"Jiusheng Tongqu":

Vulnerability of Wuhan, China to urban waterlogging events

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Abstract

In 2016, a series of unexpected storms paralyzed much of the City of Wuhan in central China, leading to severe waterlogging in the city (Figure 2.1, 2.2, and 2.3). The waterlogging event is believed to be the largest after the catastrophic 1998 flood when the entire city was heavily devastated. Though Wuhan is not the only victim of the 2016 waterlogging event, people raised their attention again to this large city in Central China, which has long been vulnerable to waterlogging caused by various flooding and storm events, including the 1931, 1954, and 1998 Yangtze river flood. This paper aims to understand Wuhan's waterlogging event, especially how inadequate research and the understanding of vulnerability, urban development and governmental policy and inadequacy lead to Wuhan's high vulnerability may increase its vulnerability.

Key words: Wuhan, vulnerability, flood, waterlogging, Urban development, Chinese politics

"Jiusheng Tongqu":

Vulnerability of urban waterlogging events in Wuhan, China

People cannot mention the city of Wuhan (武汉市) in Central China without water. On one hand, famously known as "Jiusheng Tongqu"("九省通衢"), literally means "Thoroughfare of nine provinces", Wuhan is a major transportation hub benefited from its location along the Yangtze river. On the other hand, over the last centuries, Wuhan has frequently been on the list of catastrophic flooding and waterlogging events, and ironically, the city is still infamous for its weakness from these flooding events even though the government conducted many waterlogging-reduction programs. Overall, a lack of research and understanding of the waterlogging event, the rapid urban development, and the inadequacy of political system and governmental projects lead to the vulnerability of Wuhan to urban flooding events.

Wuhan (*30°35′N 114°17′E*) is an important Chinese megacity. With a population of 10.6 million in 2015[1], it is the biggest and most populous city in Central China. The city is also the biggest city along the Yangtze river, having 2217.6 square kilometers of water surface (Wang et al., 2015), and with more than 166 lakes, is known as the "City with a hundred lakes" (Yang and Ke, 2015). The Donghu Lake itself is known as the biggest urban lake in China, attracting thousands of travelers every year. More importantly, Wuhan has the most abundant fresh water resource among all megacities, and a water per capita of 114,000 square meters, which is the highest among all cities in the world. (Wang et al., 2015) Historically, Wuhan was three individual towns-Wuchang, Hankou, and Hanyang-along the Yangtze river and the Han Shui, and the conglomeration of the two rivers separate the three distinct parts. After the three towns were combined to form Wuhan, it soon became an important economic, cultural, and political center. Nowadays, Wuhan is a capital city of the Hubei Province, a cultural and science research center with

[1] Wuhan 2016 statistics yearbook (2017).(In Chinese) (Available from http://www.whtj.gov.cn/)

renowned universities like Wuhan University, a major industrial center with an economic growth of 8.8%[2], and a major transportation hub.

However, the city of Wuhan has undergone several waterlogging events throughout history. From 1865-2000 only, Wuhan, including its nearby regions, has undergone at least 7 great floods in 1870, 1931, 1935, 1954, 1996, 1998. (Yu and Chen, 2015) Through a traditional "environmental 'supply side'" explanation, or the natural hazard side explanation of the pressure and release model proposed by Wisner et al. (2014), Wuhan is located in the flat Jianghan basin in the downstream of the Yangtze River, where over three fourth of China's flood occurs (Liu, 2014). The El Nino events brings unexpected rain storms during the monsoon season, raising Yangtze river's water level, and waterlogging many of the flat plains along the river. Moreover, the climate change and global warming may be responsible for higher level of danger and why flood events, with higher magnitude and longer duration, have become more frequent since 1950. With the riverbed higher than the streets adding more vulnerability, levees along the river channel are currently over 10-15 meters tall. (Yu and Chen, 2015; Chen et al., 2001b; Chen and Zhao, 2001; Yin et al., 2004). Therefore, Wuhan, along with many other cities and towns along the Yangtze river, is susceptible to waterlogging events because of unexpected natural hazards and its vulnerable location, which will continue threatening Wuhan in the future. This environmental determinism point of view offers a pessimistic view on Wuhan by connecting Wuhan to the entire Yangtze River basin that suffers from the same natural hazard.

Even though Wuhan relates to other cities and town in the Yangtze River basin in terms of natural disasters, Wuhan's vulnerability should be taken into consideration differently from the other regions, because vulnerability is a far complicated concept. Vulnerability is a series of conditions that may lead certain groups of people to very dangerous situations. Besides geographic contexts, it should also consider social factors, political systems, and economic situations. As a political urban center of the region, the various factors that lead to Wuhan's vulnerability is very different from those of rural areas

[2] Wuhan 2016 statistics yearbook (2017). (In Chinese) (Available from http://www.whtj.gov.cn/)

and even other smaller cities. For example, while the rural regions should focus on the vulnerability of children, disabled, and senior citizens over 65 years old due to the migration of job-seeking young adults, the city of Wuhan should consider migration as a bigger factor. The children and senior citizens in rural China are especially vulnerable to waterlogging events because they are not physically fit and when waterlogging events limit their access to resources, which is already scarce, they are struck in their house without the protection of a better fit young adult. However, in a city like Wuhan, the vulnerability caused by these groups are not as profound due to a low percentage and a better access to resources, while migrants from rural areas and other smaller cities are in a greater vulnerable position. This difference between rural areas and Wuhan is a consequence of the rapid urban development. Moreover, as the biggest city in Central China and the capital city of Hubei province, Wuhan, unlike other cities, is not marginalized. The Wuhan government conducted many coping strategies and programs to benefit Wuhan citizens, and the effectiveness of these programs and the government should be a great factor when considering Wuhan's vulnerability. Government also plays a crucial role in developing Wuhan, connecting this political factor to urban development. Therefore, because Wuhan is politically and socially differently from the other regions, people should understand Wuhan's vulnerability to have a better idea of how urban development and government policies are two important factors in contributing Wuhan's vulnerability to waterlogging events.

Before considering urban development and governmental policies, one nonnegligible factor that leads to Wuhan's vulnerability is the lack of research and understanding, both among researchers and in Wuhan's governmental agencies. Wisner et al. (2004) points out that understanding vulnerability is important in creating a safer environment, and a failure to do so will cause vulnerability. Many research papers on the topic still focus on natural events and hazards, ignoring Wuhan's vulnerability from social and political factors. Some papers still consider the Yangtze river basin as whole by analyzing exclusively on natural disasters using geologic and environmental data. Yu et al. (2009), for instance, analyzed the

characteristics and explanations of historic floods along the Yangtze river, focusing entirely on environmental factors.

Similarly, the government agencies of Wuhan also tend to understand Wuhan's vulnerability of waterlogging events by focusing on natural events. Appendix 4 lists part of the official "Wuhan waterlogging risk map", posted by the Wuhan Water Affairs Bureau.[3] This is a series of maps that consider the waterlogging regions in Wuhan and each district under a certain rainfall condition. For example, according to Map 4.5, when there is 88mm of rainfall in 3 hours or 162 mm in 24 hours, 39 sites in Wuchang district is in a huge waterlogging risk where the transportation might be affected. However, the map is based entirely on rainfall system, elevation, natural geographic condition, and the water drainage system. The maps provide limited insight in the vulnerability of Wuhan. Although Yin et al. (2015) suggests that increasing number of researches in China consider a more comprehensive definition of the vulnerability of urban floods by giving tons of recently researched examples, none of those case studies are about Wuhan. Liu et al. (2014) gives a great insight of how land-use change may affect flood exposure of Wuhan, admitting the importance of flood exposure assessment and the important relationship between hazard, exposure, and vulnerability, but still consider more of the natural side and environmental side than the social and political side.

One social and economic factor that greatly transforms Wuhan is urban development. Wuhan expanded dramatically in the past few decades, especially during 1982 and 2000. (Liu et al., 2014) Urban development may deceivingly seem to reduce vulnerability and promote economic growth. From an access perspective, with a growing infrastructure and transportation system, citizens have better access to different resources, and the growing city also accommodates more population and reduces population density in the old town, making living standard higher. However, the engineering approach's advantage is

[3] Wuhan Water Affairs Bureau, Wuhan waterlogging risk map (2016). (In Chinese) (Available from http://www.whwater.gov.cn/water/tzgg/index.jhtml)

limited when waterlogging events paralyze the city's transportation, limiting people's access, and when people are trapped in their power cut home suffering from the hot Wuhan summer and waterborne diseases. Indeed, unplanned city development will make the city extremely vulnerable. Liu et al. (2004) blames the poor city planning in Wuhan city as unplanned and unregulated, which drastically changed environmental conditions, leading Wuhan to even greater vulnerability. Wisner et al. (2004) points out that vulnerability should be analyzed before conducting any engineering program, and because of the interdisciplinary nature of city planning, the engineers should conduct with economists, educationists, architects, government workers. This unregulated city planning is an indication of the lack of vulnerability assessment in Wuhan, and how government, which is responsible for many of the city planning project, is responsible for many of the social factors.

One most significant fact of poor urban planning in Wuhan is the construction of urban infrastructures on lands filled from lakes. Lakes can absorb peak flows, controlling excessive waterfall and flows, but with the reduction of their area, they are no longer adequate to control flooding events. (Wisner et al., 2004; Xia, 2013) Throughout the years, many lakes Wuhan has undergone great area change. Using remote sensing, I constructed classified maps showing the area change of four lakes in Wuchang and Hongshan district (Map 3.1-3.12): Nanhu Lake, Shahu Lake, Shaihu Lake, and Donghu Lake. According to "Wuhan waterlogging risk map" of Wuchang District and Hongshan District, many regions along these lakes suffer from great waterlogging events. From my research, all lakes have undergone great area change from year 1989 to 2016, and many of the filled regions are also places where transportation will be significantly affected on "Wuhan waterlogging risk map", like Ziyang East Road and Nan'an Road near Shaihu Lake and Shahu Road near Shahu Lake. Yang and Ke (2015) did a more comprehensive research on the area change of Wuhan, analyzing 20 lakes in Central Wuhan. According to Yang and Ke (2015), the twenty lakes, which had a total area of 130.2478 square kilometers in 1990, only had a total area of 102.2971 square kilometers in 2013, and Shaihu and Shahu lakes have undergone the greatest change. Even though both researches did not prove that the reduction of lake areas is a factor that causes

Wuhan's vulnerability, they support many other researcher's claim that the reduction of lake area in Wuhan is a great indication of Wuhan's land-use change, causing increasing vulnerable situations. (Wisner et al., 2014; Liu et al., 2014; Wang et al., 2015; Xia, 2013; Zhang, Y., 2016)

The reduction of lake not only physically limits the capability of controlling unexpected rains and floods, but, more importantly, also socially increase the vulnerability of people that choose to live in these risky zones. Many of the lakes were transformed into residential areas and commercial areas. (Liu et al., 2014) The residential areas along the lakes are attractive, because they offer great view of the lakes, and as more people live in those regions, more population in Wuhan are under vulnerable situations. Fortunately, the lakes undergone a greater change from 1900 to 2000, than from 2000 till now, because more appropriate urban planning starting from 2000 reduced the flood exposure of Wuhan. (Liu et al. 2014) Wisner et al. (2004) claims that the Chinese government realized the vulnerable of these changing lakes and started to move millions of citizens from these risky zones. However, even though relocating citizens from the risky zones may reduce people's exposure to flood events, these people are still very vulnerable because they had to find a new home in somewhere that they were not familiar with. Moreover, the waterlogging problem in Wuhan is a city-wide problem. Although the reduction of lakes is a cause of Wuhan's vulnerability, moving citizens out of the lake area do not necessarily reduce their vulnerability because other regions of the city may also have profound waterlogging events. Still, as Wisner et al. (2004) points out, this "'living with flood' approach", recognizing and recovering the ecological status of lakes and rivers, is a genuine way in recognizing hazards and reducing vulnerability.

Besides causing the reduction of lake areas, urban development also brings population growth and migration issues, which, according to Wisner et al. (2014), is one of the most important reason why urbanization is a great source of vulnerability. The city of Wuhan has seen a dramatic population change. Population increased dramatically from nearly 5.5 million in 1978 to over 10.6 million in 2016, and the population density in the city center is very high, like the Jianghan District has a population density of

25677 people per square kilometers.[4] Many of the population are job-seeking migrants from smaller cities and rural area. These people usually have low education and low-income jobs, and when moving to a big city that is already crowded, they are marginalized, can only rent cheap unsafe households, and suffer from health problems. (Winser et al., 2004) Another group of migrants are students all over China. As an educational center in China, Wuhan has over 956,800 university students in 2015, which exceeds the number of high school and primary school students in the city. [5] The high quality of Wuhan's education attracts students from all over China, who live in collective and crowded dorms. The dorms, as part of group quarters, is considered as a part of Housing and transportation section of social vulnerability index. (Flanagan et al., 2011) The dorms are more susceptible than private homes when waterlogging events happen because these dorms are crowded and usually in a poor conditions. The students also do not have family members and properties around them, and are surrounded by people who are in the same situation. Moreover, the students, unlike local citizens, usually rely more on public transportation, and when waterlogging paralyzes the transportation, their access to resources is limited. Therefore, as a group of people who live in hot crowded group quarters, who have no family members nearby and who have to rely on public transportation, they are very vulnerable to waterlogging events.

The Chinese hukou (户口) system only makes these migrants in a more vulnerable situation. Hukou system discriminates people as "agricultural population" and "nonagricultural population", and the hukou of a citizen usually does not change as the person migrates to a bigger city. The hukou system explain the two million people difference between population and resident population in Wuhan.[6] (Graph 1.1 and 1.2) As agricultural people migrates to a big city like Wuhan, they are naturally discriminated because of their agricultural nature, and because they do not have a hukou of Wuhan, they cannot attend good public high schools, get great jobs, buy houses, and be recognized as a valid urban population.[7] The hukou system not only discriminate agricultural people, but also people with a hukou of another city, who also cannot get

[4] Wuhan 2016 statistics yearbook (2017). (In Chinese) (Available from http://www.whtj.gov.cn/)
[5] Wuhan 2016 statistics yearbook (2017).(In Chinese) (Available from http://www.whtj.gov.cn/)
[6] Wuhan 2016 statistics yearbook (2017).(In Chinese) (Available from http://www.whtj.gov.cn/)
[7] http://baike.baidu.com/item/%E6%88%B7%E7%B1%8D%E5%88%B6%E5%BA%A6, in Chinese.

those benefits. Most importantly, official documents like "Wuhan 2016 statistics yearbook" did not consider these people in many cases, despite that they live in Wuhan, ignoring their economic contribution and risky social status. This overt discrimination leads these people to extreme marginalized and risky situation, and broadens many social problems that lead to Wuhan's vulnerability, like an increasing economic inequality, the unsettlement of agricultural population, poor health situation, and the unbalanced access to resources and opportunities.

The hukou system and poor urban planning have shown how government and political factors are important in reducing or creating vulnerability. Wisner et al. (2004) stresses the importance of government role in regulating and reversing many of the root causes, dynamic pressures, and unsafe conditions of vulnerability. This governmental participation is especially important in an authoritarian state like China under the control of the Communist Party of China, which has control over many hazard reduction analysis and policies. Therefore, understanding how China's political system, government, and governmental policies and programs in reducing Wuhan's vulnerability to waterlogging events are important in understanding Wuhan's vulnerability.

The governmental of Wuhan, first of all, did not do a good job in communicating the vulnerability of Wuhan to its citizens because of the authority of the Communist Party of China. Wisner et al. (2004) points out that public awareness of hazard is a "bedrock" of reducing vulnerability. However, because of China's authoritarian nature, citizens are usually only informed well after the government made some decisions. The "hazard communication" (Wisner et al., 2004) is also limited, for citizens are not allowed to freely express their ideas and the government will block any dissent voices. Even though citizens were informed of the vulnerability of Wuhan to waterlogging events, it is worth thinking whether the governmental data are convincing. The ignorance of the conditions of people without hukou, for example, makes the reported condition unrealistic. Moreover, without thinking about social and political factors of vulnerability, citizens, like the government, may still ignore the importance of social and political

vulnerability and blame natural disasters as the sole primary reason. With limited right and understanding of hazards of Wuhan's citizens, the government itself can only conduct programs in their own interests, whose effectiveness is questioned.

The ineffectiveness of governmental programs, in fact, plays a great role in Wuhan's vulnerability. Unlike many other regions where governmental programs are scarce, the Wuhan government conducted several programs in the past few years, for example, in 2013, Wuhan proposed a "three-year aim" to solve Wuhan's waterlogging problem with 13 billion yuan, and Wuhan was also chosen as a city to construct the sponge city project. However, after the 2016 Wuhan flood, Wuhan Water Affairs Bureau admitted that they only spent 5.34 billion yuan and finished only 48 projects by June 2016, three years after the proposal of their ambitious "three-year plan". [8] The Wuhan governmental agencies, indeed, is very ineffective in reducing Wuhan's vulnerability.

In fact, the proposal itself is unrealistic in nature. The plan was to update the city's drainage system and discharge ability, so that the city of Wuhan will not be affected by waterlogging events.[9] Not to mention that the program completely ignores the social vulnerability factors, the exclusive emphasis on updating discharge ability and drainage system is flawed. The plan, as an "engineered" flood control plan, failed to recognize that no matter how great the drainage system is, the system may still fail when unexpected rain attacks Wuhan. (Wisner et al., 2014) The plan failed to realize that their plan may fail or be difficult to implement, given how it may disrupt the natural ecosystem of river and lake, and disturb citizen's normal life, and that they cannot control natural events and change Wuhan's vulnerable geographic location. After all, it is impossible for them to solve this problem in only 3 years. Instead of being that confident, the government should acknowledge that waterlogging events may not be total preventable in a short time, but that it is important how they minimize economic loss and damage, and help citizens recover from their situations and reduce their vulnerability from an unexpected natural

[8] http://www.whwater.gov.cn/water/tzgg/7709.jhtml
[9] http://www.whwater.gov.cn/water/tzgg/7709.jhtml

disaster. This unrealistic proposal is just a tip of iceberg of the Chinese "Mianzi Gongcheng"（面子工程）, or literally "face job" (Zhang, Y., 2016). These jobs contain unrealistic goals, and instead of solving the problem in the long run, they care only about the immediate interest and fame that can bring to the government.

"Mianzi Gongcheng" is a characteristic of Chinese moral politics culture. The Chinese government always makes itself a heroic image through a sympathy of people's moral values, by showcasing how the government and the great rescue team saves people from disaster with their sweat and determination. (Xu, 2016) Xu also points out how social media plays a role in enforcing such image, which many Chinese people admire by giving governmental leaders respectful appellations like " Grandpa Wen", and "Xi Da Da", which means "Father Xi". These misleading idealized figures disguises their ineffectiveness of coping disasters, and according to Xu, also gives the governmental a moral duty to create fake data in the number of casualties. Not only do people not aware of the real situation and vulnerability, but it also distracts the government from implementing useful projects. "Mianzi Gongcheng" is also responsible for many social and economic factors that lead to vulnerability, for example, unsupervised urban development and high economic development that ignores environmental issues.

Finally, corruption is another important political factor that leads to the inadequacy of governmental programs. Tang, original a manager of Wuhan's hydraulic levee construction management center responsible for various programs worth more than 1 billion dollars, received more than 96 cases of briberies from a company that may disturb the effectiveness of programs. (Zhang, Y., 2016) Moreover, Dongcai Liu, originally a vice director general of Wuhan Water Affairs Bureau, bribed a total amount of over 5 million yuan. (Fang, 2014). Luckily, the Chinese government now had a great determination in combatting corruption, and Tang and Liu were all punished for what they did.

Urban development and the abundance of governmental projects in coping Wuhan's waterlogging events may provide a beguiling image that Wuhan is less vulnerable to these events. However, the unsupervised urban development and the ineffectiveness of governmental programs raise social and political vulnerability of Wuhan, and they are not only interrelated but also cause physical vulnerability situations. With an authoritarian political system, the Chinese government is important and is truly the only organization that can solve Wuhan's waterlogging problem. Even though the Chinese government blocks opponents' ideas and limits citizens' participation in understanding waterlogging issues, with a determination to combat corruption, a comprehensive recognition of waterlogging issues, and proposal of more effective coping strategies, the Chinese government can still greatly decrease Wuhan's vulnerability to waterlogging events, and let this "Jiusheng Tongqu" shine and prosper as it should be.

Appendix

1－1 土地面积、人口密度、户数、人口数
STATISTICS ON LAND AREA, POPULATION DENSITY, HOUSEHOLDS AND POPULATION

地区 District	土地面积（平方公里）Land Area (sq. km)	人口密度（人/平方公里）Population Density (person/sq. km)	2015年户籍人口 户数（户）Households (household)	2015年户籍人口 年末人数（人）Population (person)	2014年户籍人口 户数（户）Households (household)	2014年户籍人口 年末人数（人）Population (person)	2015年常住人口（万人）Resident Population (10000 persons)
总计 Total	8569.15	1238	2970977	8292666	2880203	8273117	1060.77
江岸区 Jiang'an	80.28	11887	278705	719531	273595	711084	95.43
江汉区 Jianghan	28.29	25677	193062	486430	191409	486676	72.64
硚口区 Qiaokou	40.06	21590	207257	526494	206275	527593	86.49
汉阳区 Hanyang	111.54	5731	234640	585373	229544	576536	63.92
武昌区 Wuchang	64.58	19635	346310	1056137	341566	1076733	126.80
青山区 Qingshan	57.12	9165	152131	433676	152107	438525	52.35
洪山区 Hongshan	573.28	2730	320199	948785	301444	936139	156.51
东西湖区 Dongxihu	495.34	1064	110420	288541	107859	283103	52.70
汉南区 Hannan	287.05	456	41985	113189	41923	112889	13.10
蔡甸区 Caidian	1093.17	644	149570	456551	149520	454810	70.35
江夏区 Jiangxia	2018.31	435	222932	590510	218775	588943	87.70
黄陂区 Huangpi	2256.70	419	394008	1124832	346862	1121602	94.51
新洲区 Xinzhou	1463.43	603	319758	962617	319324	958484	88.27

注：1、人口密度按常住人口计算。

2、行政区户籍人口户数中：江汉区含水上分局85户，汉阳区含武汉经济技术开发区51738户，洪山区含东湖技术开发区112106户、东湖生态旅游风景区15293户、武汉化学工业区13158户。

3、行政区户籍人口中：江汉区含水上地区8273人，汉阳区含武汉经济技术开发区150526人，洪山区含东湖高新技术开发区339488人、东湖生态旅游风景区34643人、武汉化学工业区33259人。

4、行政区常住人口中：江汉区含水上地区0.42万人，武昌区含东湖风景区1.74万人，洪山区含东湖新技术开发区31.49万人、东湖风景区6.39万人和武汉化学工业4.45万人，蔡甸区含武汉开发区25.25万人，江夏区含东湖新技术开发区18.21万人。

Note: 1. Population density is calculated according to resident population.

2. The households of Jianghan district includes 85 households of Water Bureau. The households of Hanyang district includes 51738 households of Wuhan Economic and Technological Development Zone. Hongshan district includes 112106 households of East Lake High－Tech Development Zone, 15293 households of East Lake Ecotourism Scenic Zone, 13158 households of Wuhan Chemical Industry Park.

3. The resident registered population of Jianghan district includes 8273 people of Water Bureau. Hanyang district includes 150526 people of Wuhan Economic Technological Development Zone. Hongshan district includes 339488 people of East Lake HighTech Development Zone, 34643 people of East Lake Ecotourism Scenic Zone, 33259 people of Wuhan chemical Industry Park.

4. The resident population of Jianghan district includes 4.2 thousand people of Water Bureau, Wuchang district includes 17.4 thousand people of East Lake Ecotourism Scenic Zone, Hongshan district includes 314.9 tholusand people of to East Lake High－Tech Development Zone, 63.9 thousand people of East Lake Ecotourism Scenic Zone, 44.5 thousand people of Wuhan Chemical Industry Park. Caidian district includes 252.5 thousand people of Wuhan Economc and Technological Development Zone, Jiangxia district includes 182.1 thousand people of East Lake High－Tech Development Zone.

Appendix 1: Basic information of Wuhan (Wuhan 2016 Statistics Yearbook, 2017)

Graph 1.1: The districts and population in each district. The population density in the city center districts are very high, especially Jianghan district.

2－1 户籍总户数、总人口数与常住人口数
NUMBER OF HOUSEHOLDS AND POPULATION

年份 Year	户籍总户数(万户) Number of Households (10 000 Households)	户籍总人口数(万人) Total Population (10 000 Persons)	常住人口(万人) Resident population (10 000 persons)
1978	124.28	548.29	555.10
1979	126.53	558.36	563.08
1980	129.53	567.23	571.18
1981	135.46	577.90	579.40
1982	139.43	586.97	587.74
1983	143.16	594.4	599.68
1984	146.82	600.59	611.86
1985	151.33	608.39	624.28
1986	157.00	619.96	636.96
1987	161.88	629.34	649.90
1988	167.93	641.72	663.10
1989	173.62	653.26	676.57
1990	178.83	669.75	690.31
1991	184.76	677.03	700.64
1992	188.23	684.46	711.13
1993	190.89	691.69	721.77
1994	194.20	700.01	732.56
1995	196.34	710.01	743.53
1996	199.17	715.94	754.65
1997	201.28	723.90	765.94
1998	205.43	731.79	777.40
1999	208.71	740.20	789.03
2000	213.66	749.19	804.81
2001	218.66	758.23	813.80
2002	224.59	768.10	823.70
2003	229.91	781.19	836.80
2004	241.58	785.90	845.43
2005	249.95	801.36	858.00
2006	255.45	818.84	875.00
2007	260.46	828.21	891.00
2008	265.00	833.24	897.00
2009	269.90	835.55	910.00
2010	274.58	836.73	978.54
2011	276.50	827.24	1002.00
2012	281.29	821.71	1012.00
2013	286.39	822.05	1022.00
2014	288.02	827.31	1033.80
2015	297.10	829.27	1060.77

Graph 1.2 Population and resident population. Notice the differ

rence between population in the second column and the resident population listed in the last column. This difference is due to the unique hukou system in China. One may think that the population growth is not significant when comparing the 2014 population and 2015 population above, but that is misleading. The population growth of people migrating from the countryside to the city is much larger and should not be ignored when understanding the vulnerability.

Appendix 2: Images of the Wuhan floods

Figure 2.1 Wuhan in July/02/2016. Where is river and where is road?

(http://i2.cdn.cnn.com/cnnnext/dam/assets/160704110945-02-china-flooding-super-169.jpg)

Figure 2.2 The subway station in a commercial district in Wuchang was waterlogged. Wuchang is believed to be one of the most affected region in Wuhan in 2016. The citizen's access to different resources were reduced due to the extensive waterlogging event, making people more.

(http://shanghaiist.com/2016/07/07/wuhan_flooded.php

Figure 2.3 Waterlogged Wuchang Rail Station. Wuchang Rail Station, one of the main train station in Wuhan, was also flooded in 2006 due to the unexpected storm. Since Wuhan is a major transportation hub, people in Wuhan, from nearby regions, or even the entire China might be affected.

(http://shanghaiist.com/2016/07/07/wuhan_flooded.php)

Figure 2.4 A hospital in Wuhan during Yangtze River flood, 1998.

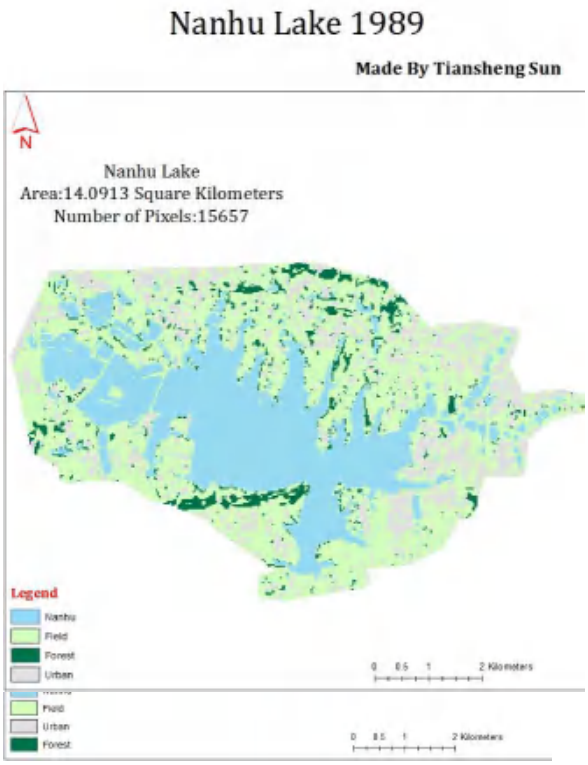
(http://www.ctdsb.net/html/2016/hubei_0512/35270.html)

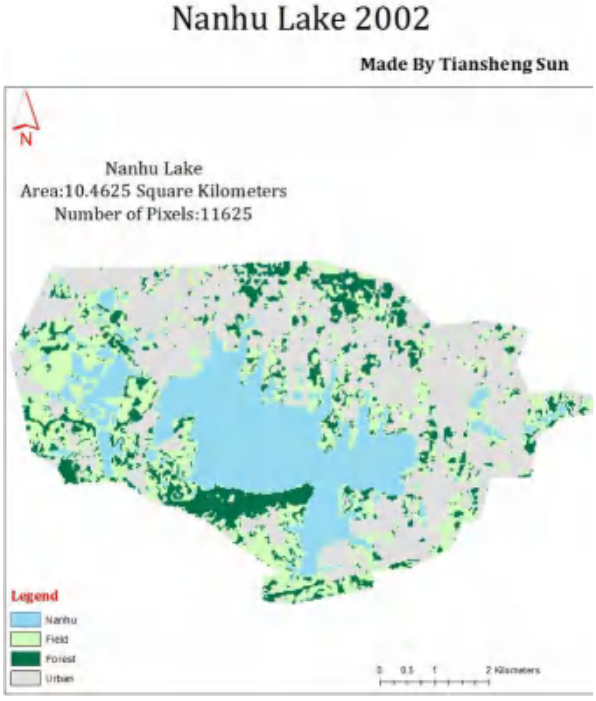
Appendix 3: The area change of four lakes using Remote Sensing

Four lakes in Wuchang and Hongshan district, Shahu, Donghu, Shaihu, and Nanhu has undergone great area change throughout the years. How did their areas change quantitively? I decided to use remote sensing to quantitively understand their area change throughout the years. I used three Landsat images: one Landsat-5 image from March/7/1989, one Landsat-7 image from March/19/2002, one Landsat-image of March/01/2016. These images were picked because they were all March images, making sure that season is not an important factor.

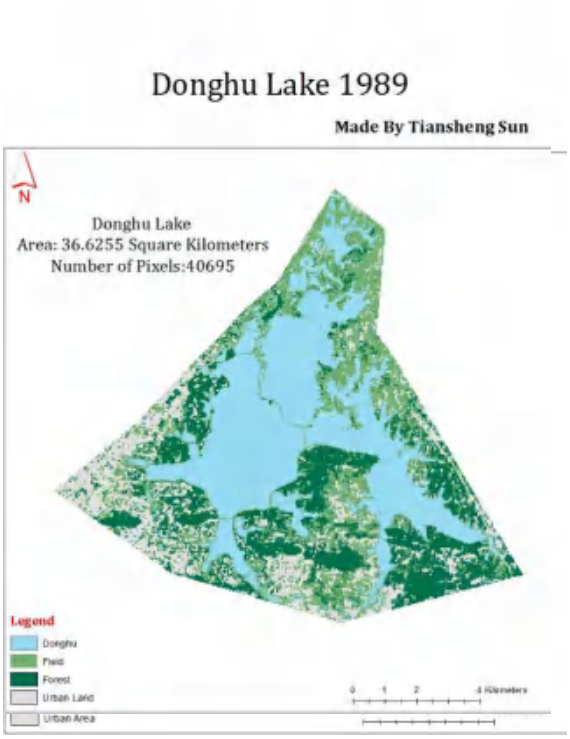
Method: Pick four study areas around these four lakes (lake and lakeshore in year 1989), and classify these Landsat images based on the study areas on each of the three years. After making three maps for each lake, calculate the number of lake pixels, and calculate the area of the lakes in each map (One pixel of a landsat image is 30*30 meters). Finally, compare the data.

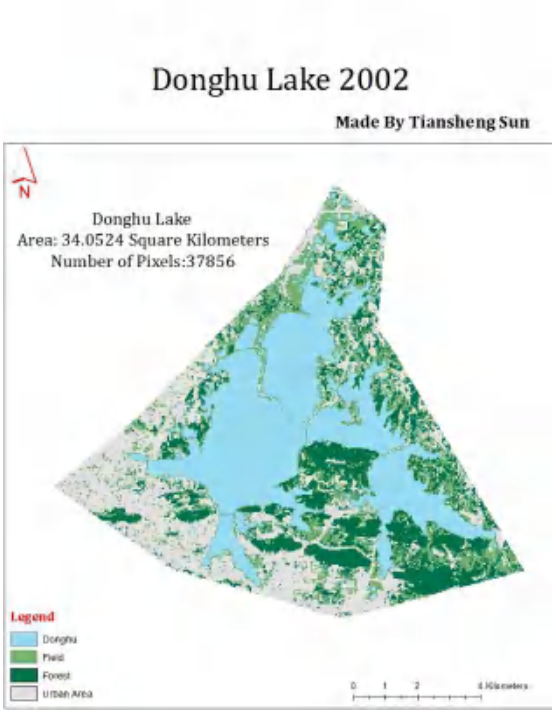
Figures 3.1-3.3: Nanhu images in 1989, 2002, and 2016



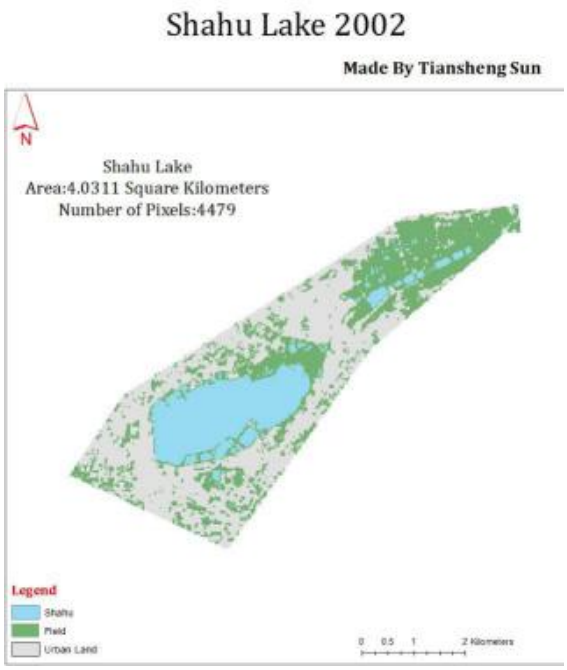


Figures 3.4-3.6: Donghu Images in 1989, 1998, and 2016.

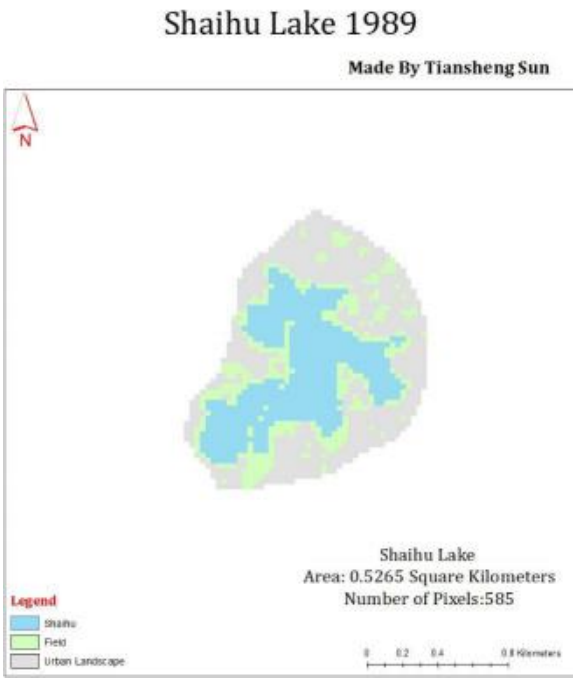


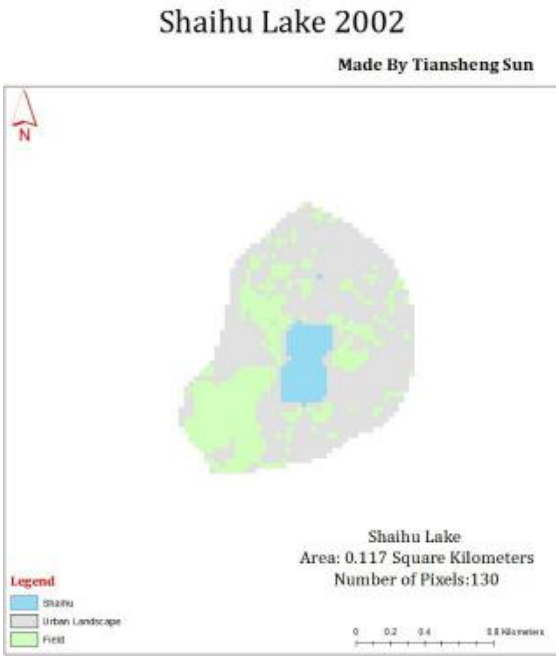


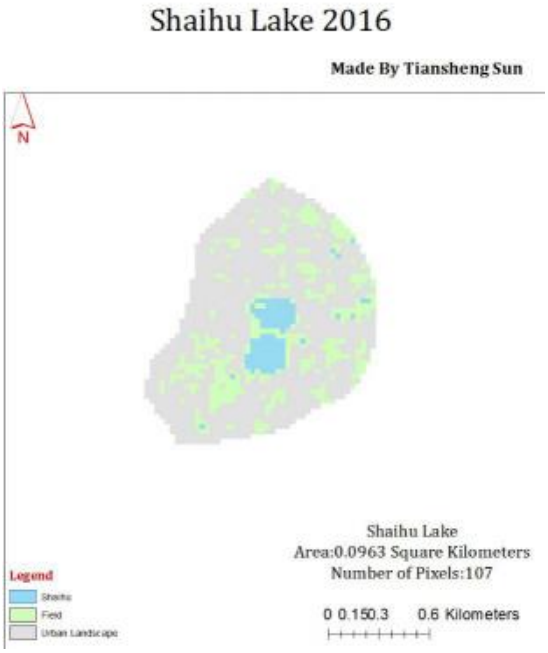
Figures 3.7-3.9: Shahu Images in 1989, 1998, 2016



Figures 3.10-3.12: Shaihu Lake in 1989, 2002, 2016







Graph 3.1: Lake Area comparison

Lake Name	Year 1989(km^2)	Year 2002(km^2)	Percentage of 1989 value (%)	Year 2016(km^2)	Percentage of 1989 value (%)
Nanhu	14.093	10.4625	74.249	6.9975	**49.65**
Donghu	46.6225	34.0524	92.98	32.1804	87.67
Shahu	7.0344	4.0311	57.31	2.4876	**35.36**
Shaihu	0.5625	0.117	**20.8**	0.0963	**17.12**

Through my graphs and calculations, the areas of these four lakes did shrink significantly. Even though my research did not directly prove that the lake change is a cause of Wuhan's increasing vulnerability, it shows how urban development can greatly alter nature, and can supplement many research's understanding of how the changing lakes may increase Wuhan's vulnerability.

Appendix 4: Waterlogging risk in Wuhan (May 2016)

(Available from http://www.whwater.gov.cn/water/tzgg/index.jhtml, in Chinese)

Below is the official waterlogging risk map of Wuhan's city center, available from the Wuhan Water Affairs Bureau. Green means a waterlogging depth of less than 0.15 meters, blue means waterlogging depth is between 0.15 meters and 0.4 meters, red means waterlogging depth is above 0.4 meters, and circle means places where transportation is affected. The map is inadequate in understanding vulnerability of Wuhan, for it only considers the Hazard, but not other crucial factors that leads to Wuhan's vulnerability.

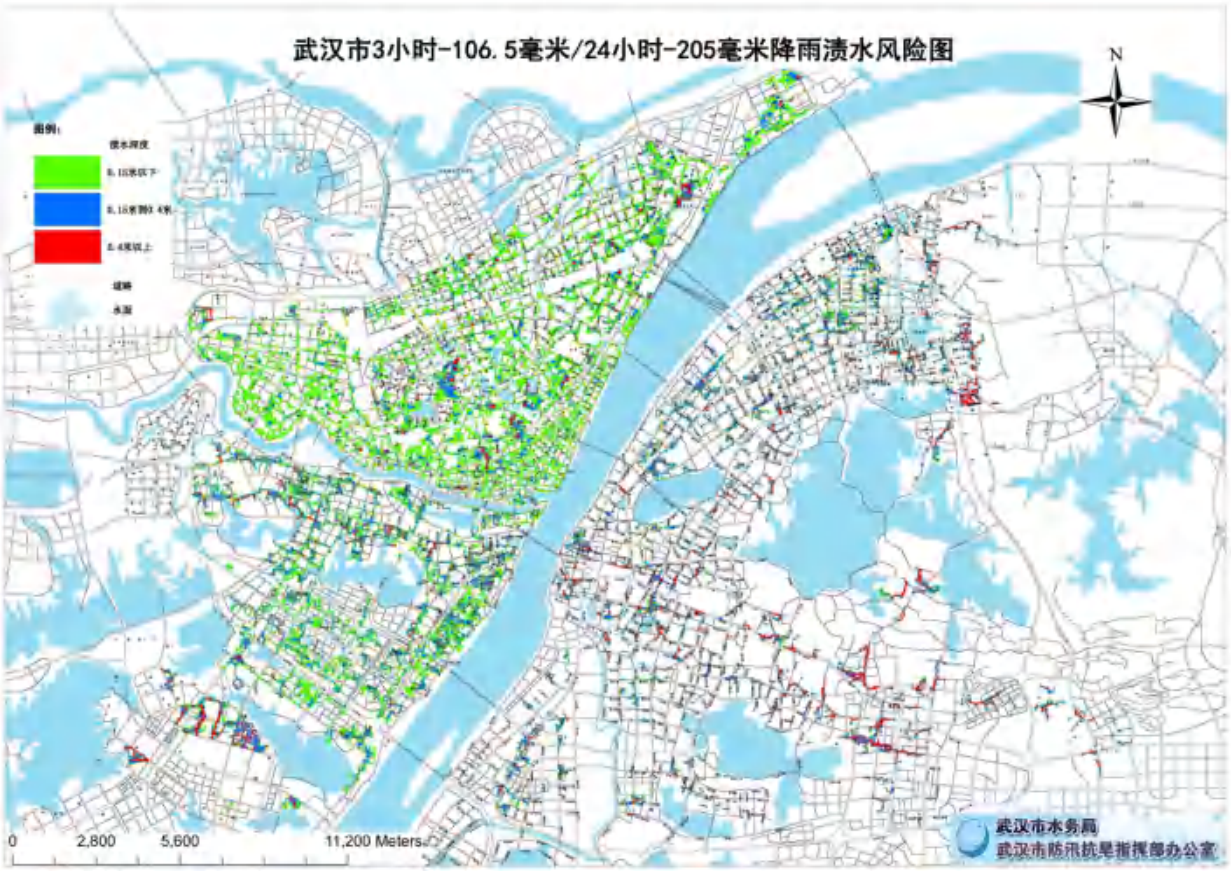
Map 4.1: Waterlogging risk map of Wuhan (3 hour-54.7mm/24 hour-95mm rainfall)

The city center has a total of 67 waterlogging sites, 3 in Jiang'an District, 3 in Jianghan District, 4 in Qiaokou district, 21 in Hanyang district, 13 in Wuchang District, 7 in Qingshan District, 16 in Hongshan District.

Map 4.2: Waterlogging risk map of Wuhan (3 hour-88.8mm/24 hour-162mm rainfall)

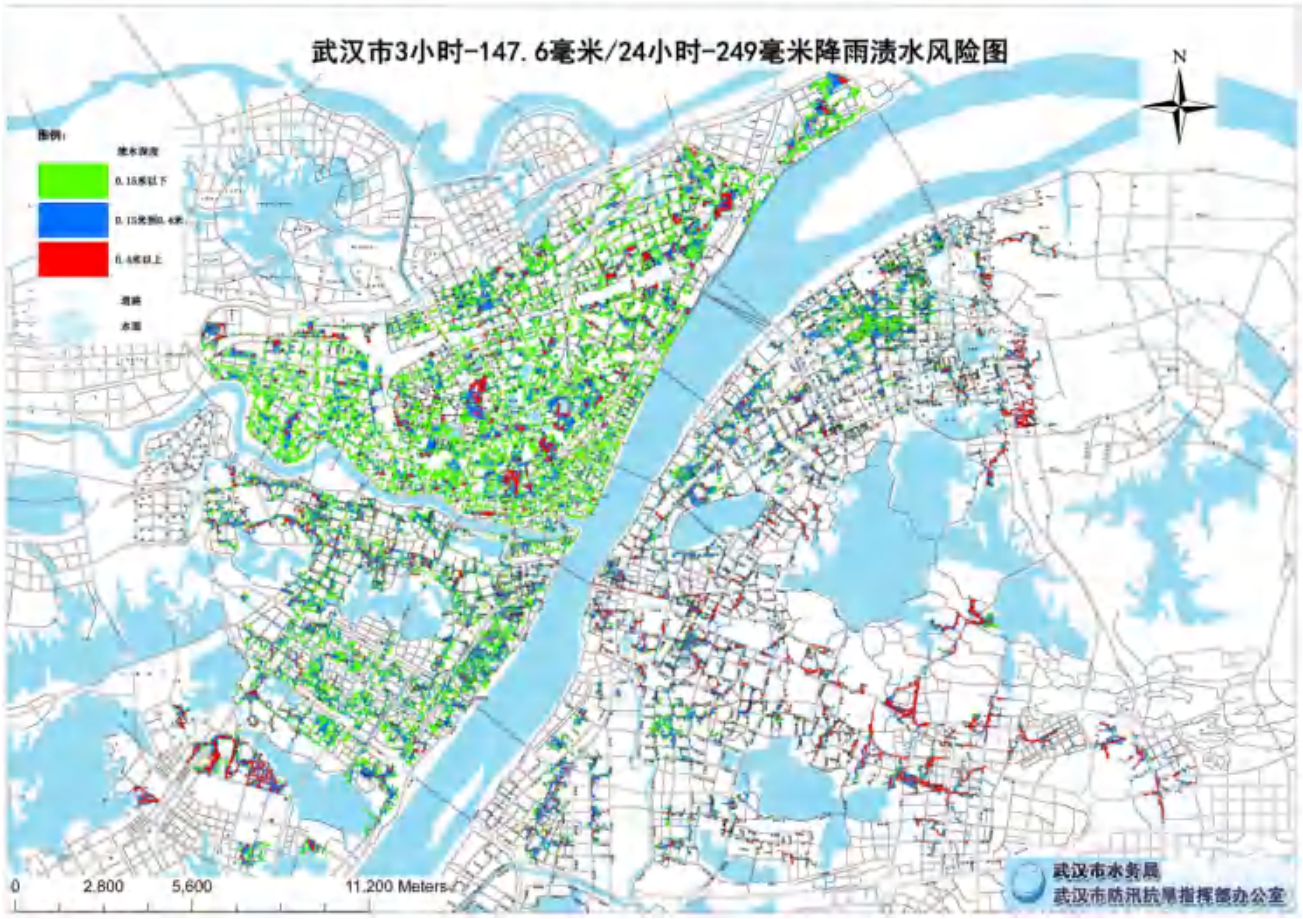
The city center will have 201 sites, 24 in Jiang'an District, 21 in Jianghan District, 25 in Qiaokou District, 36 in Hanyang District, 39 in Wuchang District, 18 in Qingshan District, and 38 in Hongshan District.

Map 4.3: Waterlogging risk map of Wuhan (3 hour-106.4mm/24 hour-205mm)



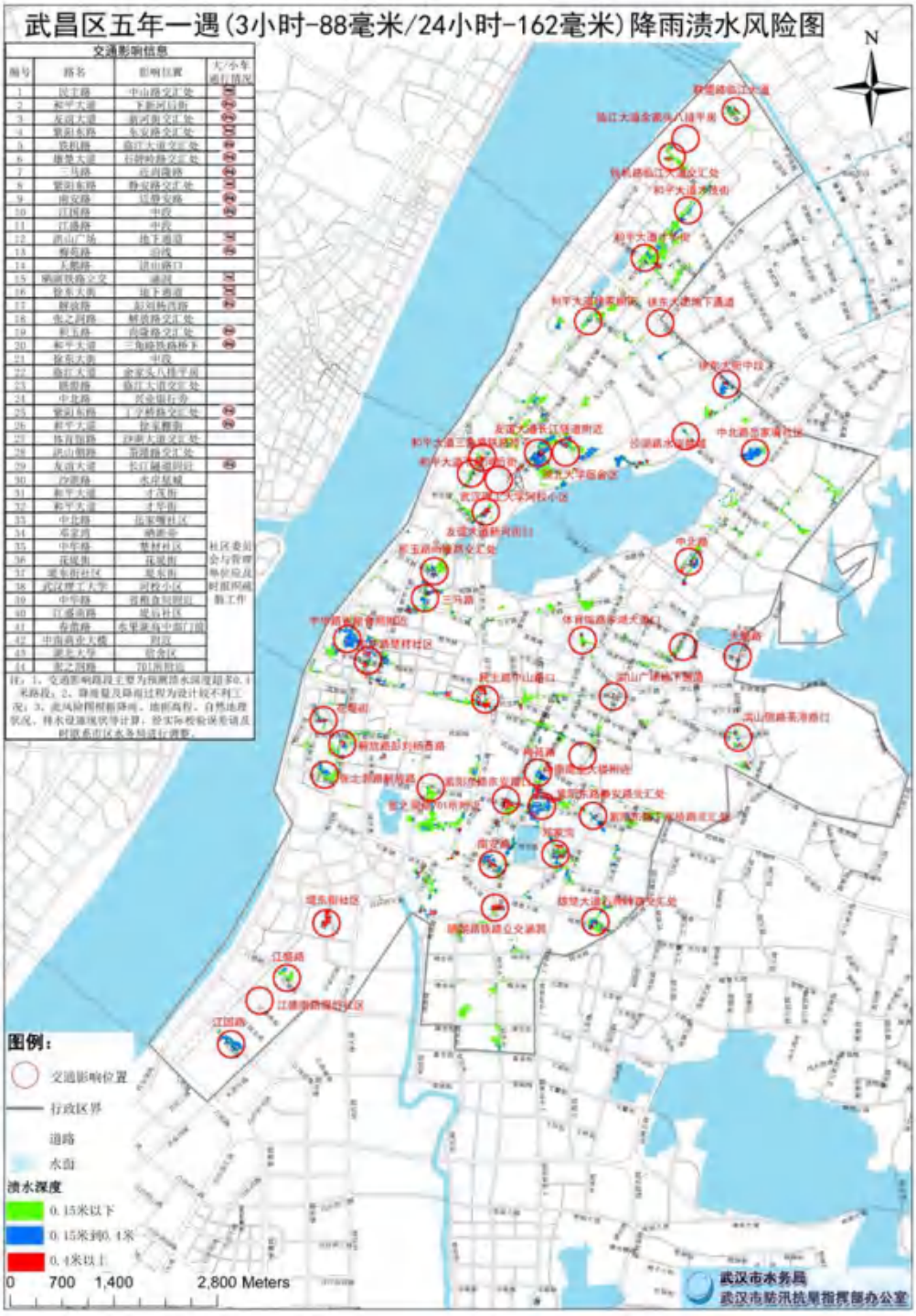
The city center will have 250 waterlogging sites, 30 in Jiang'an District, 26 in Jianghan District, 26 in Qiaokou District, 50 in Hanyang District, 47 in Wuchang District, 25 in Qingshan District, and 46 in Hongshan District.

Map 4.4: Waterlogging risk map of Wuhan(3 hour-147.6mm/24 hour-249mm)

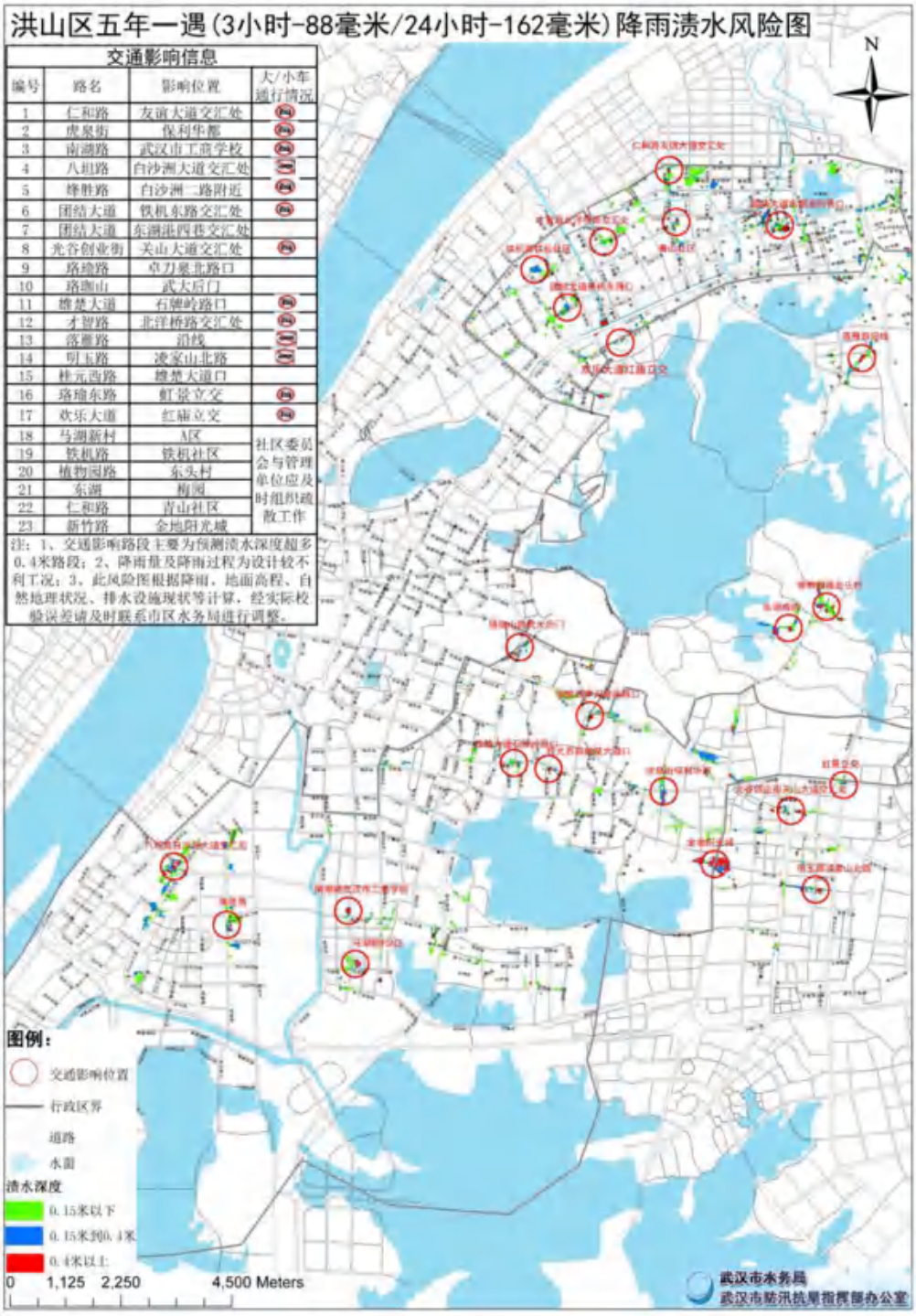


The entire city is in great danger.

Map 4.5: Wuchang District Waterlogging risk map(3 hour-88mm/25 hour-162mm)



Map 4.6: Hongshan District Waterlogging Risk map (3 hour-88mm/24 hour-162mm)



Appendix 5: PAR model of Wuhan's vulnerability

The pressure and release model by Wisner et al. (2004) is a great way in understanding the several factors that lead to Wuhan's vulnerability to waterlogging events.

Root Causes	Dynamic Pressure	Unsafe Conditions	D I S A S T E R	Hazard:Waterlogging
Authoritarian politics and ineffective government; Power in Chinese Communist Party, and a lack of power of Wuhan's citizens; The city is located in extremely vulnerable plain; Corruption; Moral politics under traditional Chinese value; The ingrained social and economic difference of city and rural areas	The construction of "Mianzi Gongcheng"; "Hukou" system makes migrants extremely vulnerable; Job-seeking migrants from rural areas and other smaller cities; Ignorance of marginalized citizens; Excessive urban development and economic growth; Economic inequality; Lack of awareness and understanding of unsafe conditions and vulnerability among Wuhan citizens; Ineffectiveness of governmental projects and coping stretegies	Household in lowland and vulnerable plains; Waterborne diseases; Extremely hot summers; Health issues; Reduction in lake areas and ecosystems; Inadequate warning; Lack of disaster preparedness; Large number of students and migrants especially vulnerable; Limited access to resources when transportation is affected; Failure of drainage systems, levees, and dams; Building easily damaged		El Nino events Unexpected typhoons Yangtze River floods

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