STUDY ON ASSESSMENT OF FLOOD DISASTER LOSS IN TAIHU LAKE BASIN

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ABSTRACT

In recent years, the highly urbanized areas in China are often threatened by floods and waterlogging, which cause serious social and economic losses and have a serious impact on regional development. In this study, the Taihu Lake Basin is regarded as a typical study area of highly urbanized areas, and the corresponding disaster loss mechanism is analyzed for various socio-economic entities, like residential property, urban industry and commerce and urban surrounding agriculture. On this basis, the assessment method of disaster losses in Taihu Lake Basin is studied. The impact of flood disasters on population, industrial and commercial enterprises, road traffic losses would be discussed. The study on assessment of flood and waterlogging disasters in highly urbanized areas would provide technical support for regional flood disaster alleviation and emergency management in China.

Keywords: *Highly urbanized areas, flood disaster loss mechanism, assessment*

INTRODUCTION

The flood disaster has been one of the greatest threats to human survival and development since ancient times. In terms of the space-time scope and their threat to human survival and development, the flood disaster ranks first among all kinds of natural disasters. China is one of the countries with the most frequent flood disasters in the world. About 2 / 3 of the land, more than 1 / 2 of the population and 2 / 3 of the industrial and agricultural output value are threatened by flood. At present, China is in a period of rapid development of urbanization, forming a number of highly urbanized regional clusters, such as the Yangtze River Delta and the Pearl River Delta. The intense human activities in highly urbanized areas have an important impact on the underlying surface, runoff and storage of the river basin. The high concentration of population and wealth makes the vulnerability of the hazard bearing body increasingly prominent. In addition to the frequent occurrence of extreme climate events in the context of global climate change, frequent flood and waterlogging disasters have become the bottleneck restricting the sustainable development of regional economy and society. Therefore, it is of great strategic significance to strengthen the research on assessment technology and risk management of flood disaster in highly urbanized areas (such as Taihu Lake Basin) for alleviating the pressure of flood control and disaster reduction in the future and ensuring the sustainable development of social economy in the region.

STUDY AREA AND DATA

Taihu Lake Basin, with a total area of 36895km^2, is the core area of urban and economic development in the Yangtze River Delta. It is located between the lower reaches of the Yangtze River and Qiantang River and Hangzhou Bay. The urban agglomerations in the basin are composed of Shanghai, Hangzhou, Suzhou, Wuxi, Changzhou, Zhenjiang, Jiaxing, Huzhou and other cities, with an urbanization rate of 75%. It has distinct regional urban agglomerations development characteristics, and it is seriously threatened by flood disaster, which has strong theoretical research and empirical analysis value. Taihu Lake Basin is a typical plain river network area with interlaced rivers and lakes, having a total river length of 120000 km and the river density of 3.25km/km^2. The annual average precipitation of the basin is 1177mm and the annual runoff is 16.15 billion m^3. The low-lying areas in Taihu Lake Basin mainly include Taipu River depression, Kunshan depression, Qingsong depression, Punan depression, and Deqing depression. These areas are prone to flood disaster. In the history, there were many floods happened in Taihu Lake Basin, and 13 large floods occurred in the 20th century. Among them, in 1931, 1954, 1991 and 1999, the disaster areas were 395000 hm^2, 293000 hm^2, 418000 hm^2 and 687000 hm^2 respectively, which caused extremely serious losses.

The basic data used in this research include: the population distribution data of 1-km resolution in 2016, the road and traffic data downloaded by GEOFABRIK website (OpenStreetMap Foundation, 2016), and the land use data of 1 km resolution in 2015 downloaded by the national geoscience data center. The socio-economic data are respectively from Zhejiang statistical yearbook (Zhejiang Provincial Bureau of Statistics, 2017), Jiangsu statistical yearbook (Jiangsu Provincial Bureau of Statistics, 2017) and Shanghai Statistical Yearbook (Shanghai Bureau of Statistics, 2017). The parameters for the fragility curve and indirect loss coefficients come from some related literature (Wang et al., 2019; Romali et al., 2015; Suppasri et al., 2013).

STUDY METHODS

Flood loss assessment is based on geographic information, and the spatial geographic data and socio-economic data are overlay analyzed and processed comprehensively. Geographic information system (GIS) provides a solution for storage, analysis and expression of all kinds of spatial data. By using GIS, we can analyze and process all kinds of spatial data related to flood disaster efficiently, at the same time, we can extract the inundation range of flood quickly. Combined with the social and economic data, the inundation and loss of various hazard bearing bodies are finally obtained. Based on the evaluation of the comprehensive database, firstly, the flood water level is calculated according to the rainfall and digital model elevation (DEM) data, then the inundation depth and inundation range of the inundation area are calculated; secondly, the economic data space is distributed to the smallest statistical administrative unit; finally, the inundation range layer is superposed with the related population distribution, building distribution and economic data space distribution layers for layer overlay analysis, and the statistical model is established The flood loss details of various objects are calculated in the set unit under the proposed scenario.

3.1 Calculation of inundation depth and inundation range of flood

In order to analyze the flood risk of plain river network area, the method of numerical simulation is often used to study the complex water system and the characteristics of flow movement in this area. However, due to the lack of measured flow data, it is difficult to calibrate and verify the model, and the long calculation time for large watershed model is not conducive to rapid flood simulation. Therefore, according to the regional topography, using ArcGIS technology to carry out hydrological analysis and simulate flood disaster quickly and accurately is an important way to evaluate the impact range of flood. Based on DEM data and ArcGIS technology, this study forms a set of effective methods to simulate flood inundation range caused by rainstorm and waterlogging through programming, which can simulate flood inundation range more quickly.

There are many reasons for flood inundation, but generally it can be attributed to the waterlogging caused by rainfall and the dike breakout caused by external flood. This can divide the cause of flood inundation into non-source inundated model and source inundated model. In non-source inundated model, any place with elevation lower than the given water level is regarded as inundation area, which is calculated as inundation range. This situation is applicable to the uniform precipitation of the whole area, so water may be accumulated in all low-lying areas. In this study, we mainly explore the urban waterlogging caused by typhoon, so we choose the non-source inundated model to simulate the inundated range. Non-source inundation also needs to consider the regional inundation under rainfall conditions. Assuming that the precipitation of a certain area is V, the flood level of the inundated area is H, the grid area of each discrete element in the regular rectangular grid model data is Δs, the number of grids is n, and the corresponding elevation of the i_{th} grid is h_i, the relationship between precipitation V and flood water level H can be expressed by the following formula:

$$V = \sum_{i=1}^{n} (H - h_i) \cdot \Delta S \qquad (1)$$

The above formula is essentially a method to get the total volume based on the given water level, which simplifies the flood level into a plane. This is similar to the process of obtaining reservoir capacity, and a relationship between water level and reservoir capacity is obtained. In ArcGIS, for the calculation of storage capacity, a surface volume modular based on DEM is provided, which can be calculated as long as the water level and DEM Terrain Data are given. Using this modular, we can get a programming algorithm to calculate the inundation depth. Firstly, assuming that the flood level is H, H can be taken as the minimum value of the ground elevation of the calculation area, then the volume of inundation V is calculated by the storage capacity module of ArcGIS, and the volume of inundation V is compared with the actual rainfall W. If the error between the two values exceeds a certain range, H is accumulated. This process is repeated all the time. When the values of V and W are close, the required inundation depth H can be obtained. After the inundation depth of the study area is obtained, the whole inundation range can be extracted. The way to extract the inundation range is to get the grid whose elevation is not greater than the inundation depth. This can be achieved through the raster calculator function in ArcGIS. For the extraction of inundation range of different water depths in multiple areas, the algorithm of ArcGIS for Python can be used.

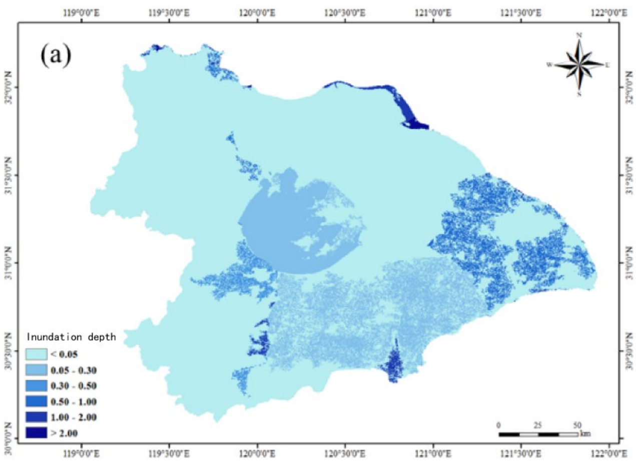
3.2 Spatial distribution of socio-economic data

Social and economic statistical data is usually the sum or mean value in a statistical unit, but in fact, the spatial distribution of social and economic data in a statistical unit is uneven. To determine the number of socio-economic indicators within a certain range, the key is to determine the distribution density function of socio-economic indicators within the range, which is usually obtained through the detailed investigation of typical regions, and then extended to other similar regions. However, for large-scale flood loss assessment, this extension often cannot meet the requirements of accuracy and rationality. It is necessary to use remote sensing (RS) and GIS technology to obtain the spatial distribution density of socio-economic data through geological spatial distribution of socio-economic data.

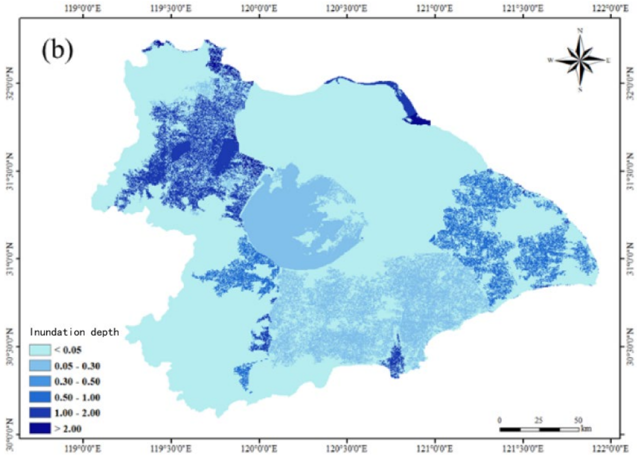
RESULTS

In this study, Taihu Lake Basin is selected as the research area to carry out flood disaster loss scenario assessment. The research period is chosen as 2016. Two typical typhoon events were selected for the flood disaster scenario simulation, namely "Matsa" in 2005 and "Morakot" in 2009. The typical Taihu Lake water level was designed as 5.2m, and the corresponding flood detention volume was 2.552 billion m^3 and 2.723 billion m^3 respectively for these two scenarios. In 2005, the rainfall of "Matsa" typhoon was mainly distributed in the west of Taihu Lake, among which the rainfall in Pudong, Puxi and Yangcheng areas were 193.56mm, 183.29mm and 170.42mm, respectively. In 2009, "Morakot" typhoon rainfall lasted a long time, with large rainfall and uneven distribution in time and space. The rainfall in ZheXi, Pudong, Hangjiahu and Puxi areas was large.

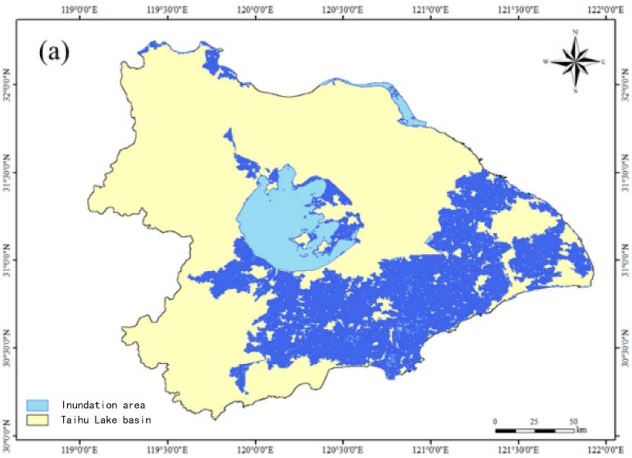
According to the flood storage capacity calculated under the two typical typhoon scenarios, the non-source inundated model is used to calculate the inundation range and water depth of Taihu Lake Basin. The results are as follows:



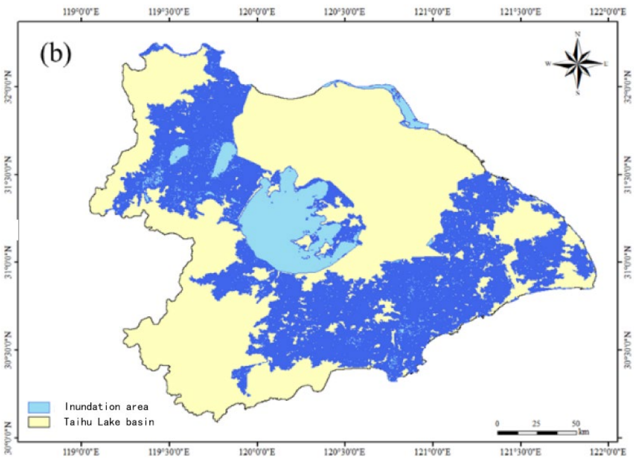
(a) inundation depth for Matsa typhoon



(b) inundation depth for Morakot typhoon



(c) inundation area for Matsa typhoon



(d) inundation area for Morakot typhoon

Figure 1. Distribution map of inundation depth and inundation area for Matsa typhoon and Morakot typhoon.

According to the results of simulation, we can see that the inundation areas under the situation of Typhoon "Matsa" are mainly concentrated in Puxi district and Hangjiahu District of Pudong, in which the inundation depth range is 0.05-0.3m in Hangjiahu District, 0.3-0.5m in Zhexi District, 0.5-1m in Puxi District of Pudong, and more than 2m in depth It is mainly concentrated in the basin boundary; the inundation area under the typhoon "Morakot" scenario is mainly distributed in the west of lake, Puxi District of Pudong and Hangjiahu District, among which the inundation depth range of the west of lake district is 1-2m, Puxi District of Pudong is 0.5-1m, and Hangjiahu district is 0.05-0.3m. Compared with the typhoon "Matsa", the inundation depth caused by "Morakot" is significantly increased.

Four kinds of social and economic data as GDP, industrial output value, agricultural output value and construction industry output value, are selected as evaluation indexes. With district or county as the minimum statistical unit, and social and economic data are spatially distributed with 1km resolution according to land use type data. It can be seen that Shanghai's GDP, industrial output value and construction industry output value are in a leading position in the basin. According to the distribution map of inundation depth and inundation range, Shanghai is a waterlogging prone area, which will cause more economic losses in the event of flood disaster. As a waterlogging prone area, Hangjiahu District, due to its relatively low social economy, the loss is relatively lower there. Therefore, we need to strengthen the flood control and drainage measures in Shanghai to reduce the loss when disasters occur. However, due to the high altitude in the west of lake and Zhexi, when rainfall occurs in the basin, flood disaster is not easy to occur, and their social economy is in the middle and lower level in the basin.

According to the layer of inundated water depth and vulnerability curve, the grid calculator of ArcGIS software is used to assign the corresponding disaster loss rate of each industry according to the inundated water depth, and the spatial distribution map of disaster loss rate is obtained. Then, the economic loss caused by flood disaster can be obtained by multiplying the layer of disaster loss rate in the inundated area and the layer of social economic distribution, and the layer of inundated area, road traffic and people can be obtained. The statistical value of the loss of the affected population, affected roads and traffic points can be analyezed by superposition calculation of the distribution layer of the mouth. The results are shown in table 1.

Table 1. Statistics of direct economic loss of flood disaster under simulation scenarios.

Evaluation index	Typhoon Matsa	Percentage (%)	Typhoon Morakot	Percentage (%)	Total value of the basin
Loss of agricultural output value (100 million yuan)	118.26	6.53	234.69	12.96	1811.11
Loss of Industrial output value (100 million yuan)	1347.69	1.23	2166.95	1.98	109473
Loss of output value of construction industry (100 million yuan)	79.26	0.60	112.58	0.85	13263.90
Affected GDP (100 million yuan)	12440.20	18.03	14836.70	21.50	69011.50
Affected population (10^4)	9031960	15.44	10898800	18.63	58514500
Inundated road (km)	17312.66	16.89	40825.33	39.83	102505.7
Inundated traffic stations	413.00	5.68	519.00	7.13	7277.00
Inundated area (km^2)	9036.88	24.43	11951.98	32.32	36985

According to the statistical results of flood disaster, the proportion of GDP, affected population and roads is relatively high, and the response to flood disaster is relatively sensitive. The flooded road caused by Typhoon "Morakot" reaches 39.83% of the total road length, which will have a more serious impact on traffic. In the disaster loss simulated under the two typical typhoon scenarios, the loss percentage of agricultural output value is far greater than that of industrial and construction industry. The percentage of agricultural loss increased by 6.43% in the two simulations, which is also greater than the added value of industrial and construction industry, indicating that agriculture is weaker in resistance to flood disaster, so we need to do a good job in key protection work. However, in terms of absolute quantity, the economic loss of industry is greater and more serious when it encounters flood disaster. This will have a greater impact on the economy and society, which requires us to do early warning and prevention work for industrial production in case of flood disaster.

CONCLUSIONS

In this study, Taihu Lake Basin is taken as the research area, and the impacts of typical flood disasters on agriculture, industry, construction industry, population, road traffic are analyzed, and the losses of flood disasters are evaluated. The research will provide technical support for flood control & disaster reduction and emergency management in the Yangtze River Delta region of China.

ACKNOWLEDGMENTS

The researchers would like to extend their thanks to the Chinese National Key Research and Development Program (2018YFC1508203) and Chinese National Natural Science Foundation (Nos. 51739011, 51879274 and 51979285). The researchers also thank the Changjiang River Scientific Research Institute (CRSRI) Open Research Program [Program Serial Number: CKWV2018494/KY]. The study was also supported by the Research Fund of the China Institute of Water Resources and Hydropower Research (Nos. WR0145B502016 and 2017ZY02).

REFERENCES

OpenStreetMap Foundation. (2016). Geofabrik GmbH Karlsruhe, Website http://www.geofabrik.de/.

Zhejiang Provincial Bureau of Statistics. (2017). Zhejiang statistical yearbook 2017. Website http://tjj.zj.gov.cn/.

Jiangsu Provincial Bureau of Statistics. (2017). Jiangsu statistical yearbook 2017. Website http://tj.jiangsu.gov.cn/col/col70123/index.html.

Shanghai Bureau of Statistics. (2017). Shanghai Statistical Yearbook 2017. Website http://tjj.sh.gov.cn/html/sjfb/tjnj/.

Wang, Y.Y., Li, N., Wang, S., Wang, J., and Zhang, N. (2019). Development and application of flood damage assessment system. *Journal of Hydraulic Engineering*, 50(9): 1103-1110.

Romali, N.S., Sulaiman, M.K., Yusop, Z., and Ismail. Z. (2015). Flood Damage Assessment: A Review of Flood Stage–Damage Function Curve. *ISFRAM 2014*, DOI: 10.1007/978-981-287-365-1_13.

Suppasri, A., Mas, E., Charvet, I., Gunasekera, R., Imai, K., Fukutani, Y., Abe, Y., and Imamura, F. (2013). Building damage characteristics based on surveyed data and fragility curves of the 2011 Great East Japan tsunami. Natural Hazards, 66:319-341.