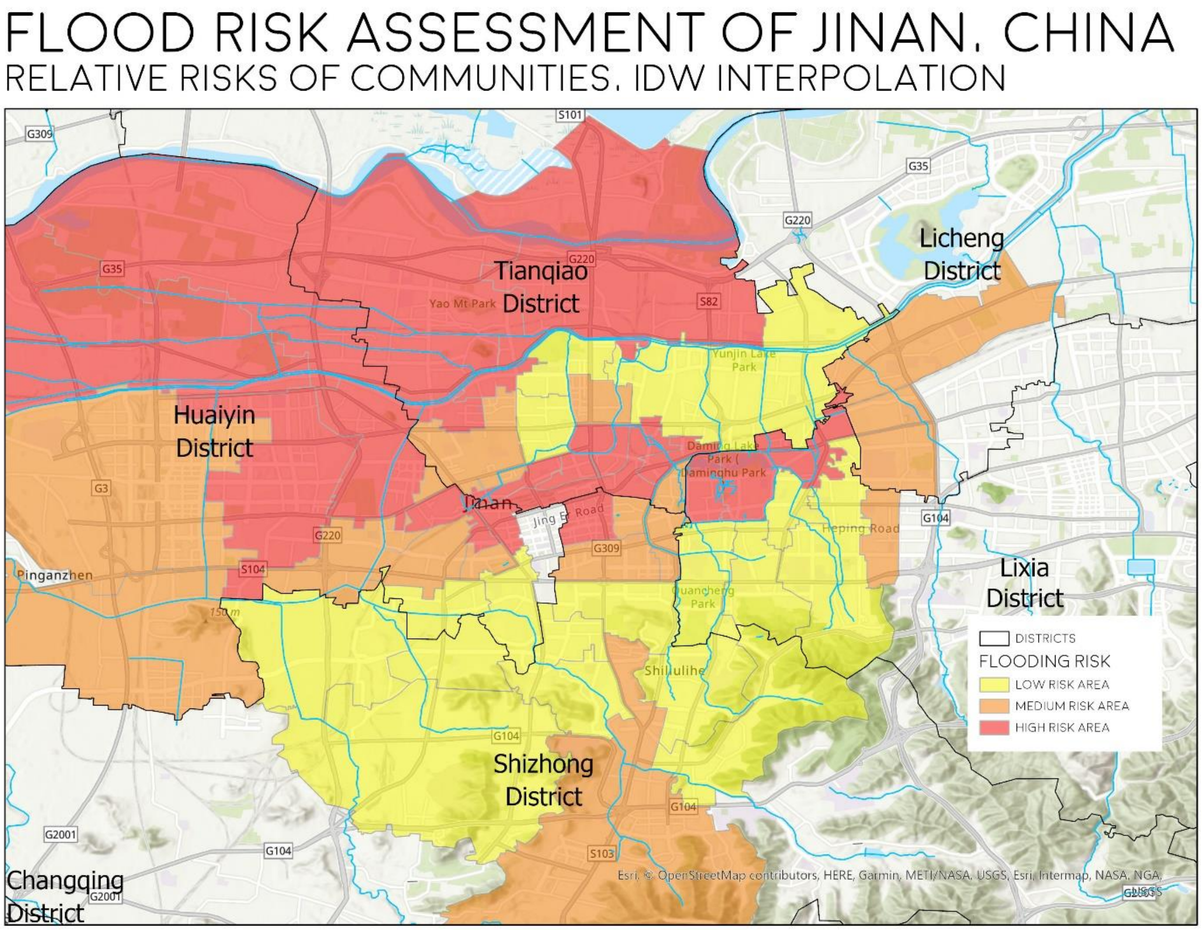
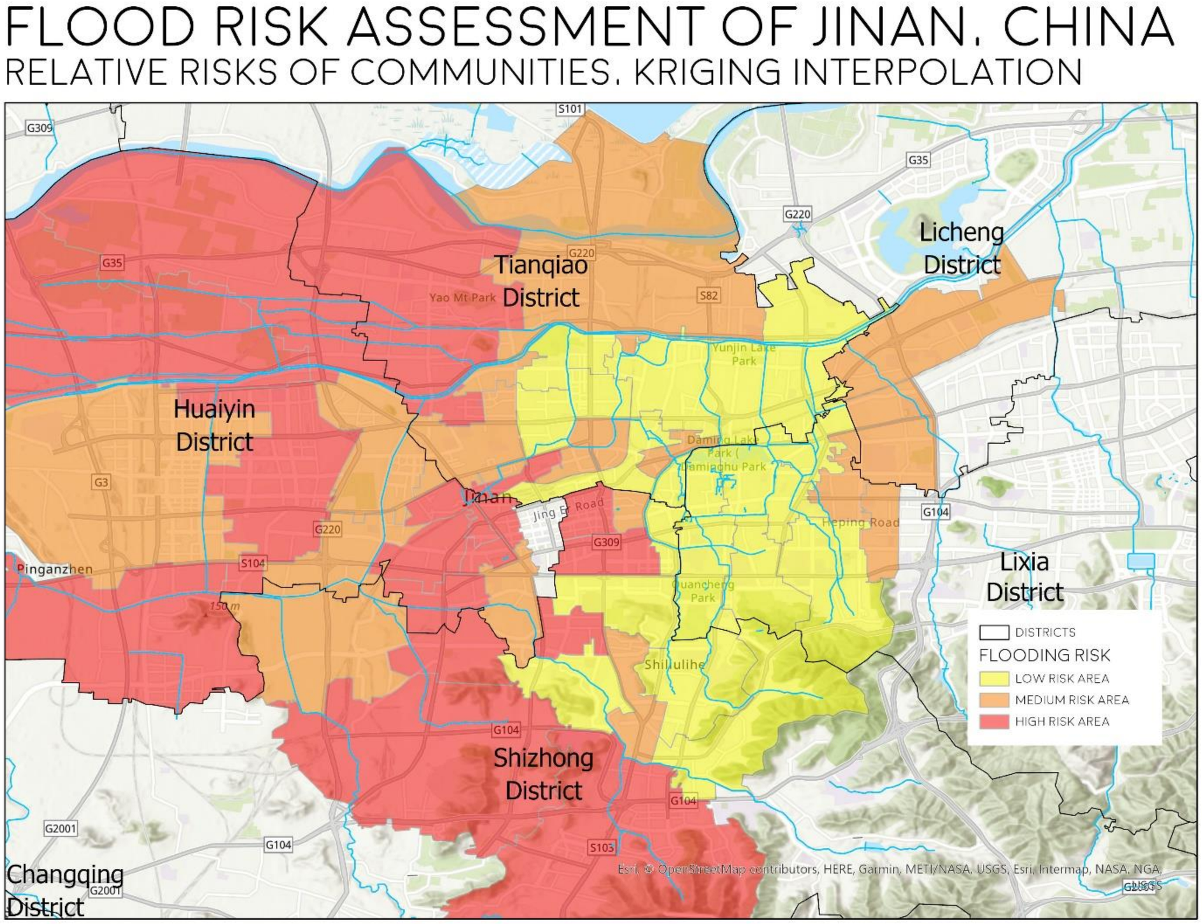


Figure 11. The Result of the values of Flooding Risks embedded into each community, via Kriging Interpolation



The result are two maps labelling communities with their relative flooding risks. The value is classed by quantile method. The data nominalization or standardization by area is not included in this draft, nor standardization by population.

Results Verification

In the history of Jinan, there are not many flooding disasters documented, or at least, not open to public. Thus, it is different to validate whether the data is correct. By retrieving all the news related to the heavy precipitation, there are various factors limiting the capacity and making Jinan City be vulnerable facing the possible flooding hazards, including massive impermeable surfaces, mismanagement of natural springs has decreased the capacity of draining water, the flawed design of pipeline systems and roads makes some parts more vulnerable to floods, and the lack of pump stations makes some regions of the city harder to drain water out. These aspects were not addressed in my previous analysis. However, according to the office staff of Tianqiao District Drainage Management Service Center, the discharge water from the Southeast always accumulated in Tianqiao District, resulting in a disastrous impact.

By comparing this statement to our results, we can find both IDW and Kriging analysis maps correspond to the general patterns of flooding, with a higher risk in the Northwest side of the city and a lower risk of the Southeast high-rise part of the city. Specifically, in 2017, Qilu Evening Post published a set of maps featuring the road segments most sensitive to rainfall accumulation.

Figure 12. The rainfall tend to accumulate in the road segments under the railroad bridges in Jinan City

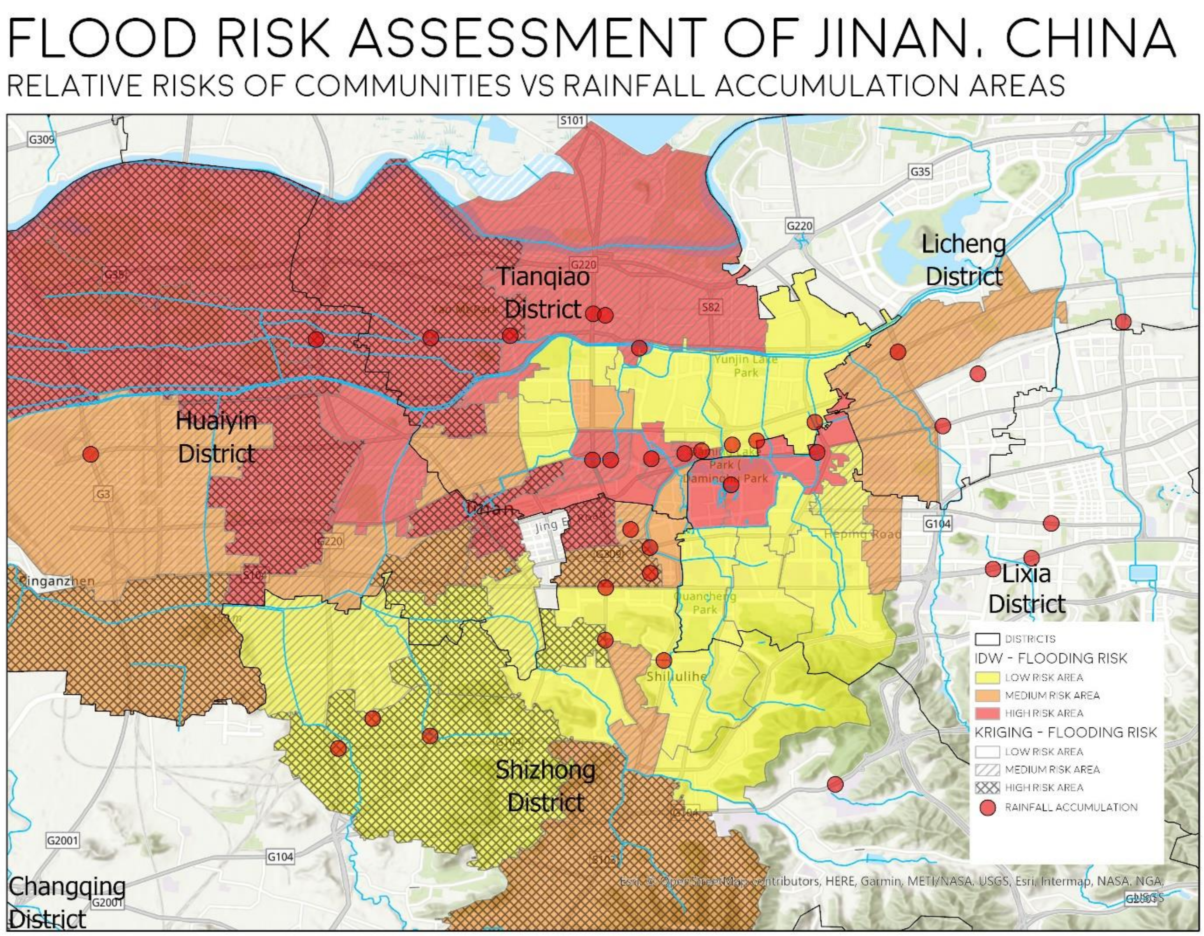
After comparing these sensitive road segments to the rainfall accumulation to our maps, we can observe a pattern here:

Table 3. The relationship between the rainfall accumulating locations and the flooding risks analysis

There are 27 points in our study area in total	Number of locations lie in High-Risk Areas	Number of locations lie in Medium Risk Areas	Number of locations lie in Low-Risk Areas
IDW	15	6	6
Kriging	10	11	6

Although the rainfall accumulation area is not representative to the areas that have a higher flooding risks, a significant correlation is still observed that more locations are in the higher and medium risk areas, which validate the result in some degree. Further discussions can be done through the spatial correlation analyses.

Figure 13. The relationship between the rainfall accumulating locations and the flooding risks analysis, the locations are labelled with red icons, and the Kriging flooding risks are represented by hatched colors.



However, there are still significant differences between the Kriging analysis and the IDW analysis, especially in the Northeast area and the Southwest area of the city, which could be further investigated with more data available.

Discussion and Conclusion

After flooding risks analysis, I identified north Huaiyin District, Tianqiao District, and North Shizhong District as the areas with higher river flooding risks. However, there are still further discussion and analyses necessary if I can get data of more monitor stations along the river channel and a higher resolution of Digital Elevation Model.

The research is not only a flooding risk spatial analysis but more like a starting point on how the flooding risk assessment can reveal the disparities of different communities and groups of people on their different resilience towards a looming natural hazard by bringing insights of Environmental Justice or Urban Political Ecology. This analysis can help local government and city council to identify the vulnerable communities toward flooding risks, but also focus on how the social-economic resource and infrastructures are unevenly distributed into different communities.

My research on river flooding can help the current scholarships identify and characterize the patterns of river flooding zones in the Chinese urban area. The analyses of how the communities that are more vulnerable to flood correlate to other socio-economic factors can also help the current scholarship discuss further and deeper the environmental justice in China.

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