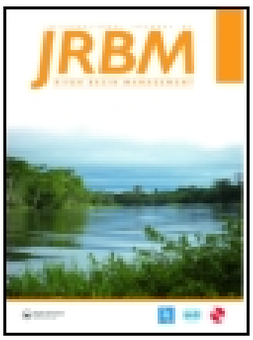

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RESEARCH PAPER

Lessons learned from the 2016 Yangtze River flood in Anhui province, China

Xiaotao Cheng[a], Hongtao Wan[a,b], Shifeng Huang[a,b], Changzhi Li[a,b] and Hongbin Zhang[a,b]

[a]China Institute of Water Resources and Hydropower Research, Beijing, People's Republic of China; [b]Research Center on Flood and Drought Disaster Reduction, MWR, Beijing, People's Republic of China

ABSTRACT

During the flood season of 2016, the middle and lower reaches of the Yangtze River suffered the worst flooding since 1999, involving Hunan, Hubei, Anhui, Jiangxi and Jiangsu provinces and the Taihu Basin. Based on the field survey at eight counties on both sides along the Yangtze River in Anhui Province, this paper analyses the features of rainstorm, flood and the resulting disaster in 2016 over there, and identifies problems and difficulties existing in flood prevention and disaster reduction under the new situation of social and economic development. Furthermore, this paper discusses the coping strategies and measures on advancing the comprehensive flood management mode of human-water harmony, managing middle and small rivers and strengthening the key basic research on flood control and disaster reduction under the new situation.

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KEYWORDS
Flood prevention and control; emergency response; risk management; comprehensive flood management

1. Introduction

During the flood season of 2016, the middle and lower reaches of the Yangtze River suffered the worst flooding since 1999, involving Hunan, Hubei, Anhui, Jiangxi and Jiangsu provinces and the Taihu Basin. Among them, Anhui Province was attacked by several heavy rainstorms, particularly the three strong rainfall processes in June 18–20, June 24–28 and June 30–July 5, which resulted in the highest water level in rivers and lakes linking to the Yangtze River after the 1999 big flood, and caused serious economic and social losses (Anhui Provincial Hydrology Bureau 2016). This paper presents the main results of the field investigation at eight counties (Feidong, Hanshan, Zongyang, Huaining and Susong on the left side; and Dangtu, Xuancheng and Nanling on the right side) along the Yangtze River from 25 August to 1 September 2016. The investigation team was organized jointly by the Research Center on Flood and Drought Disaster Reduction of the Ministry of Water Resources and the Water Conservancy Department of Anhui Province. It is aimed to understand the actual situation in the flooded areas and the needs of reconstruction, and to analyse the difficulties confronted and coping strategies to be adjusted. The findings show that the severe flood in 2016 was caused by extreme rainfall in the context of super El Nino event 2015/2016, and meanwhile, reveal the problems and challenges in the new situation of unprecedented urbanization process and land transfer trend to intensive management in rural areas.

2. Main features of 2016 Yangtze River rainstorm and flood disaster in Anhui Province

2.1. Rainstorm characteristics

(1) Long duration and large amount of rainfall. From 1 May to 20 July 2016, the mean areal rainfall in Anhui Province was 733 mm, 60% more than that of the average year and 40% more than 1998. The accumulative maximum rainfall was 1544 mm at Tianli Station in Xiuning County. During the mould rain period from 18 June to 5 July 2016, the average rainfall in the Yangtze River Basin in Anhui Province was 551 mm and the accumulative maximum rainfall was 1314 mm at Shuilongshan Station in Nanling County (Figure 1) (Anhui Provincial Hydrology Bureau 2016).

(2) Heavy intensity and unfavourable temporal-spatial distribution. Since June 18, at the Yangtze River Basin in Anhui Province, the maximum 1, 3, 7 and 15 d mean areal rainfall was 89, 243, 363 and 507 mm, respectively. The maximum 3 d rainfall ranked first in the history, more than that in 1969 (205.8 mm), with the return period of over 50 years. The maximum 7 d rainfall ranked at the top as 1999's record, and the maximum 15 d rainfall ranked the second on record, just below that in 1969, with the return period close to 50 years. The spatial distribution of rainfall was also unfavourable, the cover areas with cumulative rainfall of 300, 500 and 700 mm reached 81,500, 57, 600 and 28,400 km^2, respectively.

2.2. Flood characteristics

(1) High base water of rivers and lakes along the Yangtze River. Since April, due to the impact of inflow from upstream of the Yangtze River, the water level of the main stream of the Yangtze River in Anhui Province was higher than usual. The water level was 1.21~3.34 m higher than that of the average year at Datong Station and 2.79~5.13 m higher at Anqing Station (Figure 2). The water level of the Yangtze River was generally higher than the water level of lakes along the river, which resulted in the failure of the drainage from the lakes linking to the river and difficulty in offering enough capacity to regulate and store floodwater.

(2) High lateral inflow and sharp flood rising. By July 5, from the upstream control stations of Anhui Province, i.e. Huikou Station to Datong Station, the overall water level of the Yangtze River main stream was lower than

CONTACT Xiaotao Cheng chengxt55@qq.com

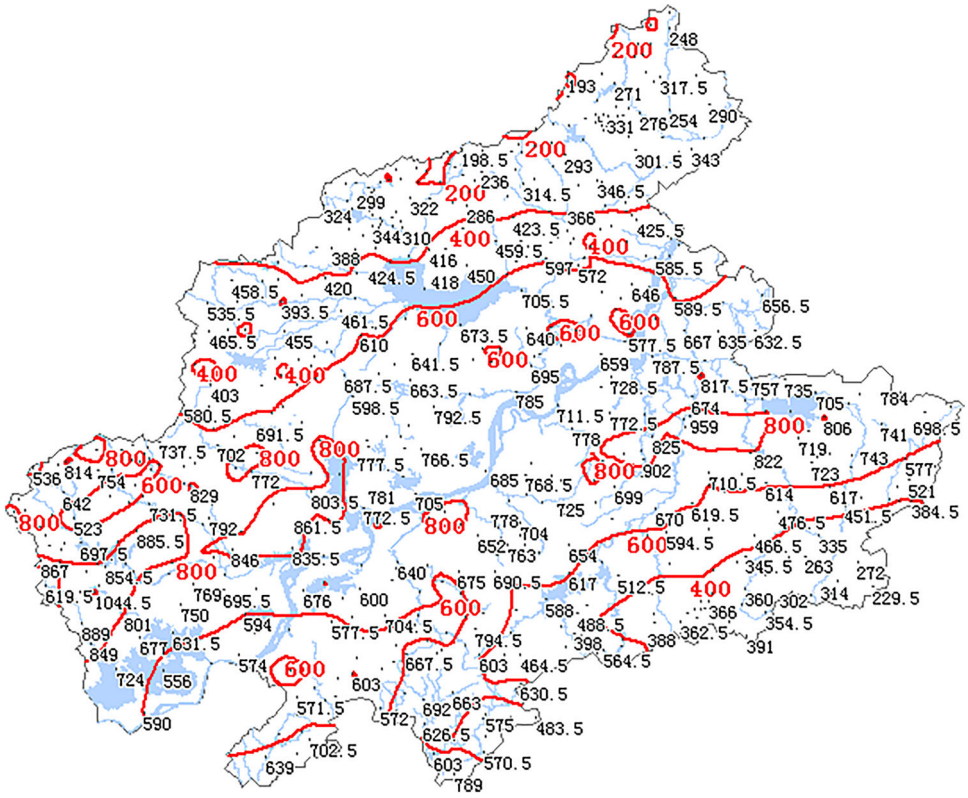

Figure 1. Rainfall contour map of Yangtze River basin in Anhui province from June 18 to July 5.

in 1998 and 1999. It was lower than the maximum water level of 1998 by 0.80~1.50 m and 1999 by 0.30~0.90 m. Due to the impact of the inflow of the rivers in Anhui Province, at 15:00, July 5, the maximum water level was 11.16 m at the downstream control station (Ma'anshan Station), similar with the maximum water level of 1999. The high water level at Ma'anshan Station was mainly due to the flow concentration in Anhui Province and was similar with the maximum water level in 1998 and 1999 (Figure 3).

(3) Many small- and medium-sized rivers and lakes exceeding the historical highest water level and safety water level. There were 34 rivers, as tributaries of the Yangtze River in Anhui province, consecutively observed the floods exceeding the warning water level, among which 17 rivers including Shuiyang River and Yuxi River observed floods exceeding the safety water level, and 13 rivers including Zhanghe River, Xihe River and Yongan River, observed floods exceeding the historical water level. All the lakes linking to the Yangtze River exceeded the safety water level, among which Baidang, Fengsha, Caizi and Shengjin lakes all exceeded the historical maximum water level, and Chaohu Lake was close to the historical maximum water level. In general, compared with the maximum 1, 3, 7 and 15 d flood volume of the rivers along the Yangtze River with the historical typical years, the flood volume of Qingyi-Shuiyang-Zhanghe rivers basin, Chaohu Lake basin, Erlang River, Huangpen River and Yaodu River, etc., in 2016 was greater than that in 1998 and 1999, only less than that of 1954.

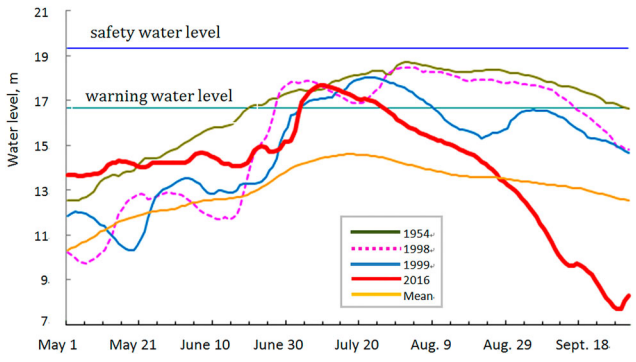

Figure 2. Comparison of typical annual stage hydrographs at Anqing Station.

2.3. Flood disaster features

(1) During the long period of high water level, no large dangers occurred along the main dykes of the Yangtze River, which had been heightened and consolidated after the big floods of 1998 and 1999, but many dangerous cases, such as leakage, piping and landslide, appeared along the dykes in small- and medium-sized rivers as tributaries of the Yangtze and polder areas around the lakes. According to the statistics from the Office of Flood Control and Drought Relief Headquarters of Anhui Province, since June 18, all the main stream and important branches and lakes linking to the Yangtze River exceeded the warning water level for more than 20 days. Due to the long period of retaining high water level, river and lake dykes were frequently observed with dangerous cases, accumulatively at 1831 places, leading to breaches for 129 polders with area above thousand mu (mu: a Chinese unit of area, 15 mu = 1 ha), of which 12 breaches were observed at polders with farmland more than 10,000 mu. The inundated cultivated land area is about 474,300 mu. Nevertheless, the overall disastrous situation was relatively light compared to the case of similar scale floods in history as shown in Table 1, because of the

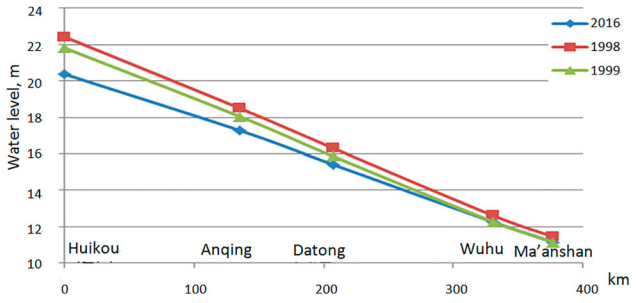

Figure 3. Comparison of water surface level of Yangtze River main stream in Anhui in 2016, 1998 and 1999.

reinforcement of main dikes and dams since the 1998 and 1999 floods, and effective flood fighting activities during the 2016 flood, that ensured the safety of all dams and all cities above county level, and the social stable order in the flooding affected areas.

Among the 129 polders, 125 were overtopping breaches (including 4 active storages for dyke protection) and only 4 were breaking breaches. Additionally, 38 small-size reservoirs were at risk, but all were timely and effectively controlled.

(1) Polders around the lakes linking to the Yangtze River were severely affected by the flood disaster (Huazhong 2016, Office of Anhui Provincial Flood Control and Drought Relief Headquarters 2016, Project Team of Flood Control and Drought Mitigation Center, MWR 2016). Jacked by the high water level in the main stream of the Yangtze River, the floodwater in most of the lakes could be hardly discharged. The water level remained too high in most lakes because of their weak pumping and discharging capacities, and dykes along the lakes were in danger and many polders along the lakes were overtopped and breached.
(2) Middle and small rivers were affected severely, especially the direct tributaries of the Yangtze River. The flood control standards of middle and small rivers are lower on the whole. Especially, the level-I tributaries carried the flood water from the level-II and III tributaries, and also jacked by high water level of the Yangtze River. The multiple factors caused some polder dykes to be overtopped and breached, with serious losses.
(3) The flooding was characterized by large affected areas, a large number of evacuated people and heavy losses. According to the statistics of the Office of Flood Control Headquarters of Anhui Province, since the beginning of the mould rain season, the heavy rainfall affected 11 cities and 73 counties and districts to varying extent, with affected population of 12.75 million, evacuated population of 1.175 million, and 16.744 million mu of affected crops, 50,800 collapsed houses and 72,000 damaged water resource facilities. Most of these losses were in the Yangtze River Basin (Figure 4; Government of Lintou Town 2016a, Office of Anhui Provincial Flood Control and Drought Relief Headquarters 2016).

Table 1. Comparison of flood damages in 2016 and 1999 (Office of Anhui Provincial Flood Control and Drought Relief Headquarters 2016).

	Dike dangerous situation		Breached polders		
Year	Total	Main dike	Above 1000 mu	Above 10,000 mu	Inundated area of cropland (thousand mu)
2016	1831	24	129	12	12,100
1999	8662	257	180	14	36,930

3. Problems and challenges

During the 2016 flood control and disaster relief actions, a series of effective measures were taken in Anhui Province in flood fighting, project scheduling, monitoring and early warning, emergency rescuing, relocating and post-disaster reconstruction, that reduced the negative impacts of the floods and maintained the stability of the society. In the meantime, many problems and challenges for flood security in the new circumstances were also exposed (Dangtu County Water Resources Bureau 2016, Flood Control and Drought Relief Headquarters of Zongyang County 2016, Flood Control Headquarters of Nanling County 2016, Water Resources Bureau of Susong County 2016, Water Resources Bureau of Xuanzhou District 2016, Government of Lintou Town 2016b).

3.1. Current flood control management cannot adapt with changes in economic and social development

After the big flood in 1998, the economic and social characteristics of Anhui Province experience significant changes, causing a relatively high impact on flood control situations.

(1) Since a large number of rural young adults become migrant workers in cities, leaving most elders, women and children at home, the labour force is severely inadequate for dyke patrol, inspection, risk elimination, rescue, evacuation and relief during the flood season, and flood prevention and control mainly depend on the soldiers and armed police, etc.
(2) With the new policy implemented for land circulation and transfer since 2005 in China, the lands under the intensive management of crops and animals in the polder areas have already been up to 40%~90%. When the flood broke the polder dyke, not only the crops of the season and cultured products suffered a big loss, but also the previously constructed infrastructures and equipment were massively damaged. Some intensive operators were no longer the victims in a traditional sense, but the debtors with millions Chinese yuan debt, thus greatly increasing the flood risk. As the protected objects and actual beneficiaries of flood control, they should bear more obligations for flood control and rescue, but that are often unaffordable for themselves with their limited capacity to take preventive and restorative actions.
(3) An integrated mechanism for market and planning has not been established effectively for flood management. Migrant workers still have properties in the polder, but actually, they can hardly return to undertake the statutory obligation for flood fighting and rescue. Since the protected big-specialized-households and migrant workers fail to pay or pay little, the flood control responsibility completely rests with the rural collectives, which does not comply with the marketing mechanism. It is necessary to explore an approach to integrate market and plan for the construction of flood fighting team, the storage and management of facility and equipment, etc. in order to ensure the well-organized flood control work.

(a) Draining after the breach was blocked in Wuqi Polder, Zongyang county.

(b) Breach of Yaobu Polder was blocked with shipped soil

(c) Houses under inundation at Dusheng Polder for over 2 months after the flooding.

(d) Xingfu Polder: a breach was closed by net for fishing in the polder.

Figure 4. Typical dyke breaches and coping with emergency.

3.2. Weak links in flood fighting have been revealed and flood control capacity needs to be enhanced urgently

(1) The governance and planning of middle and small rivers are lagged behind and the flood control standard of the polders along the lake is generally low. The weak reservoir consolidation, dyke construction, middle and small river rectification and other projects showed a significant effect in the flood control and disaster mitigation of 2016, but the governance system still needs to be improved (Changjiang Water Resources Commission of the Ministry of Water Resources 2003a, 2003b). The polders and dykes around Chaohu Lake, Nanqi Lake and some other lakes linking to the Yangtze River generally did not reach the standard of flood prevention. During the governance of dykes of the Yangtze River main stream, the dykes for part of the direct tributaries were not consolidated correspondingly according to the equivalent standard, and the attacked polders in 2016 were all around the middle and small rivers and lakes.

(2) The river and lake water areas were occupied somewhere and silted, and the run-through capacity of tributaries and storage capacity of inner lake decreased. After the flood in 1998, the policy of 'returning farmland to lake and migration for township' was once implemented, but to maintain the public production, livelihood and social stability, the original 'double-return' polders (i.e. both residents relocated and farmlands recovered to lake) were later changed to 'single-return' (i.e. residents relocated only) polders which became further 'no-return' polders. Meanwhile, such phenomenon is still observed that joint-polder construction and polder gate construction occupies the flood pathway and the lake storage capacity is reduced.

(3) The polders, cities and countries along rivers and lakes have inadequate drainage capacity. The logged-water discharge facilities of new city areas in some plain lake areas and developing areas are still built according to the previous rural logged-water discharge standard and thus the low areas in part of the city areas and towns are subject to being flooded.

(4) The active flood inflow mode is beneficial for the whole situation, but can hardly be implemented. For active flood inflow, the location, flow and time can all be controlled and the dyke damage is relatively reduced. It is beneficial to protect the key areas and objects, beneficial for the orderly evacuation of the people in the polder, beneficial for the optimal allocation of flood control resources, and also beneficial to reduce the cost of flood control and rescue and subsequent blocking and restoration for the sake of after-disaster prompt production and minimizing the overall losses, but its implementation is quite difficult. Some 'single-return' polders after the 1998 flood were facilitated with inflow gates, which could be hardly enabled, and some even failed to be opened when the dyke breached.

(5) During the flood control, the responsibility was unclear for county, town and village, and the public obligation could hardly be fulfilled. The flood emergency response plan requires to define the relevant duties corresponding to the three water levels of 'safety, defence and warning',

but the 'three levels' defined previously already failed to reflect the real situation and needed to be adjusted. Responsibility was allocated to persons for the officials of counties (cities and districts) at all levels who will be assigned to work basically at the relevant towns. During the flood control, the responsibilities were not clearly classified for counties, towns and villages. The flood emergency response plan has not included the principle for the choice of protecting or abandoning. Facing with the dyke in danger, if it is protected, the water level will be even higher, and if the protection fails, the loss will be even bigger. However, if abandoning and taking in flood fighting actively, it will result in a series of problems for compensation and responsibility.

(6) Management and maintenance is rather weak for part of the basic-level water resources facilities. Water conservancy projects depend '30% on construction and 70% on maintenance'. After the obligation is cancelled for farmers to work for water conservancy projects, many of the basic-level water resources facilities is lack of regular maintenance and the dykes, culverts, gates and reservoir works are seriously aged and lack of maintenance. For some dykes, the top elevation is up to the standard, but the cross-section is inadequate. In many counties (cities and districts), the standard for flood control roads is low. In case of flood, these roads will become muddy, and big-size machinery and equipment cannot timely reach the place in danger.

3.3. Relatively centralized and prominent problems with policies and regulations on fund management, compensation, insurance and planning

(1) The project-type fund management mode cannot meet the actual demands for local flood control and disaster mitigation. The river channels, reservoirs, gates, pump stations, monitoring and warning system, etc. in the flood control system involve different phases and modes of construction, reconstruction, promotion and replacement and operation and maintenance, and the strength and weakness of different counties (cities and districts) are also much different, but since the fund management requires that the specific fund is used for specific purpose, the counties (cities and districts) cannot use the central subsidy fund according to their actual conditions and apply the limited funds for the weak and urgent points of the local flood control and disaster mitigation.

(2) The compensation and insurance mechanism constrains and affects the actual work of flood control and disaster mitigation at local government and community. It is a common sense to 'lose in big flood and harvest in small flood' for polder areas, but it is hard to implement in reality. As Xuanzhou District reflected, if the cultivated land is inundated once in 5~10 years, the loss will not be large, but the difficulty is to balance the interests and no compensation policy is available to support. Therefore, Shuiyang River and Qingyi River cannot arrange for flood storage (Changjiang Water Resources Commission of the Ministry of Water Resources 2003b, 2011). As Nanling County reflected, for the flood storage area, the assurance measures are required, and comprehensive policies should be available to integrate such engineering assurance measures such as returning farmland to water, fallow land and rural countryside development, so that the flood can have pathway to drainage. As Huining County reflected, it is not feasible for the big polders to actively draw off flood as it is a big pressure to transfer more than 10,000 people; as for the small polders with less residents, the measure of active in-take can be taken into account, but the precondition is that the rational compensation policy should be available.

(3) The governance of middle and small rivers lacks of systematic planning. The present governance of middle and small rivers is mainly to raise the flood control standard for key river reaches. It is urgent to change the sectional governance of key protection to the general planning and phased governance. In terms of the participation of stakeholders, the width and depth for the participation of different relevant departments needs to be increased. For instance, many of the projects such as new rural construction, land management, migration for town, compensation for additional cultivated land, increase–decrease linkage, and homestead withdrawal can be integrated with the flood control and disaster mitigation.

4. Coping strategies and discussions

4.1. Pay high attentions to post-disaster reconstruction and actively advance the comprehensive water governance mode of human-water harmony

In post-disaster water conservancy construction, more attentions should be paid to the human-water harmony, not only promoting the capacity for controlling flood and drainage, but also promoting the capacity for rain and flood regulation and storage to avoid the vicious circle of higher dyke and higher water level (Dan 2007, Han, Mark and Ernst 2016). It is recommended to take 'set the overflow weir along the dyke for naturally overtopping flood' as the governance mode of promoting the human-water harmony. The weir top elevation is the condition for natural flood in-take, avoiding the contradiction of difficult decision-making and high risk for manual gate-opening flood diversion and; the weir top overflow maintains the flood discharge capacity of river reach and "empty-stomach" flood storage can weaken the flood peak; the water in-take process of polder increases slow and damage is limited for the sake of organizing safe evacuation; polder in-take water is limited, without the necessity of blocking before restoration, drainage can be carried out according to the actual conditions when the river water level falls below the safety level and the time of inundation is greatly shortened, which facilitates early restoration of production and home reconstruction.

Based on the survey's results, the recommended protection measures include: (1) rationally determine the location of weir crest and the weir top elevation and width based on science and technology; (2) ensure the dyke safety, without breaching though overtopping by engineering means combined with surface energy dissipation and allocation of water withdrawal facilities and surface measures to minimize the range and time of inundation; (3) compensate and guide with economic measures; the central government will only

select the polders taking such active flood in-take mode and sharing the flood risk as the key cases, and establish the example and grant the prior support of funds for reconstruction; (4) advance the implementation by administrative means and draft the supporting policy measures, achieve the inter-departmental coordination and interaction, change 'one-way push' to 'two-way control': i.e. 'gaining more' should be linked with more obligations so that it will be beneficial to achieve the healthy interaction and appropriate control (Changjiang Water Resources Commission of the Ministry of Water Resources 2009).

4.2. Take the approach of systematic governance for middle and small rivers and change 'passive governance' to 'positive governance'

In 2016 Anhui Province, the middle and small rivers were mainly observed with extraordinary floods and even floods exceeding the historical record of the water level. All the counties (cities and districts) generally expressed the will of changing the 'key river reach governance' to 'general planning and phased governance' for middle and small rivers and required to break through the limit for the total investment of 30 million RMB and promote the overall flood control and disaster mitigation capacity and comprehensive governance level of rivers.

According to the principle of river management by relevant administrative levels, the governance of middle and small rivers should be the duty of the local governments. However, after the central finance increased the investment on the governance of middle and small rivers, some local governments regarded it as the duty of the central government to govern local rivers. In China, there are a large number of middle and small rivers on a large scale. Different rivers have different flood features and different countermeasure for water governance. For the same river, at different stages of economic and social development, the demand, target and investment capacity of water governance will also change significantly. Only by implementing the principle of river management by relevant administrative levels, will it be possible for the administration of middle and small rivers to suit the measures to local conditions, meet the diversified demands and possible to proceed in an orderly way, and achieve gradually the goal of comprehensive governance. Since middle and small rivers are rivers under their jurisdiction, the local water administrative departments are most familiar with the conditions of these rivers and most responsible to generally plan the governance demand of different parties, and propose the feasible overall planning and implementation programme. As for the governance of middle and small rivers, only when the local governments play their respective role in 'positive governance' rather than 'passive governance' it will be possible to plan generally, implement step by step, focus on the key points, act according to the local conditions, raise funds from different sources and form a joint force. The attention and investment of the central government plays a supporting, encouraging and guiding role only (Xiaotao 2016).

4.3. Strengthen the basic research

(1) Study on the amendment of the Flood Control Law of the People's Republic of China. The key points are to: (1) introduce the risk management mechanism. Under the changing environment, the uncertainty of flood characteristics increases and the flood control decision risk increases. Only when the Flood Control Law includes the mechanism of risk management will it be beneficial for advancing the change from flood control to flood management; (2) implement the general-planning mechanism with multiple plans integrated into one. Currently, under the demand of comprehensive water governance, it is urgent to integrate many plans with one single target. Only by improving the regulatory system will it be possible to better obtain the comprehensive benefit; (3) identify the operation mechanism of 'government leading, departmental interaction, local management and social participation' under the new situation.

(2) Establish the rational compensation mechanism and measures for the regions of active flood inflow. As for the polders around the middle and small rivers and lakes, only by improving the relevant staged compensation mechanism and measures will it be possible to ensure the practical implementation of the active flood in-take mode of human-water harmony.

(3) Introduce and establish the management mechanism of social/national flood insurance in the flood risk areas. At present, the policy-oriented agricultural insurance is already established for the polder agriculture, but as for the operational mode of big-specialized-households after the land circulation, especially large-scale households of aquaculture, livestock and poultry, it is necessary to discuss further on how to promote the rational adjustment of industrial structure in compliance with the flood risk by introducing the insurance mechanism.

(4) Improve the management system and operation mechanism. For flood control, China plans in general by basins or regions, implements by levels, and combines the basin management and administration region management. The middle and small rivers often cross multiple administrative regions and lack of the management system and operation mechanism for general planning of the basin. It is also an urgent project on how to integrate the planned system of general planning with the market mechanism of acting according to the ability, including mainly: the implementation mechanism for the comprehensive coordination of flood control planning and proceeding in an orderly way; adequate participation mechanism for stakeholders; operation mechanism integrating the project-type management and demand-type management for construction funds; sustainable management and maintenance mechanism for different flood control facilities; management and operation mechanism for different departments from planning and project implementation; socialized management and operation mechanism for flood control material reserve, rescue team building and other emergency response.

(5) Strengthen capacity building for the local government and community. The flood control institutions of the local government and community have a heavy task, with wake capacity, and lack of awareness for risk management with regional difference. These phenomenon needs to be changed. For the purpose of strengthening the capacity building, in addition to increasing the financial and technical input and promoting the 'hard power'

of the flood control engineering system, it is a major project worth of deep discussion on how to enhance the 'soft power' of governments and water resources department at different levels in undertaking the comprehensive management of flood risk. It is important to strengthen the safety monitoring and warning capacity of dykes, culverts, gates and pump stations, especially enhance the automatic and remote monitoring capacity for the purpose of reducing the pressure of inadequate labour force for flood control and hazard inspection.

(6) Establish the human-water harmonious water governance mode in compliance with development stage. Currently, China is still at the stage of medium-rapid development, with 10%~20% points away from a balance state for urbanization. It is the basic precondition for human-water harmony to establish an environment-friendly flood control engineering system with appropriate standard, rational arrangement and wise application. For this purpose, it is necessary to carry out the deep research on: how to effectively advance the policy to give a pathway for flood by making comprehensive use of law, administration, economy, science and technology, and education; how to integrate the actions of relevant departments to steadily advance the move of residents from the high-risk area by taking advantage of the opportunity of changing the development mode to intensive operation so that the residential places will be away from flood; how to ensure the social stability and rapid restoration of production and livelihood in the polder by establishing the system of risk-sharing and rational compensation for the polder undertaking active flood in-take and playing an actual role in rainfall-flood regulation and storage.

5. Conclusions

The 2016 big flood on both sides of the Yangtze River in Anhui province reflected not only the impacts of extreme heave rainfall events in context of global warming that the maximum 3 and 7 d rainfall reached or exceeded the highest records in the past, but also the changes of flood hazard mechanism and the components of flood damages along with the unprecedented process of urbanization in the past two decades.

(1) The sustained investment on enhancing main dikes and dams after the 1998 big floods played an important role in fighting against the 2016 flood. The dangerous cases along the main dike of the Yangtze River reduced to less than 10% comparing with the case of the similar big flood in 1999, and there were no dam failure occurred during the 2016 flood in Anhui, that reduced the inundated farmland to about 1/3 of 1999. In the meantime of further reinforcing and maintaining flood control systems for large rivers, we should pay more attention to comprehensive improvement of small- and medium-sized rivers in the future.

(2) The dike breach cases in polder areas were significantly related to the difference of local economic growth level. Among the eight counties, Dangtu with the highest GDP per capita exceeded $8000, while Zongyang with the lowest GDP per capita was less than $3000, since a large number of young people go out as migrant workers, there are an incremental labour shortage in rural areas especially in routine maintenance of dikes and during flood fighting in polder areas. For the richer counties like Dangtu, some professional teams are set up for dike maintenance and they can get subsidy from the local governments at town and county levels. However, for the poorer counties like Zongyang, some dikes disrepair for years. That's why most of the dike breaches occurred in the polder areas in the poorer counties. How to break the cycle of the poorer the more flooded, and then, even poorer, must be a problem worth exploring deeply.

(3) The transformation of rural land use mode from farming by individual households to intensive operation requires a stronger and more effective flood control and security system. In the polder areas of the eight counties surveyed, land transfer to intensive operation has reached 40%–90%. Once the intensive operators suffered severe flooding, they are not only victims but also descend to debtors, who are hard to pull through the crisis by the traditional relief mode. Flood insurance patterns should be studied and introduced as one of the means to regulate the intensive operation structure, enhancing the risk tolerance capacity of the intensive operators and avoiding some too vulnerable assets concentrated to the areas with higher flood risk.

(4) It is necessary to seek harmony mode between human and flood based on the basic national conditions. Despite a series of measures taken by the Chinese government after the 1998 floods to promote harmony between human and floodwaters, whether 'double-return' or 'single-return' could not played the role of storing flood actively. Because of the large number of population and scarce land resources, we have to use more land with flood risk and return some lands temporarily for storing floodwater in case of extreme floods. 'Set the overflow weir along the dyke for naturally overtopping flood' is recommended as a governance mode to promote human-floodwater harmony. Such mode can reduce the huge pressure of flood fighting, avoid the devastating disasters of dike breach and speed up the recovery activities. Implementation of such mode needs integrated measures of legislation, administration, education, economic compensation and technical support.

(5) Institutional mechanism innovation and capacity building must be placed high importance on the development of flood management system. Faced with the increasing complex flood control situation and improving security requirements in the rapid development phase, we can neither blindly follow the traditional successful experience nor simply copy the advanced practices of other countries. For instance, the planning and construction of flood control system by taking watershed as unit has yet to be established for small- and medium-sized rivers across multiple administrative areas, and taking flood insurance as a means of flood risk sharing and management in the areas protected by dikes needs more attention and urgent research work. Enhancing flood risk management and emergency response capacities for small and medium cities and towns as well as polder areas have still a long way to go.

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