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Guangwei Huang
Zhenjiang Shen *Editors*

Urban Planning and Water-related Disaster Management

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Preface

Urbanization has been accelerating worldwide in recent decades. Today, more than half of the world's population lives in urban areas. The continuing trend of urbanization and population growth is projected to add 2.5 billion people to the urban population by 2050, making the proportion of the world's population residing in urban areas reach 66%. Besides, nearly 90% of the increase will take place in Asia and Africa. Nevertheless, the question "urbanization for what?" has been insufficiently addressed and inadequately explored. As a result, rapid and unplanned urban growth threatens sustainable development when the necessary infrastructure is not developed or when policies are not implemented to ensure that environment conservation is given top priority. A typical example is flood disaster, which has shifted from a rural phenomenon to a predominantly urban suffering. It has been well documented that urbanization increases peak flow and shortens its arrival time. So, it is ironic that city dwellers live with higher flood risk due to urban development which is supposed to bring better life to them. In addition to elevating flood risk, urbanization also impacts the health of aquatic ecosystems in many different ways.

To overcome various urbanization-induced problems and connect the urbanization process to the three pillars of sustainable development – economic development, social development, and environmental protection – new ways of thinking and new approaches are indispensible. Spatial planning is one of the promising methods, which can be employed by the public and private sectors to influence the distribution of people and activities in spaces of various scales with various considerations on environment protection, the safety of residents, and the conservation of cultural diversity as well.

This book is one in a series of books focusing on the relationship between spatial planning and sustainable development. It brings together expertises on various aspects of urban water management from different regions. It is aimed at promoting more in-depth dialogues between water researchers and urban planners and serving as a catalyst for innovative research in the arena of sustainable urban water management.

Tokyo, Japan Guangwei Huang

Contents

Chapter 1
Overview of Urban Planning and Water-Related Disaster Management

Guangwei Huang, Zhenjiang Shen, and Rifai Mardin

Abstract The most important message delivered by this book is that water management is multifaceted and the approaches to deal with water-related issues are diverse so that wise water governance including the incorporation of wise water management into urban planning should be pursued in order to achieve an integrated solution for sustainability. The emphasis of the discussions in this book, includes (1) disaster and urbanization; (2) monitoring and simulation of water-related disaster; (3) integrating urban planning and water-related disaster management using shared indicators. In planning process, it is helpful to employ shared indicators for cooperative design in order to integrate the requirements from both planning site and disaster management site.

Keywords Integration · Monitoring · Shared indicators · Cooperative design · Flood disaster

1.1 Introduction

Disasters affecting human society often classified into two main categories: (1) nature-caused disasters such as earthquakes and volcanic eruptions; (2) human-induced disasters such as water and air pollution. In this book, water-related disaster as one the highest threat to human society will be discussed from the views of nature-caused and human-induced disasters due to urbanization, which consist of floods, wave and surges (tsunami), slides, drought, epidemics and extreme storms or windstorm. We mainly focus on the flood hazards, the most anticipated disaster from the group of water-related disasters.

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Flood disaster become one of the prime disaster threat, especially in urban area. Population growth and urbanization are the two primary drivers of the increasing of flood risk in urbanized countries. As many Asian cities have been increasingly urbanized, the changes in land-use associated with urban development have affected surface water runoff and rivers flood regimes in many ways. Thereby, flood disaster is natural disaster while increasing due to rapid urbanization. Having highest tension by providing a better urban arrangement to minimize the water-related disaster, the urban planning is required to contribute to flood mitigation (Howe and White 2004; White and Richards 2007). The reason is that urban planning can influence the incidence of flooding and its consequential damage through regulating the activity locations, types of land-use, scales of development, and designs of physical structures (Neuvel and Van Der Knaap 2010; White and Richards 2007). However, the practical obstacles are impeding the integration of urban planning with disaster risk management due to the diverse causes. Therefore, the attempt of the authors in this book is to integrate water management and urban planning in order to decrease the happening of water-related disasters.

1.1.1 Flood Disasters

Human beings have been dealing with both floods and flooding for millennia. In ancient times, flooding was mainly a natural hazard in the sense that humans could not interfere in river dynamism. Despite the negative impacts of flooding, agriculture in ancient times largely depended upon flooding since floods deposited nutrients and made soils more fertile, this makes humans chosen to live close to waterways defying the danger for convenience. According to historical records, there were 1.092 great floods disasters counted from 206 BC to 1949 in China, equating to one every 2 years on average over the 2155-year period, and the Yellow River breached 1593 times during the period from 602 BC to 1938 AD (Huang 2014).

As previously mentioned, there are several types of water-related disasters, which are flood, wave and surges (including Tsunami), slides, drought, epidemics and extreme storms or windstorm (Yoganath Adikari and Yoshitani 2009; Asian Development Bank 2015). These disasters are water-related disaster that threaten people or economic goods. The impact of the water-related disaster is profound, since in top 10 countries with highest disasters events throughout 2016, the 69 disasters (or more than 47%) among the recorded 146 disaster cases were caused by hydrological or water-related disaster alone (Guha-sapir et al. 2017). Referring to world data of human impact by disaster type from 2005 to 2015, the number of death and casualties are 99,197, and 271,822,414. In total, 271,921,611 peoples were affected (UNISDR 2016). Based on this data, the majority of casualties came from flood disaster is 41.43% and followed by drought 31.62% and earthquake and Tsunami (5.74%). The data is parallel with the number of disasters occurrences.

Among the total 713 cases, flood disasters contribute 324 times (45.3%), followed by drought 47 times (6.59% and earthquake and Tsunami 44 times (6.17%). Over the last 30 years, flooding has killed more than 500,000 people globally, and the displaced population was up to around 650 million and caused damage more than $500 billion (Brakenridge 2016).

Recently, most of the newspapers and TV news widely reported flood disasters from the world. In 2000, flooding in Nagoya City, Japan paralyzed metropolitan functions with the associated economic loss reaching 70 billion yen (US $7 billion). In June 2001, floods from Tropical Storm Allison killed over 30 people in the Houston, Texas. In 2002, a series of flash floods occurred in Glasgow, Scotland, causing severe damage with around 140,000 people affected. The number of Chinese cities affected by floods has more than doubled since 2008. The 2009 flooding in Manila due to the Tropical Storm Ketsana inundated more than 80% of the city. In April 2010, Rio de Janeiro, Brazil experienced its worst-ever flood, with over 250 people killed. In 2016, flash flooding caused the main street of Ellicott City, Maryland to be paralyzed for more than 2 months as commerce and residents cleaned up from the flooding and began repairing damaged buildings and sidewalks. These maters represent only a small proportion of the flood disasters that have occurred in urban areas but provide a stark demonstration that flooding, once a classical rural phenomenon, has become a predominantly urban concern.

1.1.2 Increased Risk of Flooding in Urban Areas

Flood risk management and river ecosystem conservation have not been traditionally considered as components of the urban planning process. This fact is due in large part to the division of academic fields. Those who deal with flooding and water quality are trained in river engineering, hydrology, geology, chemistry or geophysics, whereas the urban planners are most likely trained in architecture, traditional landscape, road engineering or social science. The missing or insufficient link to water management can be considered a fundamental flaw in the system of urban planning to date.

It is also increasingly clear that the structural measures put in place to manage drainage in cities are not always an optimum solution. The core problem, as summarized in a World Bank report (Jha et al. 2012), is that poorly designed and managed urbanization contributes to the growing flood risk due to unsuitable land-use change. As cities and towns expand and grow outwards to accommodate population growth, large-scale urban expansion often comes in the pattern of unplanned development in coastal and inland floodplains, as good as in other flood-prone regions. Therefore, the need for a close working relationship between the urban planner and the hydrologist is increasingly recognized. Despite this recognition, many cities are still expanding without sufficient consideration of flood risk. The difficulty in translating the concept of flood risk management into practice may be at least partially attributable to the lack of, or non-practicing of, appropriate planning approaches that take the flood issue into account. Increasing indication suggests that the 100-year floodplain is neither accurate nor sufficient in leading communities and family decisions to mitigate the adverse impacts of rising tides. The unfitness of the floodplain designation to efficiently capture the likelihood of loss of property, and possibly human lives, have left potentially millions of property owners unaware of their flood risk and made it more problematic for local communities to be better organized for potential flood disasters.

We can check statistic data related to urbanization and rivers in those city areas. Shenzhen, today a major city in China, was a market town of 30,000 people before 1980. In the past four decades, the Shenzhen region experienced a rapid urbanization process and the population reached more than 10 million, probably the fastest growing city in the world. A consequence is that the length of rivers in the region shortened by 355.4 km, accounting for 17% of their 1980 length, and river density changed from 0.84 to 0.65 km/km^2 (UPLRC Shenzhen 2018). Such changes are also seen around the world, many waterways have either disappeared or been transformed into ditches during the last century due to urban development.

We are solicitous about flood disasters that could be another consequence of urban development. For example, in many urban areas, stream-bank erosion represents an ongoing threat to infrastructure such as roads, bridges that are difficult to control even by normalization or to harden the stream banks. Dams are often constructed for flood regulation, which may lead to a considerable decrease in flood discharge and its probability proportional to the sizes of dams. However, dams are often the cause of irrational development of floodplains because they reduce the inundated areas of small and medium magnitude floods which make the land available for development and give residents the false perception of safety. Besides, dams may reduce beach width around the river mouth by disrupting sediment transport from the upstream, which may increase the vulnerability to coastal flooding in downstream areas.

How the process and pattern of urban sprawl affect the formation of urban flood risk is a question worth exploring. The amount of urban land has more than doubled in the process of urbanization, almost all of which covered with concrete and asphalt. To overcome the flood risk which always threatens the community, the urban planner needs to think of an integrative form of city planning that can minimize the danger of flooding. As a new, broad, collaborative and integrative planning methodology, urban planning provides more opportunities to decrease disaster from the beginning of planning process of urbanization. It goes beyond traditional land-use planning to integrate policies for the development and land-use with other policies and activities which impact the nature of places and how they function and influence the future distribution of activities in space.

All chapters in this book are organized as three parts in order to present our contribution regarding the concept of integration of urban planning site and disaster management site for disaster mitigation and better human settlement.

1.2 Part I: Water-Related Disaster and Urbanization

1.2.1 Flood Disaster and Human History

In ancient time, humans had chosen to live close to waterways for convenience and benefited from the waterways. They defied the danger but dared not to think about imposing reins on rivers. Instead, they prayed for the mercy of nature, and this is an adapted process which became a culture. Culture, as the characteristics and knowledge of a particular group of people defined by everything from language, lifestyle, religion and social habits, can be viewed as urban assets and a growing trend of refurbishing and re-branding properties at worldwide level. Related to how the cites changing their way on adapting the impact of water, Chap. 2 of this book, authored by Yan provides a review on the relationship between floods and culture through some cases in Egypt, China, Italy, and Thailand. It stresses that appropriate water management may produce long-lasting positive effects which can be labeled as water culture. It is intended to deliver the message that we need to take water culture into urban planning. The chapter carried initial thinking about why we need integrated planning from an integrated perspective of urban planning, water-related hazard risk, hydrologic cycle and urban social culture.

1.2.2 Flood Disaster and Urbanization

Disaster Management is a planned process undertaken to minimize disaster impact. It is linked to sustainable development, especially concerning people and economy. In light of the shift of flood hazard in urban area from being nature-caused to largely human-induced, we must address two fundamental questions about water environment degradation related to urbanization and population growth. Firstly, why we have failed in avoiding the negative impacts of urbanization and population growth on river systems and watershed characteristics, and secondly, what we must do to achieve sustainable watershed development. Those issues can be approached in a multifold way that includes urban policy, institutional and planning involved in the process of urbanization.

Chapter 3, authored by Liu, et al., presents historical records of the extreme storm flood events in Beijing. The chapter analyzes the characteristics and causes of storm-induced flooding in Beijing and outlines the overall pluvial flooding management plan including an integrated emergency response system and new initiatives such as sponger city development, strengthening flood warning system and increasing the public awareness of urban flooding. In Chap. 4, authored by Huang, explains the hydrologic cycle and how it may be affected by urbanization. It points out the need to consider the impact of road network on urban flood risk in urban planning and advocates the incorporation of flood damage estimation into urban planning, which is a new concept. By conducting disaster damage estimation in the planning stage, a city can be better prepared for potential losses and post-disaster recovery.

1.3 Part II: Monitoring and Simulation of Water-Related Disaster

To gain a better understanding of flood disaster, planners in the planning process require monitoring data. Appropriate data can help identify flood risk areas and help the plan to reduce the impact of flood disasters. Water-related disaster management depends on monitoring data and hydrological simulations to a large extent. A key to the accuracy of a hydrological simulation is the accurate representation of the spatial and temporal variation patterns, intensity, and duration of precipitation. However, it is hard to obtain reliable and appropriate precipitation data for hydrological modeling. Nowadays, with the advanced of technology, the study of flood disaster models expected to carry out more accurately.

In Chap. 5, authored by Li et al., provides an evaluation of the latest satellite-based precipitation products for the Lower Mekong River basin with a distributed hydrological model. Such an assessment is essential for hydrological modeling works to be conducted in ungagged river basins. The quality of integrated urban planning can only be guaranteed with accurate and detailed simulation results in many cases. Chapter 6 authored by Binaya Kumar Mishra et al., evaluates the impact of climate change on extreme rainfall intensities under different greenhouse gases emission considering a future period. The results can assist the water manager and urban planner to design the sustainable and robust water infrastructure.

The two chapters above show how an advanced technology data acquisition and delivering it to models can generate detailed and reliable results. The monitoring data and simulation are essential to be used as thinking base in urban planning disaster mitigation.

1.4 Part III: Integrating Urban Planning with Water-Related Disaster Management

An important but less discussed work for disaster management is to integrate urban planning and disaster management at the beginning of planning process. The indicators and parameters employed for both urban planning and disaster management have not been investigated carefully till now. For example, evacuation road and shelters discussed in both planning field and disaster prevention filed. However, the shared indicators which can be used as planning criteria for preventing human-induced disaster in the planning process have not investigated. As a result, experts in the field of disaster prevention are always to start their work after urban planning, they have to start their work after urban development in most of cases.

In a word, to set up a social system that can integrate both planning and disaster management organizations are essential. For this, researchers on planning institution are necessary. Meanwhile, how to unitize the indicators integrating both fields is necessary too so that solutions for disaster management can be found at the beginning of planning process.

1.4.1 Water-Related Disaster and Institution Issues

It is worth mentioning that the effects of planning institution on disaster management are most pronounced for establishing safe society to follow disaster prevention guidelines issued by local municipalities. For preventing city and population damage from water-related disasters, social organization and planning institution for disaster prevention becomes important condition for integrating planning work with disaster management in local communities. In the process of urbanization, the construction of evacuation facilities often lags behind the development of residential areas with urban severe vulnerability occurring. Till now, the effects of urbanization and population growth on flood risk and waterway health have been studied separately. The integration of the two types of studies should be pursued, which may lead to innovation in disaster management.

The world has learned from bitter experience in Indonesian Tsunami in 2004 and Japan Tsunami in 2011. The number of casualties and losses are significant and thus local municipalities realized the need of mature city planning for evacuation process, community involvement (Community Participation Planning) in order to improve the public awareness. Chapter 7, authored by Yamato et al., is focused on the plan formulation for Tsunami evacuation in some Japanese coastal cities, which is intended to classify planning-making methods in different municipalities. Based on the questionnaire survey results, planning-making methods in surveyed cities are classified into three categories, among which the planning-making method of public participation is highly evaluated by officers in local municipalities.

1.4.2 Integrated Indicators of Planning and Disaster Management

There are some studies on indicators that are important to integrate urbanization aspect with disaster management aspect. For example, Wang et al. (2016) investigated the backwater effect of eight bridges along the Huaihe River in China. It found that, in order to eliminate the cumulative effect of two bridges, the minimum distance between two bridges should be larger than 215 times of the bridge pier width. Furthermore, increased delivery of sediment into the channel network is a common consequence of urban development (Douglas 1985). Sediment and debris carried by floodwaters can further constrict a channel and increase flooding. Thus if those issues could be discussed in the urban planning process, flood mitigation would be possible. In addition, indicators reflecting water chemistry can be employed to investigate function changing of waterways because of population growth (Porcella and Sorenson 1980). It can in turn further connect to changes in the biological communities of aquatic ecosystems (Morse et al. 2003; Chadwick et al. 2006; Voelz et al. 2005; Walsh et al. 2005).

In this book, Mardin and Shen proposed a methodology about how to integrate urban planning with flood disaster mitigation in planning process. In Chap. 8, the authors explain their work on integrated criteria of flood disaster mitigation and housing-settlement suitability in urban planning according to the Indonesian planning regulations and present a case study in Palu City, Indonesian. It identifies suitable and unsuitable areas in the city by dangerous degree of flood disaster. It provides a good example of considering flood disaster in the process of urban planning.

1.4.3 Cooperative Design for Sponge City

Integrating urban planning and water management is a land-based engineering concept and an engineering approach that integrates urban water cycles, including rainwater, groundwater and wastewater and clean water management, into planning and management works, it intends to minimize environmental damage and enhance the use of the water. Sponge cities focus on imitating the water system that existed pre-evolution through the utilization of micro-controls distributed throughout a developed site. Rainwater can also be harvested in reservoirs for landscape irrigation and other beneficial purposes. Thereby it creates an urban environment that absorbs water then releases it when required, in a similar manner to a sponge. A sponge city pilot program, the Ministry of Water Resources was launched in China at the end of 2014. The overall objective of this program is that 70% of rainwater will be absorbed and reused. This goal should be met by 20% of urban areas in China by the year 2020, and by 80% of urban areas by the year 2030 (The General Office of the State Council 2015).

In the level of implementation, to use the excess rainwater, the urban planners can promote a rainwater harvesting through all suitable buildings. The rainwater harvesting is the accumulation and deposition of rainwater for reuse on-site, rather than allowing it to run off. It is considered as a solution for both drought and flood management. Chapter 11, authored by Lin et al., proposes a cooperative design method aimed at improving the cooperation of urban planners and rainwater harvesting designers for a more efficient implementation of this solution. It employs numerical simulation to assess the performance of rainwater harvest system under various combinations of cooperative design parameters. It is an example of linking water resources management with urban architecture.

1.5 Conclusion

Learn from different regions of Asia with a different orientation, which spans from medium size city, Palu in Indonesia to mega-city such as Beijing in China. The most important message delivered by this book is that water-related disaster management is multifaceted and the approaches to deal with water-related issues are diverse so that wise water governance including the incorporation of wise water management into urban planning should be pursued to achieve an integrated solution for sustainability.

The emphasis of the discussion in this book, includes (1) water-related disaster and urbanization; (2) monitoring and simulation of water-related disaster; (3) integrating urban planning and water-related disaster management using shared indicators. At the beginning of planning process, it is helpful to employ shared urban planning indicators and building design parameters for cooperative design between both planning site and disaster management site. In the urban planning process, urban plan get much help from technological advances with spatial database, and water management should have a detailed modeling process. Thus, the integration of urban planning and water-related disaster management should be assessed by considering the measurable parameters and criteria shared by both sides. The integration of the two types of studies should be pursued, which may lead to innovation in urban planning and disaster management for disaster mitigation and better human settlement.

References

Asian Development Bank (2015) Water-related disasters and disaster risk management in the People's Republic of China. www.adb.org

Brakenridge GR (2016) Global active archive of large flood events. Dartmouth Flood Observatory, University of Colorado. http://floodobservatory.colorado.edu

Chadwick MA, Dobberfuhl DR, Benke AC, Huryn AD, Suberkropp K, Thiele JE (2006) Urbanization affects stream ecosystem function by altering hydrology, chemistry, and biotic richness. Ecol Appl 16(5):1796–1807

Douglas I (1985) Urban sedimentology. Prog Phys Geogr 9:255–280

Guha-sapir D, Hoyois P, Wallemacq P, Below R (2017) Annual disaster statistical review 2016: the numbers and trends. Centre for Research on the Epidemiology of Disasters (CRED)/Institute of Health and Society (IRSS)/Université catholique de Louvain – Brussels, Belgium, Brussels. https://doi.org/10.1093/rof/rfs003

Howe J, White I (2004) Like a fish out of water: the relationship between planning and flood risk management in the UK. Plan Pract Res 19(4):415–425

Huang GW (2014) A comparative study on flood management in China and Japan. Water 6(9):2821–2829

Jha A, Bloch R, Lamond J (2012) Cities and flooding: a guide to integrated urban flood risk management for the 21st century. GFDRR/World Bank, Washington, DC

Morse CC, Huryn AD, Cronan C (2003) Impervious surface area as a predictor of the effects of urbanization on stream insect communities in Maine USA. Environ Monit Assess 89:95–127

Neuvel JMM, Van Der Knaap W (2010) A spatila planning perspective for measures concerning flood risk management. Int J Wat Resour Dev 26(2):281–296

Porcella DB, Sorenson DL (1980) Characteristics of nonpoint source urban runoff and its effect on stream ecosystems. EPA 600-3-80-032

The General Office of the State Council (2015) Guiding opinions on advancing the construction of sponge cities

UNISDR (2016) 2015 disasters in numbers. http://www.emdat.be

UPLRC (Urban Planning and Land Resource Commission) Shenzhen (2018) http://www.szpl.gov.cn/xxgk/sjfb/tjsj/

Voelz NJ, Zuellig RE, Shieh SH, Ward JV (2005) The effects of urban areas on benthic macro invertebrates in two Colorado Plains Rivers. Environ Monit Assess 101:175–202

Walsh CJ, Fletcher TD, Ladson AR (2005) Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. J N Am Benthol Soc 24:690–705

Wang H, Tang H, Xu X, Xiao J, Liang D (2016) Backwater effect of multiple bridges along Huaihe River, China. In: Proceedings of the institution of civil engineers – water management. pp 1–12

White I, Richards J (2007) Planning policy and flood risk: the translation of national guidance into local policy. Plan Pract Res 22(4):513–534

Yoganath A, Junichi Y (2009) Global trends in water-related disasters: an insight for policymakers. The United Nations Educational, Scientific and Cultural Organization, Paris

Part I
Water-Related Disaster and Urbanization

Chapter 2
Floods and Culture

Fei Yan

Abstract This chapter aims at exploring the substantial impacts that floods could have on the society in different regions around the world from a cultural perspective. By looking at the historical and ongoing flood control efforts of human society, interesting findings could be obtained on the positive contributions to the formation of cultural prosperities in the selected countries in their fight against the floods.

The case studies chosen in these countries all have high frequency of floods occurrences either in the past or in present times. And the studies show that the cultural benefits may not manifest in a short time span, but in the long run in most of the cases, cultural values and assets in many dimensions have been gained through experiences of control and co-existing with floods, such as the creation of the distinctive social sprit and commercial prosperity in the regions in China, the considerable contributions to the ancient civilization in Egypt, the influences on the rethinking of the Buddhism doctrines towards nature and the promotion of eco-concept in the regions in Thailand, however, our modern world is still facing some kind of failures of preserving cultures related to floods like in the case of Italy.

This chapter points out the importance to carry out more researches and studies on the interactions between floods and culture, so as to help to find more insightful and sound solutions for floods management in the future.

Keywords Floods and culture · Interlink · Social prosperity · Ancient civilization · Buddhism · Social spirit · Cultural price · Ecotourism

When reviewing the records of floods in human history, floods were basically regarded as natural disasters, and the recognitions of floods in stories written by our ancestors were always about fears, painfulness and vulnerabilities of human beings against the floods.

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Ever since we realized the constant and destructive characteristics of floods, in order to reduce the life losses and damages to the living environment caused by natural disasters like floods, eventually we started to actively fight against floods and search for control solutions.

To our ancestors, usually floods were considered to be unavoidable and unbearable. However, our wisdoms, which have been inspired by the nature through centuries, make us to believe that floods as one of the natural phenomena should not only be deemed as evils. The goods of floods were also well recognized and appreciated by living with floods not just fighting against them in some of the human's history of civilization.

This chapter will explore and look at cases from different countries around the world: Egypt, China, Italy and Thailand. For the people living in flood frequent regions of these countries, they have been continuously experiencing and co-existing with floods and have gained benefits by forging their typical cultures that were strongly connected with floods and water.

The explorations on how the floods in a sense could bring cultural impacts to those regions and their people would, to some extent, provide us with different perspectives and thoughts on human's floods history.

2.1 EGYPT-The Importance of Annual Nile Flooding for the Ancient Egypt Civilization

The annual Nile floods have historically been the most important natural event in Egypt. The inundation happened yearly, the first signs of the inundation were seen at Aswan by the end of June, reaching its peak at Cairo by September, some weeks after, the river would begin to recede, leaving rich silt deposits and bringing fertile soils for crops (Bell 1970). It is acknowledged that Ancient Egypt could never have existed without the ever-flooding Nile river. The inundation also made the Ancient Egyptians calendar a unique one. The inundation was around the time when the Egyptians noticed the rising of the "dog star" Sirius. During the flooding season, the Sirius was clearly visible in the sky, this convinced the ancient Egyptians that Sirius is the bringer of new life, so instead of solar and lunar calculation, the Egyptians relied on the star as the herald of both new year and the yearly flood (Moret 1996).

One of the most important contributions of the floods to the Egyptian civilization is the invention of the device to measure the Nile floods: the Nileometer. The Nileometers were constructed in different shapes and forms, from vertical columns submerged in the Nile, to steps down to the river. These Nileometers in all different formats were calibrated using the same unit of measurement, the cubit. The Egyptians broke the cubit into smaller units, by which the crop yields could be predicted and the tax can be determined by monitoring these Nileometers. Nileometers could be found at the temples at Elephantine, Philae, Edfu, Esna, Kom Ombo and Dendera. There were built through pharaonic times up until Roman times. Records could show from these sites on how high the Nile would rise and the maximum height of the inundation every year (Moret 1996). Despite being able to measure the flood, to Ancient Egyptians, the inundation was truly in the hands of gods.

Other than creating measurement device with ancient wisdoms, during the inundation, there was nothing to do for the farmers, since usually the crops were harvested in early June before the returns of the floods. Therefore, the farmers who had nothing to do for the flooding season helped building pyramids. This is considered to be an important driving factor to the achievements of this pyramid project (Oglesby et al. 1972).

2.2 CHINA-Floods Bring Social Prosperity

2.2.1 Floods, and the Flourishing of the Commercial Culture

Hankou (also known as Hankow), is one of the three towns that compose the mega city of Wuhan in central part of China, lying in the estuary of Hanjiang River to Yangtze River. Hankou was once the second biggest city in China in the late 1800s and early 1900s being recognized as a metropolitan in far east by the westerners due to its economic prosperity. It then became of importance and was even titled "Oriental Chicago" by *Chicago Tribune* in the United States (Rowe 2015). Most importantly, Hankou is well known for its frequent exposures to floods in history.

According to Wuhan Local Chronicles, the first big flood was recorded in August 1390 (Ming Dynasty) caused by heavy rains, which took the lives of local residents and their poultries'. Since then, the floods have been occurring after every 3 years. Prior to 1465, Hankou was an inhabited sandbar which later on emerged to be one of the towns of strategic importance in Wuhan between 1465 and 1487 due to a flood that occurred[1] resulting into a project that redirected Hanjiang water into Yangtze River. After the diversion of the Hanjiang waterways, the sandbar turned to be a perfect and safe port for vessels, and this was the time when flood-flushing land became a harbor for shipments and cargoes. In the following couple of years, the salt traders were the first group that recognized the convenience of this new emerging town as a salt distribution and sales center, and after salt business, the rice shipping took over. A prosperous business town was then officially born (Zeng Yanhong 2002).

To continuously prevent floods from invading, the first long dyke was constructed in 1635 by the local government, and Hankou fort was built in 1860s and the small town was then expanded to three times bigger than it was before. In 1905, three more dykes were added again for the purpose of avoiding inundations (Rowe 2015). This reinforcing movement provided huge opportunities of business development and eventually brought Hankou to walk on the path towards a metropolitan in the far east (Zhiguo Ye 2016).

[1]The written record was not well kept as to when exactly this flood happened, according to the Wuhan Local Chronicles.

Map of Hankow, China. Hubei Hankou zhen jie dao tu/Hubei guan shu ju bian zhi. [Hubei]: Fang si kan, Qing Guangxu 3 nian. (Source of this map: Library of Congress, USA)

Floods and the developing of commercial culture in Hankou (Zeng Yanhong 2002)

Period of floods visiting	Major projects	Business activities
1465–1487	Hanjiang waterway redirection	Salt trading
1634	First dyke	Rice shipment, salt trade
1860	Hankou fort	Rice shipment, salt trade, silk, medicine
1905	Zhang Gong Dyke, Wu Feng Dyke, and Wutai Dyke	Rice, tea, salt, silk, banking…

2.2.2 The Forging of Social Spirits in Flood Prone Regions

Zhejiang, formerly romanized as Chekiang, is an eastern coastal province of China. The north of the province lies just south of the Yangtze Delta, and consists of plains around the cities of Hangzhou, Jiaxing, and Huzhou, where the Grand Canal of China enters from the northern border to end at Hangzhou. Major rivers include the Qiantang and Ou Rivers. Well-known lakes include the West Lake of Hangzhou and the South Lake of Jiaxing.

Since the ancient times, people's daily life in Zhejiang has always been strongly connected with floods and waters, the earliest culture related to floods could be dated back to as early as 5500 BC (the Hemudu Culture, as "河姆渡文化"in Chinese). Hemudu Culture is also recognized as one of the earliest cultures to cultivate rice (Baorong 1993).

During Song Dynasty in Hangzhou, the capital city in Zhejiang, the West Lake dredging and Su Causeway Project were constructed between 1060 and 1080, and which was led by the Governor Su Shi (1037–1101), in an attempt to diverge the sea water and the floods from big rivers to inner water system (Yu-tang 2012). And this was for the first time when the local people had engaged in this floods prevention project in the floods history in China.

Just a couple of years after the foundation of new China, the Xin Anjiang Hydropower Station Project, built between 1957–1971 in Jiande, Zhejiang, was recorded to be the first large size hydropower station in China which was designed, equipped and constructed by Chinese Government itself, to avoid threats by future big floods. The project therefore resulted in 291,500 villagers being reallocated.

In 2008, the Zhejiang Government made a very bold decision to start "Reinforcement Project" (as "强塘工程"in Chinese character) (Wang Xiaoyi 2008), this was a very innovative design of project, with a holistic approach to explore the most effective way to protect the whole region from floods and other natural disasters. All the local governments in the region were required to participate in this project.

Through thousands of years experiences in facing the natural harshness, the floods in return have been influencing and forging the distinct social cultures and thus made the spirits of the Zhejiang People very unique ones in China: smart and intelligent, open-minded and inclusive, constantly striving and innovative, adventurous and pragmatic (Luo Chang-zhi 2007).

2.3 ITALY- Floods, a Cultural Cheque to Pay

Venice has been known as "City of Water", "City of Bridges", "the Floating City" and "City of Canals". It is also known for its several important artistic movements and its substantial contributions to Europe as well as to the entire world, especially during the Renaissance period. Parts of Venice are renowned for the beauty of their settings, their architecture, and artwork. The lagoon and a part of the city are listed as a World Heritage Site.

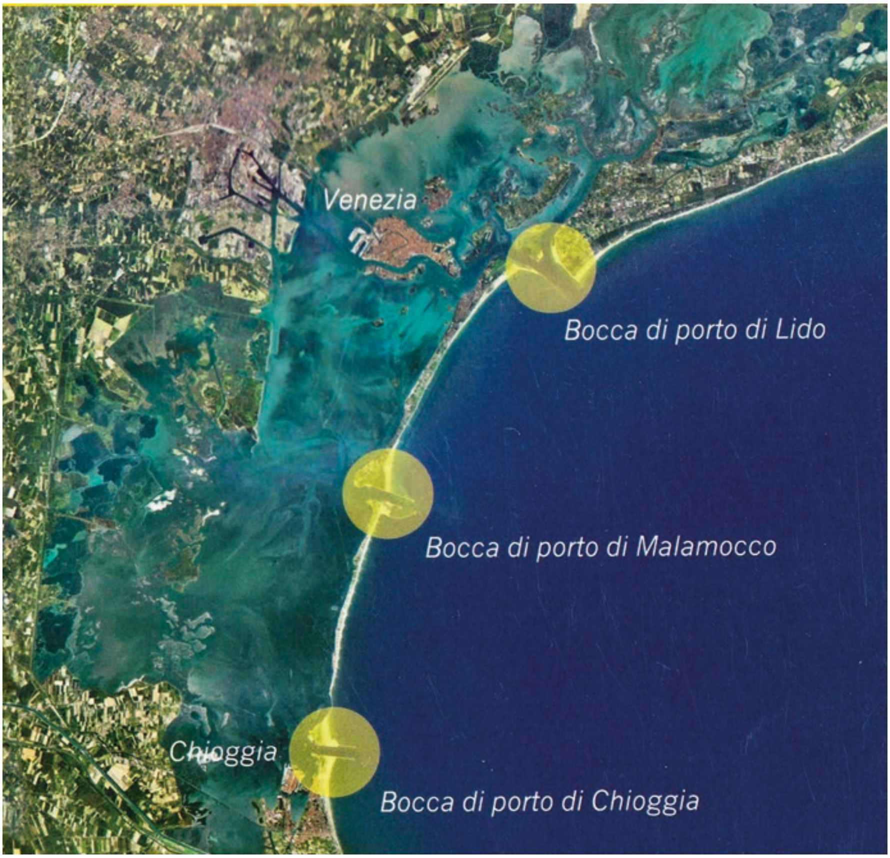
However, due to the sea tides, each year Venice is being washed by over 100 floods, and every 15–20 years a huge flood would be expected. The worst flood which happened in 1966, made nearly 5000 Venice residents homeless (Nosengo 2003). Even though every year Venice attracts 15–20 million visitors from all over the world, the tourism and the preservation of the cultural treasuries in Venice are still heavily affected by the frequent floods.

2.3.1 The Most Plan

Since the giant flood that happened in 1966 and in order to save the precious cultures in Venice from washing away from the unavoidable yet frequent floods in the future after nearly 40 years' debates, The Government of Italy in January 2003, launched a project called "Modulo Sperimentale 'E'lettromeccanico"

(The Italian name for "the Mose Plan").[2] The project aims at building up to 79 water gates in three of the waterways which connect the Venice lagoon and the Adriatic Sea (see below the picture). All those water gates or sluices will be deeply rooted in the seabed and could be easily operated to adjust the water flood flows coming from the Adriatic Sea (Pirazolli and Umgiesser 2006).

The construction officially begun in April 2003 which was earlier than the expected date of 2012. The total cost was estimated about 4.5 billion euros, and most of which probably would have to be borne by the local government of Venice. To make up this huge deficit, the Venetian Government had no choice but to go for public auctions of 13 palaces and historic architectures from the Renaissance times. Unfortunately, this project has not yet finalized up to now due to a series of corruption scandals.



The three waterways connecting the lagoon and the Adriatic Sea

[2] "Modulo Sperimentale 'E'lettromeccanico", the Italian name for "Mose Plan", in a wish that this plan could be saving Venice like the Mose from the Bible who once protected the civilians from the sea.

Can "Mose" be the ultimate solution for Venice? Is the culture really being protected? How should the Venetian people continue their bitter-sweet life with floods? These questions are not answered yet and perhaps will remain unanswered for a longer time.

2.4 THAILAND-Floods with Buddhism and Dams for Ecotourism

2.4.1 Buddhism, in Harmony with Floods

Thailand is a country that has a long record of being ravaged by floods and tsunamis. It is well known as a Buddhism country and according to the 2000 census, 96.4% of the country's population is self-identified as Buddhists (GreenFaith Webinar, Dr. Stephanie Kaza 2012).

In 2011, Thailand suffered the worst floods in more than a half century. The floods inundated more than 6 million hectares of land in 66 of the country's 77 provinces, and affected more than 13 million people.

When the science is still insufficient to respond, the beliefs and the old wisdoms always could be appreciated to cope with natural disasters in a harmonious way. Some even argue that those who put in faith in technology alone to save the world are bowing to a false god. Although floods can be considered as apocalyptic, their annual occurrence made them part of life's relationship with nature (Darlington SM 2003).

A monk walking in the floods in Ayutthaya, Thailand, 2011. (Source: http://www.fjnet.com/shxx/tj/201010/t20101026_170821.htm)

Based on the Buddha's teachings, living in contentment does not mean the elimination of desire of knowledge and truth, but to live in harmony with all beings and with nature including living with floods. As the floods in Thailand in the past never stopped, Buddhism through its teachings offers the people who have beliefs in them: to respect nature, to do no harm for nature, to seek green wisdoms, to be fearful of nature and natural disasters and to care for other as self (GreenFaith Webinar, Dr. Stephanie Kaza 2012).

However, following and encountering the series of events of natural disasters such as floods, Thai people and their beliefs are put to the test. There is a need to revive some of the principles coming from the Buddhist ideas on nature (Donald 2016).

2.4.2 Dams to Become New Ecotourism Attractions

According to Electricity Generating Authority of Thailand, there are 33 large dams, 367 medium-sized reservoirs and 4000 small reservoirs across the country (Sinthusiri et al. 2014). While those dams at different sizes functions as flood-adjusting projects and mostly are built for the purpose of agriculture irrigations, the government is recognizing their cultural values as new ecotourism destinations (Wongduy 2003). It is amazing to realize that dam areas could also support the country's economy by boosting ecotourism, given the importance of tourism to the Thai economy. Efforts have been made in the North-eastern region of the country, to attract tourists to visit the dam areas within the region and to learn about the local lifestyle and traditional knowledge (Jaroenpon et al. 2014).

Ecotourism could improve the livelihoods of the local residents who were once forced to move out of the dam areas, and by increasing the incomes of local community it will also provide incentives for the government and the local people to attach great importance to preserving their traditional cultures and beautiful natures which will bring the tourists both domestically and internationally.

2.5 Conclusions

Floods, as a natural disaster, have always been unexpected yet causing countless casualties, damages and deaths in human's history. Each human's civilization cultivated by the rivers usually carries unforgettable stories and memories with floods. Although we are in the modern times, with well-structured facilities, early warning systems, and flood control technologies, human beings are still vulnerable in face of the merciless floods. Dams, dykes and residential houses could still be easily washed down by flood waters, however there are some fortunes and legacies that have never been flooded away and have consistently been strengthened by what is referred to as culture.

Culture is created and developed in the process of confronting and unifying man with nature. It is an inevitable outcome. Nevertheless, due to occasional characteristics of floods, the distinctive cultures of regions, cities and towns frequented by floods were forged, and the identities of people who live by the flood prone areas were cultivated while they live with and combat against big or small but never-ending floods for centuries in the past. Although Floods could affect the living environment and our human society might suffer from economic and cultural losses due to the flooding, like in the Venice's case. But in the long run, through history to recent times, the new civilization and prosperity in many parts of the planet could also attribute to the influence of the floods, that is to say, the positive contributions of the floods and the cultural values which the floods have brought to the human society, should not be neglected, and furthermore should be appreciated. The history of flood controls is also a reflection of evolving path of human's civilization. Hence, for a better flood management solution without major compromising of human and nature assets, more studies are needed in identifying the interactions of floods and culture improvements, and vice versa, the researches on how the culture and people's mindset would proactively deal with floods and harmoniously live with floods should therefore be strengthened as well in the future.

References

Bell B (1970) The oldest Records of the Nile Floods. Geogr J 136(4):569

Darlington SM (2003) Nature across cultures: views of nature and the environment in non-western cultures. Springer, Dordrecht

Donald KS (2016) An assessment of Buddhist eco-philosophy. Cambridge University Press, Cambridge

Fletcher CA, Spencer T (2005) Flooding and environmental challenges for Venice and its lagoon: state of knowledge. In: Cambridge University Press, Cambridge

GreenFaith Webinar, Dr. Stephanie Kaza (2012) Buddhist teaching and the environment. University of Vermont

Jaroenpon T, Yodmalee B, Phaengsoi K (2014) Natural meadows: development of ecotourism in Chaiyaphum Province. Asian Cult Hist 6(2)

Lei Baorong (1993) The research on ecological culture of Hemudu. J Cult Southeast, No.4 (in Chinese)

Lin Yu-tang (2012) The gay genius: the life and times of Su Tungpo. Hunan Art and Literature Press (in Chinese)

Luo Chang-zhi (2007) On the "water character" of Zhejiang culture. J Zhejiang Gongshang Univ 83(2) (in Chinese)

Moret A (1996) The Nile and Egyptian civilization. Routledge, London

Nosengo N (2003) Venice floods: SAVE OUR CITY! Nature 424:608–609

Oglesby RT, Carlson CA, McCann JA (1972) River ecology and man. Academic, New York

Pirazolli PA, Umgiesser G (2006) The project "MOSE" barriers against flooding in Venice (Italy) and the expected Global Sea-level rise. J Mar Environ Eng 8(3):247–261

Rowe WT (2015) Hankow: commerce and society in a Chinese city 1796–1889. China Remin University Press, Beijing

Sinthusiri O, Yodmalee B, Laoakka S (2014) Culture and ecotourism Management of Dams in North-Eastern Thailand. Asian Cult Hist 6(2)

Wang Xiaoyi (2008) Zhe Jiang Province launched the reinforcement project to address big flood. 163 News. http://news.163.com/08/0815/15/4JD7P4RT000120GU.html (in Chinese)

Wongduy B (2003) Management of natural resources and the surrounding environment in communities with home-stay programs: a case study of Mae Kampong King Village, Wiengmae-on District, Chiang Mai Province. Chiang Mai University Press, Chiang Mai

Zeng Yanhong (2002) The geographic factors for economic development in Hankow during Ming and Qing Dynasty. J Cent China Norm Univ 36(1). www.cqvip.com/qk/91246x/200201/6078984.html (in Chinese)

Zhiguo Ye (2016) Cities under siege: the flood of 1931 and the environmental challenges of Chinese urban modernization. In: Carola Hein (ed) International planning history society proceedings, 17th IPHS conference, history-urbanism-resilience, TU Delft 17–21 July 2016, vol 2, p 79. TU Delft Open, 2016

Chapter 3
Urban Storm Flooding Management in Beijing

Jiahong Liu, Chaochen Fu, Chenyao Xiang, Hao Wang, and Chao Mei

Abstract Beijing is located in the piedmont plain of Taihang Mountains. It suffers from the floods formed in the Taihang Mountains as well as the local waterlogging. The precipitation in flood season (June to September) accounts for more than 80% of the annual precipitation, and it is often concentrated in late July to early August, which sometimes leads to serious urban flood disasters. For instance, in 1939 the precipitation in July and August was up to 1137 mm (recorded in Changping rain gauge); in August of 1963 the precipitation from 4th to 9th is more than 350 mm. Under the rapid urbanization in Beijing, the urban flood is becoming more serious, such as the pluvial disasters on 21st July of 2012. This chapter analysed the characteristics, evolution processes and main influencing factors of urban flood in Beijing based on the historical records. The four main measures of flood management in Beijing are summarized, which are: (1) upgrading and reconstruction of rainwater pumping stations; (2) improvement projects of small and medium rivers; (3) Sponge City construction; and (4) the West Suburb Storm-water Regulation Project. These measures have been put into use, and have played significant benefits on pluvial disaster mitigation in Beijing. On 20th July of 2016, the precipitation in urban area is 274 mm, which is more than that on 21st July of 2012, but there were no serious waterlogging events in urban area. In addition to early prevention measures, the flood warning and emergency management system has been established in Beijing.

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Beijing has also planned two deep tunnels to deliver overflowed rain water, which would greatly improve the defence standards of urban waterlogging in Beijing in the future. With the improvement of management and engineering measures, Beijing will be more resilient and safer under the heavy rains. The experiences of Beijing can also provide references for flood control in other cities.

Keywords Urban flood management · Extreme storm · Pluvial disaster mitigation · Beijing

3.1 Urban Storm Flood Events and the Causes in Beijing

Beijing is located on the northwest end of the North China Plain. The terrain inclines towards the northwest. It covers 16,400 km^2 in total, with the urban area of 1381 km^2 (approximately 8% of the total area). Five rivers flows through Beijing, namely the Juma River from the Qing River, the Yongding River, the North Canal, the Chaobai River and the Juhe River from the Jiyun River, all of which are parts of the Hai River Basin (Fig. 3.1).

In order to drain floods in the central urban districts of Beijing as quickly as possible, water bodies such as inner-city rivers or lakes are used for storage, and facilities such as water gates or dams are used for control (Xie 2014). The management

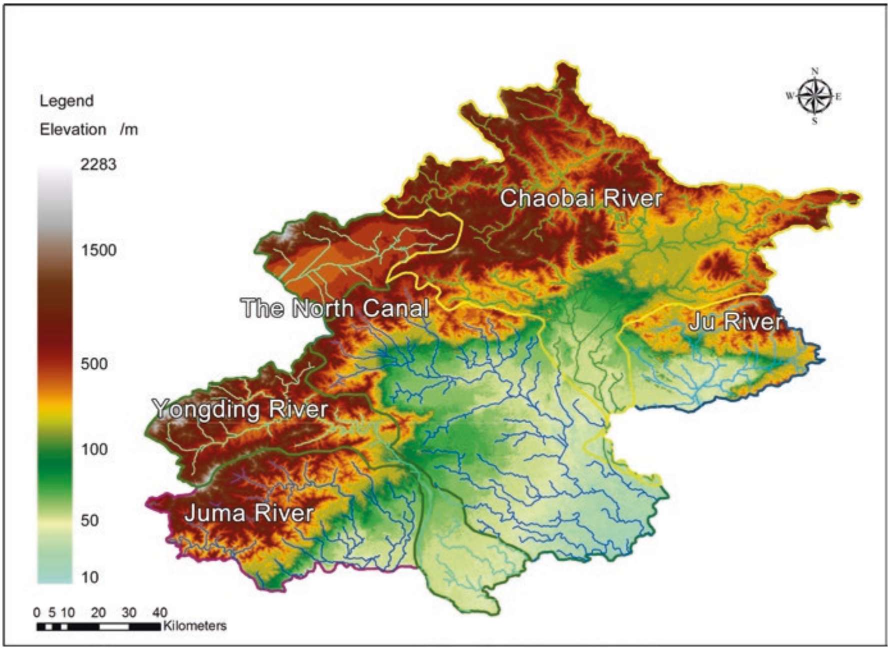

Fig. 3.1 Catchment division of Beijing

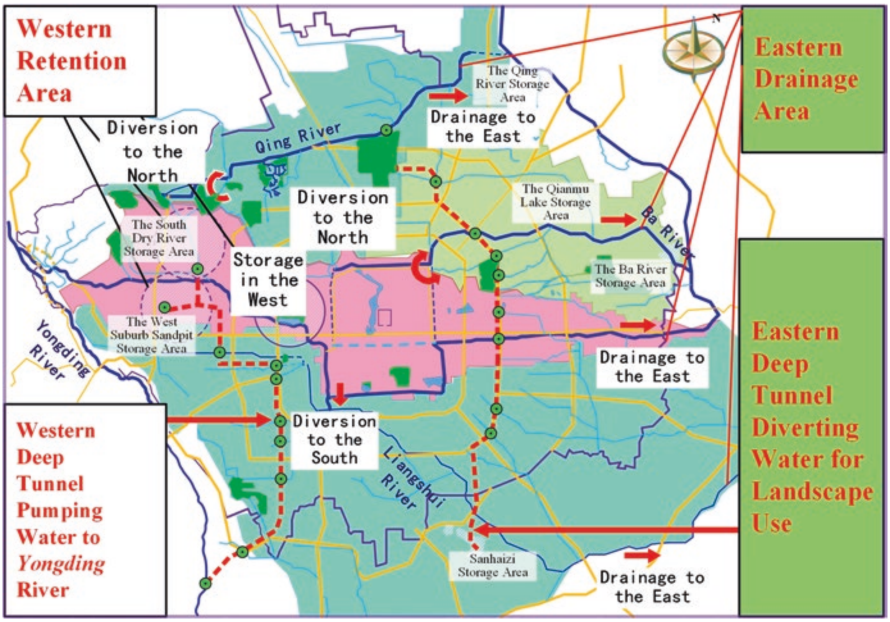

Fig. 3.2 The flood control configuration in the central districts of Beijing

protocol follows three principles: storage in the west, drainage to the east, and diversion in the north and the south. Storage in the west means that the flood waters from the upper region of the North Canal catchment are led to the creeks and lakes of the Yongding River in order to reduce the draining pressure on the midstream and downstream regions, and small floods in the Yongding River are retained by a reservoir before a barrage for recycling. Drainage to the east means that the flood from the upper and middle region of the city are led through creeks into the North Canal. Diversion to the south means that when the south moat is under full capacity, the rubber dam is filled and the sluice is opened so that the water flow is led via the Liangshui River to the North Canal. Diversion to the north means that when draining pressure is heavy in the northwest of the city, flood waters are diverted towards the northeast through three routes: (1) to the Qing River through three barrages; (2) to the Qing River through two creeks and one barrage, and (3) to the Ba River through one floodgate and one sluice (Fig. 3.2).

Beijing has a typical temperate continental monsoon climate, with uneven precipitation distribution. Precipitation in the wet season is over 80% of annual precipitation, and is usually brought by several storms between late July and early August. This climate is extremely likely to cause storm flood disasters, threatening economic and personal safety (Fig. 3.3).

The flood disasters brought by storms in Beijing can be classified into four types: (1) water logging disasters in urban areas, which includes fluvial floods, large scale water logging, traffic paralysis, old building collapse, water intake by underground

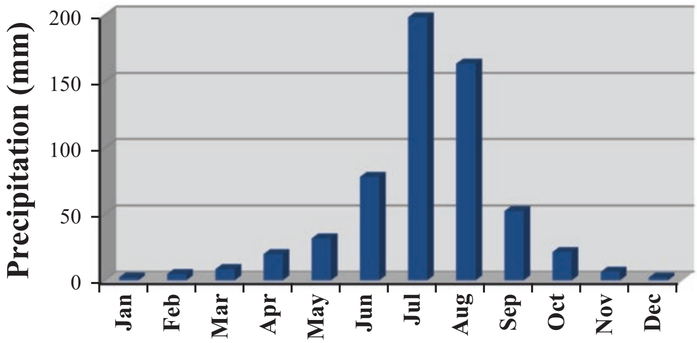

Fig. 3.3 Temporal distribution of the precipitation in Beijing

facilities, and related blackout and water cut-off; (2) flood disasters in reservoirs and big rivers, including piping, cracks, dam collapse, superflux, breach, inrush, river rise and other risks of important flood control facilities; (3) water logging in the outskirts and related secondary disasters, and (4) induced disasters in rural areas, including torrential floods, mudslide, landslide, ground collapse and so on.

3.1.1 The Extreme Storm Flood Events in Beijing

3.1.1.1 The Extreme Storm Flood Events in History

(1) 1939 Flood Event

The flood in 1939 is one of the greatest flood disasters in modern times in Beijing. The storm lasted for 30 days and severely flooded four inner-city rivers (namely, the Chaobai River, the North Canal, the Yongding River and the Qing River). On July 25th, the peak flow in the Yongding River reached 4665 m^3/s and several breaches were found downstream. The flood bent a railway bridge and surged over the Lugou Bridge, pushing down the stone handrail. On July 26th, the peak flow in Chaobai River reached 15,000 m^3/s. The flood ruined the railway bridge and roads, as well as the Suzhuang Watergate. All traffic was paralyzed. On July 27th, the North Canal, with a peak flow of 1670 m^3/s, was breached in the left dyke, and joined the Chaobai River. Based upon the analysis of peak flows, this storm led to an over-100-year flood in the Chaobai River, and 50-year floods in the Yongding River and the North Canal. This flood disaster was caused by three storms. The first was induced by two inverted troughs between July 10th and July 13th, falling mainly on the windward areas of the Tai-hang Mountains and west of Yan Mountain. The second, lasting from July 24th to July 29th, was induced by a typhoon landing on the Shandong Peninsula on July 24th and moved northwards. This storm mainly affected the Chaobai River, the Yongding River, the North Canal and the Qing River, and centered at the upstream of the North Canal and the valley area of the Yongding River. The last storm was induced by a low-pressure trough in the westerlies between August 10th and August 13th, mainly falling on the northwest region of Beijing. The total precipitation in July and August recorded was 1137.2 mm, which is the highest observed record in northwest Beijing.

(2) 1963 Flood Event

In the early days of August 1963, affected by a low vortex flow in the southwest, the Tai-hang Mountains in Hebei Province faced an extraordinary rainstorm. Between August 8th and August 7th, the precipitation in Xingtai reached 2051 mm (in which 1457 mm occurred in the last 3 days). Sicang of Baoding city received 704.3 mm of rainfall on August 7th alone, and the event is called "the 63.8 Storm". Beijing, which is encircled by Hebei Province, also suffered from a storm between August 4th and August 9th. The suburb area received over 300 mm of precipitation. There are five storm centers where daily precipitation was over 100 mm. This storm lasted a long time and was distributed unevenly, for example, between August 8th and 9th one storm center received 401 mm of precipitation in 24 h.

The 63.8 Storm raised the question of what could occur if a storm's center was in Beijing city center or upstream of the city, and how this could be handled. To better respond to flood disasters in Beijing's urban areas, Beijing Municipal Government raised the standards utilized in the 1964 Beijing Urban Flood Control Plan based upon investigations into the 1963 storm event. The Plan requires that designs for constructions relating to urban riverways must be able to withstand a 100-year flood event, and the drainage system a 20-year flood event, meaning that a 20-year flood event in the river should be lower than the tops of the inner main rain drainage outfalls to allow normal drainage. This standard still applies in the planning and regulations of constructions on the main rivers in Beijing.

3.1.1.2 Extreme Storm Flood Events in Recent Years

Since 2000, Beijing has suffered from several extreme storm events (Jisong et al. 2015). These events centered in a relatively small area, with high intensity and short duration. They paralyzed traffic, especially around concave flyovers. For a whole basin or the whole city, these events were only medium or large rain events, but by occurring in a single part of the urban area they caused enormous damage (Table 3.1).

Table 3.1 Extreme storm events in Beijing in recent years

Date	Depth	Duration	Consequences
2004.07.10–2004.07.11	53 mm on average, 159 mm at max	21 h	41 roads were heavily flooded, the highest ponding exceeded 1.7 m, 5 bungalows collapsed, 90 air defense fortifications were drowned.
2011.06.23	Maximum hourly rainfall 128.9 mm		Three deaths, 22 roads were paralyzed, 3 subway lines in danger, 1295 trees fell.
2012.7.21–2012.7.22	215 mm on average in urban areas, maximum daily precipitation 541 mm	19 h	Hourly precipitation exceeded 70 mm in more than 1/6 of the whole city.
			The peak flow in the Juma River reached 2570 m^3/s, and that in the North Canal was 1200 m^3/s. Several regions faced torrential floods of depth over 2 m.
			This storm caused 79 deaths. By July 28th, 1.19 million people were affected, farmland totaling 5.4 billion m^2 was damaged, 11.9 thousand houses collapsed, and 40 thousand cars were drowned.
			The direct economic loss reached 11.835 billion yuan.
2016.7.19–7.21	203 mm on average across the whole city, 274 mm on average across urban areas, the maximum depth was 422 mm	55 h	The total precipitation and duration both exceeded the 7.21 storm. Soil was waterlogged and fluvial floods occurred in several rivers.
			Ten districts, 97 towns and over 100 thousand people were affected. 485 breaches were found. 3394 houses collapsed. 21,380 ha of farmland were damaged. The direct economic loss was 2.15 billion yuan.

3.1.2 Characteristics of the Extreme Storm Events in Beijing

3.1.2.1 Frequencies of the Storms

Analysis on the frequencies of storms in Beijing region in the recent five decades shows the following (Fig. 3.4):

(1) Regional storms, which means that all areas in Beijing received over 25 mm rainfall within 24 h, occurred more frequently before 1980, happening 6–8 times annually; after 1980, the precipitation in Beijing region decreased notably, as well as the occurrence of regional storms, down to five times a year.
(2) In the recent decade, the storms in Beijing region have been showing new patterns. These storms are created by one single small-scale cumulonimbus cloud or a rain cell, and are concentrated on a small area. This weather is more random, and it appears/disappears very quickly, which adds difficulty to forecasting. These storms could easily cause local water logging and traffic paralysis.

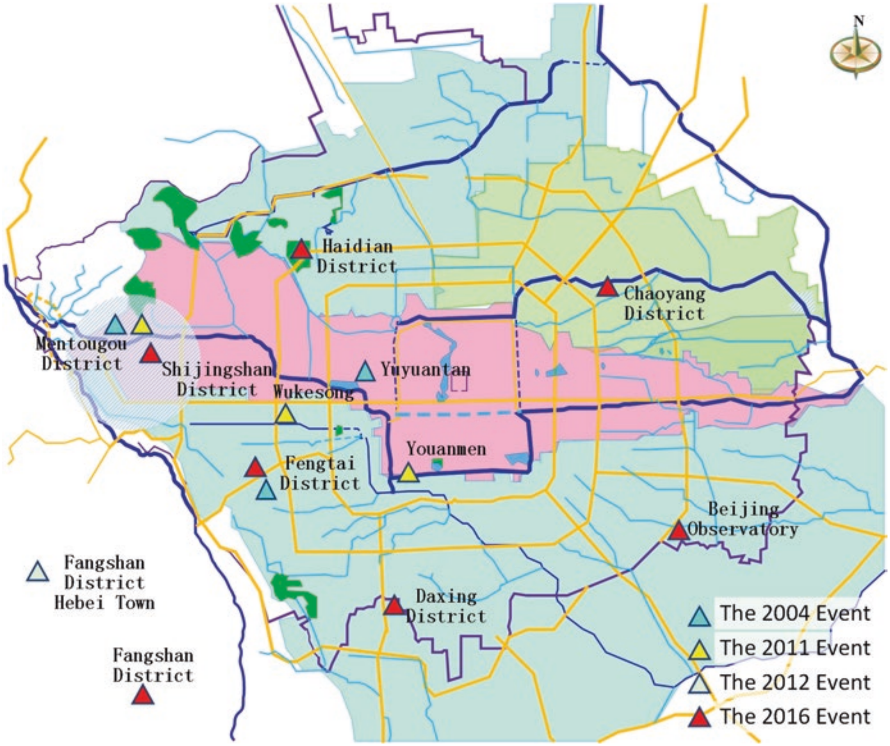

Fig. 3.4 Storm centers

(3) According to statistics from 2003–2012, the short-duration extreme storms that produced over 70 mm rainfall in 1 h happened 82 times in the last 10 years. This figure has tended to climb after 2000, along with the intensity of these storms (Fig. 3.5).

3.1.3 Causes of the Pluvial Flood Disasters in Beijing

3.1.3.1 Urban Development

Changes in land utilization in Beijing have significantly altered hydraulic processes, such as canopy interception, evaporation, transpiration and infiltration. Road construction has disturbed the natural surface draining system, and affected the runoff process. While urban impervious areas have expanded, grasslands, woods, farmland and water bodies have all shrunk. As a result, the runoff coefficient has increased. These alterations to the ground surface in Beijing's urban areas, and the new rainfall-runoff pattern accompany them, are important factors in the extreme storm-flood events (Wang 2011).

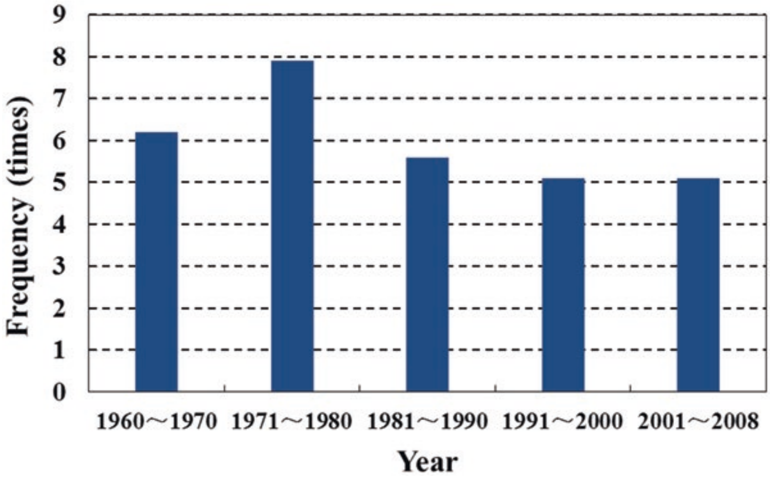

Fig. 3.5 The temporal trend of frequencies of storms in Beijing region

Table 3.2 Comparison of the flood events on "12.07.21" and "63.08.09" at the Lejia Garden Station

Event	Rainfall depth (mm)	Runoff depth (mm)	Runoff coefficient	Peak time (h)	Flood duration (h)	Peak flow (m^3/s)
63.08.09	359.1	187.3	0.52	20	44	261
12.07.21	197	106.4	0.54	7	16	440

According to statistical data, the impervious area in the central Beijing districts has increased from 60% in the 1960s to the current 85%, while the area of water surface decreased by 80 hm^2. This means that the natural water storage volume decreased by 400,000 m^3 for an average water depth of 0.5 m. The shrinking of water bodies directly caused a surface runoff increase and, consequently, greater pressure on urban pipeline systems.

Moreover, rapid urban development has caused a heat island effect in central Beijing, and in several big cities nearby. The strong thermal updraft confronts high-level cold air and creates rainfall that concentrates on urban areas. In comparison, the surrounding rural areas have received less rainfall.

Taking Lejia Garden Station on Tonghui River as an example, the flood events on July 21st, 2012 and August 9th, 1963 are compared in Table 3.2.

3.1.3.2 Low Flood and Drainage Standard in the City

Currently, the flood prevention standard of the whole city is to resist storms of a 200-year return period (mainly focusing on the Yongding River), and that of the four main inner rivers are the 20-year storm, the 50-year storm or the 100-year storm. However, for the basic hydrological units of urban catchments, such as residential quarters, rainwater drainers, roads and flyovers, the design standard storm is usually the 1-year storm event. For important roads, or areas where even short periods of waterlogging could cause serious damage (Liu et al. 2011), the design standard is usually the 3-year–5-year storm event, and for particularly important regions that is the 5-year–10-year storm event. If the intensity of a short-duration storm exceeds that of the 10-year event, i.e. precipitation exceeds 65 mm per hour, the urban drainage system would exceed its capacity and waterlogging would occur (Hou 2015; Suriya and Mudgal 2012).

3.2 Urban Flood Management in Beijing

The establishment of the flood prevention standard is a systematic issue. Firstly, the drainage system usually consists of subcatchments, rain grates, rain drainers, branch drains, main drains, riverways and pumping stations if the drainage area is low (Shi et al. 2006). Any problem in any part of this system can cause inefficient drainage or waterlogging in the system. Secondly, the drainage capacity depends upon that of the receiving river, which depends upon the capacity and conditions of the downstream river (Debo and Reese 2002).

The extreme storms in Beijing in recent years are typically short-duration, of high intensity and are concentrated, which brings new challenges to traditional urban drainage system. Therefore, reconstruction of drainage systems, storage infrastructures and riverways is needed in response to these new problems.

3.2.1 Upgrading and Reconstruction of Rainwater Pumping Stations

In Beijing there are 192 rainwater pumping stations, which are able to drain 2,360,000 m^3/h. These rainwater stations are mostly built along with roads or flyovers in different periods, so they were designed according to very different standards. For example, 90 rainwater stations are in the central districts. Four stations (4%) among them are designed for 1-year rain events; 81 stations (90%) are designed 2 or 3-year rain events, and five stations (6%) are designed for 5-year events. However, in recent years the storms that produce over 70 mm of rainfall per hour occur more frequently, and most stations are overwhelmed.

In addition, the runoff coefficient has increased along with the expansion of hard ground. In the last 5 years, the urban surface runoff coefficient has increased by 15%, from 0.55 to 0.63. Catchment areas, especially around flyovers, are flooded and face waterlogging as water exceeds the capacity of water pumps.

To secure the safety of the city, Beijing launched the “Three-year Project of Rainwater Pumping Stations Upgrading and Rainwater Harvesting in Beijing Urban Districts” in 2013. The project has upgraded 77 pumping stations at low-ground

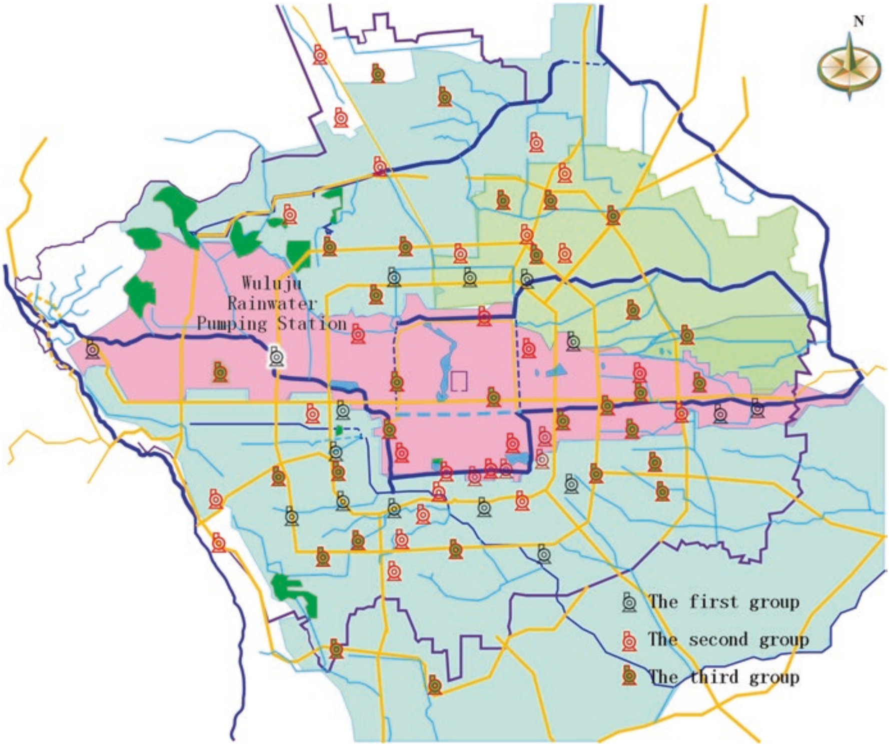

Fig. 3.6 Rebuilt pumps in Beijing central districts

flyovers in different groups. The project reconstructed rainwater harvesting systems, enlarged water pumps (enlarging the total pumping capacity from 374,000 m^3/h to 718,000 m^3/s), built 60 new storage tanks (creating 210,000 m^3 of storage volume) and drainage pipelines. The goal of implementation is to keep the main roads clear under 10-year storm conditions. In addition, new storage tanks built under greenbelts, parks and parking lots can harvest rainwater for recycling (Fig. 3.6).

Example: Upgrading in Wuluju Rainwater Pumping Station

The Wuluju Rainwater Pumping Station Upgrading Project has been finished and is ready to be used. This project included rainwater harvesting system reconstruction, water pump enhancement, new storage tank and drainage pipeline construction. As the upgrade projects of rainwater pumping stations were usually at corners of districts or busy traffic spots, the construction sites were very limited. To deal with this problem, pipe-jacking construction was applied. Two pipes of 3 m diameter, 150 m length were set as storage tanks, able to store 2090 m^3 of water. This method significantly reduced the work of land requisition and saved on costs (Fig. 3.7).

Fig. 3.7 A 3 m-diameter drainer and storage tank at the Wuluju Rainwater Pumping Station

3.2.2 Improvement Projects of Small/Medium Rivers

There are 425 small/medium rivers totaling 6448 km in length in Beijing. The ungoverned rivers were usually polluted and unable to drain efficiently. To deal with this problem, Beijing announced the "Beijing Implementation and Construction Plan for Hydraulic Engineering" in 2013, organizing the dredging and improvement of 1460 km of river channels where flood risks were high, infrastructures were weak, population was large or there were important objects. Riverways were properly connected to surrounding underground drainage pipelines, improving the flood prevention standard from being under the 5-year event to being over the 10-year event or 20-year event.

There are four approaches to the management of small or medium rivers: infiltration, storage, retention or drainage. The specific method used depends on the local urban-rural layout, the economic conditions and social environment. The primary problems with urban channels are the disconnection of water bodies and pollution. For plain rivers, managers should build water networks based on natural conditions. For rivers in mountainous regions, the villages and roads along the rivers should be key focuses for protection, and flood water should be channeled out with full respect to the local natural landscape.

Moreover, riverway management should be consistent and integrated with six tasks: (1) pollution control; (2) water body connection; (3) the South-to-North Water Diversion Project and groundwater recharge; (4) the construction of flood detention and storage areas; (5) water-soil conservation and afforestation of plain regions, and (6) greenbelt construction and tourism development (Fig. 3.8).

Fig. 3.8 Construction sites

3.2.3 Sponge City Construction

The construction of sponge cities is comprehensive, systematic engineering. It involves Low Impact Development, drainage and flood prevention, rainwater reuse, groundwater restoration, flood disaster relief and other fields. It requires taking precedence over rainwater harvest and using natural routes to drain rainwater, to purify rainwater or to allow infiltration when improving urban drainage systems. In the philosophy of sponge city construction, the impact of urban development on the ecological environment should be minimal. The aim is to avoid waterlogging and pluvial flood disasters in non-extreme rain events, to clear malodorous, black rivers, and to relieve the urban heat island effect (Liu 2016).

For a sponge-city built-up region, no less than 70% of annual precipitation should be retained or reused locally (Ning et al. 2017). For instance, urban green spaces should be able to absorb all the rainwater falling onto them, and take in the surface runoff from surrounding impervious areas to their maximum capacities (Zhang et al. 2014; Shao et al. 2016). Roads and plazas should collect, purify and reuse rainwaters, lifting pressure on the drainage system. By 2020, the sponge-city region should account for 20% of the built-up area of Beijing, and 80% by 2030. New constructions or districts should be planned and built to the sponge-city standard, while old urban areas should be transformed gradually (Fig. 3.9).

3.2.4 The West Suburb Stormwater Regulation Project

The West Suburb Sandpit Construction was one of the key elements of the flood prevention regulation of Beijing's central districts. Water division by a control sluice ensures drainage in three catchments totally approximately 27 km^2 under 100-year storm conditions. Construction included the sluice and two buried culverts that connected to two sandpits individually. The larger sandpit is 680,000 m^3 and able to contain 700,000 m^3 water (Figs. 3.10 and 3.11).

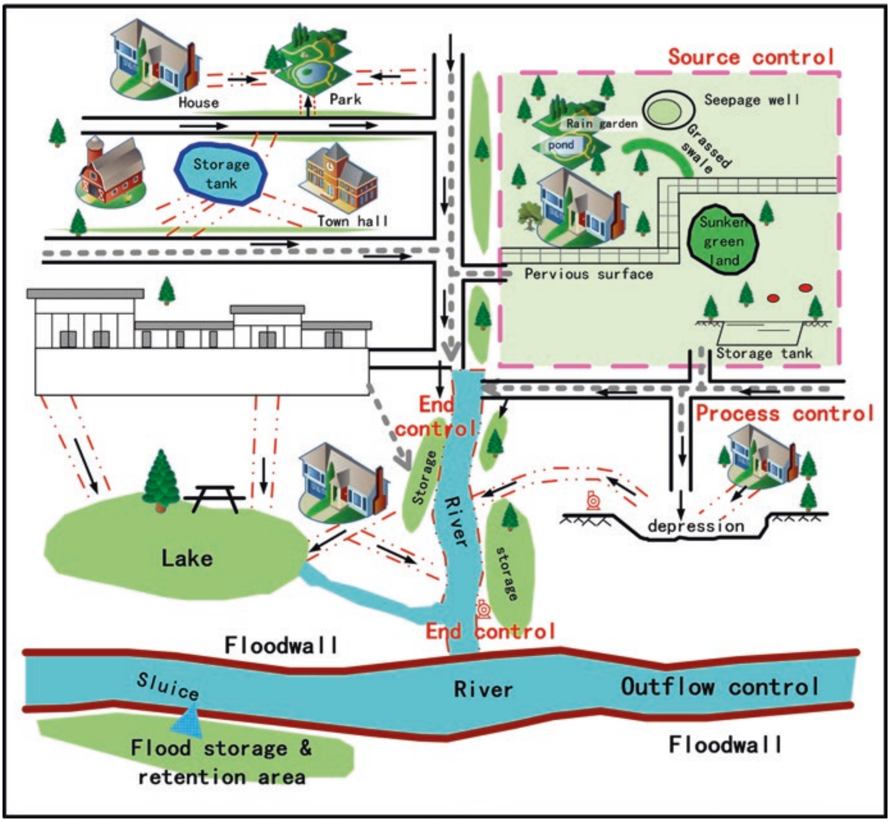

Fig. 3.9 Approaches of sponge city construction

3.3 Urban Pluvial Flood Warning and Emergency Management

Storms in recent years have brought extraordinary number of casualties and economic loss, which has exposed problems such as weaknesses in flood prevention facilities, a deficiency of equipment and stocks for emergencies, late statistical reports, narrow warning coverage, defective command systems and people's weak awareness of flood disasters (Wang et al. 2017). Learning from experiences, Beijing established a new flood prevention command system called "1 + 7 + 5 + 16".

The "1" means strengthening command effectiveness over flood prevention work. Beijing established the flood prevention headquarters to organize the entire flood response operation, with the deputy mayor taking charge.

The "7" means establishing 7 branch units to manage flood prevention in specific fields, namely publicity, housing and construction, traffic, underground systems, geological disasters, tourist attractions and integrated support. The housing and

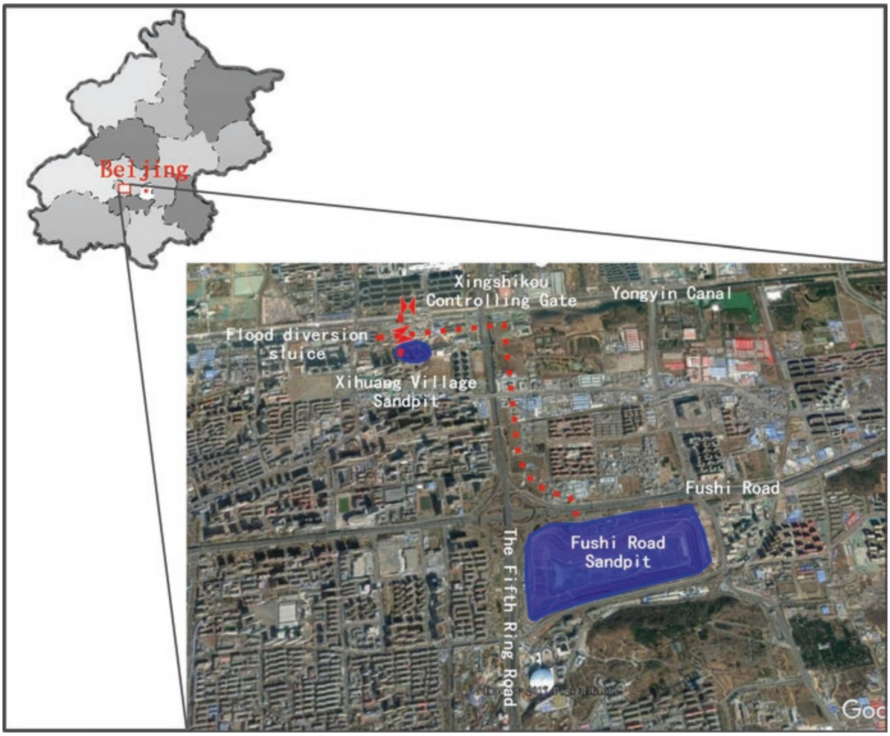

Fig. 3.10 Layout of the West Suburb Sandpit Project

construction branch helps all buildings, ongoing constructions and general underground facilities through floods safely. The traffic branch guarantees the safety of roads and urban rails during storms. The underground system branch focuses on protection and emergency management for water, electricity, gas, heat supply and other vital supply lines. The geological disaster branch takes charge of precautions and control over areas liable to geological disasters and goaves. The tourist attraction branch takes charge of flood prevention at tourist attractions. The integrated support branch organizes and coordinates all the branches in general. The publicity branch improves public awareness of urban flood disasters and related self-rescue education.

The “5” means strengthening protection construction along 5 main rivers. Five command offices have been established for organizing and supervising the flood prevention, emergency rescue and disaster relief work in the Yongding River catchment, the Chaobai River catchment, the North Canal catchment, the Qing River catchment and the Ji River catchment.

Fig. 3.11 Before-and-after comparison of the West Suburb Sandpit Project

The "16" means placing responsibilities on 16 county administrative chiefs. The county command offices organize and supervise all flood disaster prevention and response work within the county boundary.

Flood control discussion and announcement protocols were also improved. The discussion system with meteorological departments, and a flood season news release system, were established to normalize flood warning announcement work (Henonin et al. 2013). A basin cooperation system was established to help counties in the same basin unit deal with flood disasters together. For key targets of flood prevention, governments, industries and operation units should collaborate on planning, teamwork, safety measures and disaster relief (Rosenthal and Kouzmin 1996).

Army and armed police forces should also be united on flood control work, especially in extreme events. The supervisory work and the responsibility investigation system should be improved. Officers who do not perform their duties should be called to account. The principles are "unified command, unified dispatching, unified decision making". Oversight should be strengthened and measures such as self-examination and inter-checking should be taken. The implementation of responsibility systems, planning, teamwork, emergency commodity, safety measures, publicity, training and exercise should be checked (Petak 1982). Flood drills of different types, patterns and in different regions should be carried out. Emergency precautions should be improved. The release of warning information should be enhanced, and the flood response plans should be operable (Apel et al. 2006). Emergency commodities should be secured and necessary funding guaranteed. The operation and maintenance of hydraulic engineering facilities should be ensured.

Internet technology, the internet of things, and the Intelligent Water Network were also applied. Automated remote monitoring systems were built for urban drainage infrastructures. Dense hydrological monitoring on urban roads, blocks, lakes and other water bodies, as well as monitoring over rainwater drainage pipelines, enables real-time knowledge about urban storm and flood disaster conditions, which is the basis for quicker emergency management (Fig. 3.12).

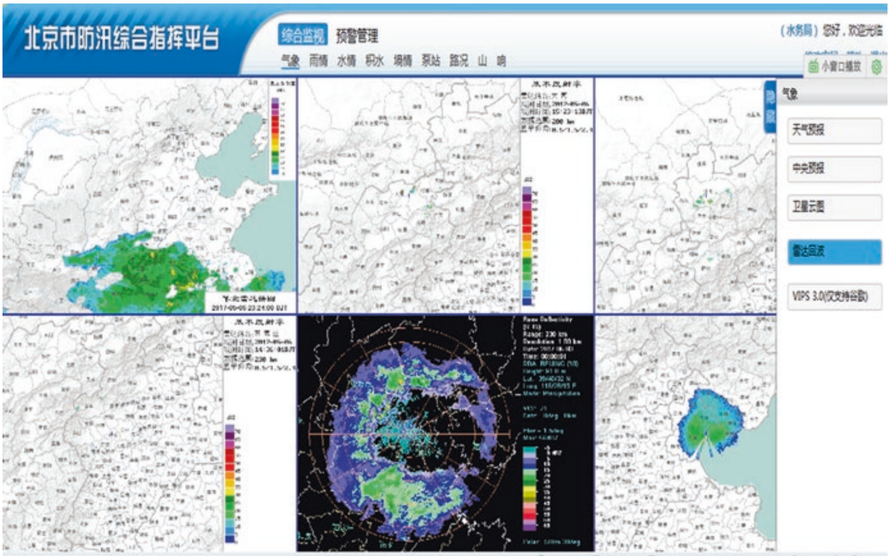

Fig. 3.12 Beijing flood control command platform

3.4 The Prospect of Urban Flood Management in Beijing

Flood prevention in Beijing is related to the reform and development of the capital of China, so it is particularly important to improve the quality of flood control work.

3.4.1 Further Improvement of the Flood Control Management System

Firstly, Beijing should strengthen the "1 + 7 + 5 + 16" command system to realize the river basin management. It is also important to implement monitoring and communication mechanisms. To achieve that goal, Beijing will improve the system and regulation protocols.

Secondly, the work of flood prevention management should be divided and classified. Both normal and emergency working systems should be established, standardized and institutionalized.

Thirdly, Beijing's rescue teams should be more specialized and professional. Meanwhile, social volunteers should be united, establishing a linkage mechanism.

3.4.2 Further Improvement of Flood Control Plans

Firstly, risk assessments should be conducted for key areas. To secure the safety of people and transport facilities, risk assessments should be conducted at weak spots, especially overpasses and underground spaces.

Secondly, linkage mechanisms should be built between departments, especially for the management of emergencies in public places, such as the main transport stations, airports and train stations (Yajie and Su 2005). If there are large quantities of passengers stranded in those places, related departments are responsible for taking steps to resettle passengers.

Thirdly, supervisory mechanisms should be developed. The responsibility system is such that the head of the department is the first person responsible. The execution of flood control plans and emergency response should be specified, insuring the measures and information can be transferred to towns, sub-districts, villages and people.

Fourthly, professional plans for flood regulation should be improved. The detailed regulation mode for regional rainfall or medium/small rains should be developed. The plan's foundation is risk assessment; its basis is hydrological forecasting and its measure is a scheduling model. Beijing should make an elaborate scheduling model for the water systems' connecting rivers and lakes, and also develop emergency measures for floor drains.

3.4.3 Further Strengthening the Flood Warning System

Firstly, the system of warning dissemination should be improved, including its targets, standards, the programs, region identification and content. Beijing should build a joint work system and develop regulations for disaster prevention. It is important to guarantee the efficient co-operation between departments.

Secondly, the government should further mobilize society. Governments at all levels should intensify their efforts and clarify responsibilities in aspects such as publicity of warnings and disaster relief knowledge, the government order, job deployment and media announcements. Weather, land and traffic management information should be integrated to realize the publication of all-around and multichannel warning information.

Thirdly, the ways in which warning information is transferred to the public should be diverse. Radio, television, websites, newspapers, microblogs and mobile phone messages should all be utilised. Warning information messages should also be easy to understand. Beijing will comprehensively improve the capacity, timeliness and coverage of the flood warnings release. Before the advent of disaster, the warning messages will be transferred to every citizen.

Fourthly, the research on flood control should be conducted, to improve the judgment of magnitude and risk of storms (Local Capability Self-assessment and Accreditation Tool, Florida Emergency Preparedness Association 2002). Weather forecast and discussion work should be reinforced, especially for the risk assessment on all kinds of rainfall regime, to deploy flood control work and the rescue force easily. In a word, more research should be conducted on the patterns of heavy rains and floods, realizing the more elaborate and precise warning system.

3.4.4 Further Strengthening Social Management and Public Awareness of Flood Prevention

Urban flood control is not only a technical endeavour, but also involves social management. Social management and education to increase public awareness of flood prevention should be directed to all citizens.

Firstly, all members of society should pay more attention to flood prevention and flood control. Governments should give positive guidance to let all sectors take part voluntarily. The popularization of knowledge of flood control and disaster relief is also very important. The main point is to enhance: the risk aversion ability and self-rescuing ability of the public; the ability of staff to deal with emergency situations; the commanding ability of new leaders; the degree of cooperation between sectors, and the emergency capacity of rescue teams.

Secondly, the standard mechanism of social management should be developed and varying contingency plans should be created. Effective cooperation should be achieved. Flood drills should be normalized and popularized. Governments should build volunteer teams and try to cover all counties and villages. The volunteers should be trained systematically under the guidance of professionals.

Thirdly, particular attention should be paid to publicity and education, increasing public awareness of flood prevention and disaster relief. The self-saving awareness and ability of citizens, especially students, mountain villagers, people in rural-urban continuum, outlanders and migrant population, should be improved.

Fourthly, posters, brochures, public service advertisements, the internet, microblogs, radio, television, street newspapers and billboards should be utilised to disseminate knowledge of flood prevention and mitigation (Tedim and Carvalho 2010). Every company, school, scenic spot, village, community and family should be reached. Knowledge of flood prevention and safety should be communicated in the squares and streets, to reach every family and every citizen.

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References

Apel H, Thieken AH, Merz B, Blöschl G (2006) A probabilistic modelling system for assessing flood risks. Nat Hazards 38(1):79–100

Debo TN, Reese A (2002) Municipal stormwater management. CRC Press, Boca Raton

Henonin J, Russo B, Mark O, Gourbesville P (2013) Real-time urban flood forecasting and modelling–a state of the art. J Hydroinf 15(3):717–736

Hou L (2015) Reflections on City waterlogging disaster emergency management and its countermeasures[J]. Public Adm Law 01:5–9

Jisong S, Lei L, Yu Bo LANLAN (2015) The fundamental features of extreme severe rain events in in the recent 10 years Beijing area[J]. Acta Meteor Sin 04:609–623

Liu D (2016) Water supply: China's sponge cities to soak up rainwater. Nature 537(7620):307–307

Liu HW, Liu S, Zhu JL, Yin Y, Li YC (2011) Discussion on the crux of urban waterlogging and policy suggestions[J]. China Flood Drought Manag 6:27–28

Local Capability Self-assessment and Accreditation Tool, Florida Emergency Preparedness Association. September, 2002

Ning YF, Dong WY, Lin LS, Zhang Q (2017, March) Analyzing the causes of urban waterlogging and sponge city technology in China. In: IOP conference series: earth and environmental science, vol 59, no 1, p 012047. IOP Publishing

Petak WJ (1982) Natural hazard risk assessment and public policy: anticipating the unexpected (No. 363.34 P477). Springer, New York

Rosenthal U, Kouzmin A (1996) Crisis management and institutional resilience: an editorial statement. J Conting Crisis Manag 4(3):119–124

Shao W, Zhang H, Liu J, Yang G, Chen X, Yang Z, Huang H (2016) Data integration and its application in the sponge city construction of CHINA. Procedia Eng 154:779–786

Shi PJ, Du J, Ji MX (2006) Urban risk assessment research of major natural disasters in China[J]. Adv Earth Science 21(2):170–177

Suriya S, Mudgal BV (2012) Impact of urbanization on flooding: the Thirusoolam sub watershed–a case study. J Hydrol 412:210–219

Tedim F, Carvalho S (2010) Flood management strategies in frequent and small scale events: lessons learned from Amarante (Portugal). Quaestiones Geographicae 29(3):69–84

Wang Y (2011) Main causes and countermeasures of urban flood disaster in Beijing[J]. China Flood Drought Manag 21(6):27–28

Wang Y, Sun M, Song B (2017) Public perceptions of and willingness to pay for sponge city initiatives in China. Resour Conserv Recycl 122:11–20

Xie YF (2014) Discussion on emergency response mechanism of flood control in Beijing[J]. Beijing 4(46–48):58

Yajie M, Su Y (2005) Preliminary study on risk assessment of disaster prevention parks. Progress in safety science and technology, vol V, Part B

Zhang WS, Xie Q, Zhu JJ, Feng MC, Liu BH (2014) The Early Warning and Algorithm Implementation of Urban Road Submergence in Heavy Rains. In: Applied Mechanics and Materials, vol 543. Trans Tech Publications, Durnten-Zurich, pp 1671–1676

Chapter 4
A Revisit to Impact of Urbanization on Flooding

Guangwei Huang

Abstract It briefly describes the main components of water cycle from precipitation to storage and explains the impacts of urbanization on water cycle with a particular focus on the increase of flood inundation depth due to urbanization, which has been very much insufficiently studied and poorly understood so far. It also points out even a small-scale rainfall event may cause flood damage in urbanized areas, which may be considered as a reflection of poor urban planning. Furthermore, it advocates the need to embed flood damage estimation into urban planning as a new strategy for better flood risk management.

Keywords Land use change · Inundation depth · Underpass · Damage estimation

4.1 Introduction

Urbanization is the process by which rural communities grow to form a new environment that is named as urban areas or cities. The earliest city to rise in the region of Mesopotamia is considered by modern-day scholars to be Uruk, around 4500 BCE, and then that of Ur, which was a city in the region of Sumer, southern Mesopotamia, around 3800 BCE, both of which were then situated in proximity to the banks of the Euphrates River (Mark 2014). From the very beginning, urbanization was linked to water. There were a large number of publications on impacts of urbanization on floods in the twentieth century (Anderson 1968; Leopold 1968; Johnson and Sayre 1973; Hollis 1975), which led to good understanding on this issue and various mitigation measures such as storage facilities (DeGroot 1982) and flood hazard map as a non-structural measure (Bates and De Roo 2000). However, there are an even larger number of publications on this issue during recent decades (Campana and Tucci 2001; Shi et al. 2005; Xu et al. 2010; Pattison and Lane 2012;

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Singh and Singh 2012; Morita 2014; Yao et al. 2017; Jeremie et al. 2017), which serves as an evidence that it is still an insufficiently explored issue and floods remain an ever-present threat. The accelerated urbanization and rapid growth in urban population in recent decades have made urban landscapes increasingly susceptible to flood disaster and the lack of rational planning for the rapid urbanization may be considered as one of the root causes for problems cities are faced with today. The present work is intended to shed new light on the consequences of poorly-planned urbanization in relation to flood risk by analyzing a number of flooding cases. It is also aimed at serving as a call for more in-depth studies on flood damage and its integration with urban planning.

4.2 Hydrological Cycle

The science of hydrology began with the concept of the water or hydrological cycle, which is a continuous cycle whereby water keeps moving and changing between solid, liquid and gas states. The global water cycle can be described with eight major physical processes as follows.

1. *Precipitation* is the process that occurs when any and all forms of water particles fall from the atmosphere and reach the ground. The amount, intensity and forms of precipitation vary with season and geographic location.
2. *Evaporation* is the process by which water changes from a liquid to a gas or vapor. It is the primary pathway for water to follow when moving from the liquid state back into the atmosphere as water vapor. About 80% of evaporation occurs from the oceans and the remaining 20% from land.
3. *Transpiration* is the process by which plants lose water through small pores on the underside of leaves. It accounts for approximately 10% of all evaporating water.
4. *Condensation* is the process by which water vapor changes it’s physical state from a vapor, to a liquid. Water vapor condenses onto small airborne particles to form dew, fog, or clouds. It is crucial to the water cycle because it is responsible for the formation of clouds, and clouds may produce precipitation, which is the primary route for water to return to the Earth’s surface within the water cycle.
5. *Runoff* is the movement of water in a drainage basin or watershed including flows of water over the land surface, through channels, and subsurface and groundwater runoff as well. Runoff is extremely important since it supplies water to rivers and lakes, and affects the landscape and human society in many ways.
6. *Infiltration and percolation* are two related but different processes describing the movement of moisture through soil. Infiltration is the process by which a portion of precipitation seeps into the soil or rock that makes up the Earth’s surface.
7. *Interception* is the process of interrupting the movement of water in the chain of transportation events leading to streams. The interception may take place by vegetal cover, depression storage in puddles, or in land formations such as rills and furrows.

8. *Storage* is known as 'reservoirs' in the planetary water cycle. Water is stored in the atmosphere, on the surface of the earth, and in the ground as well. Surface storage includes oceans, glacier ice, rivers, lakes, man-made reservoirs and living organisms. Underground storage occurs in the soil, in aquifers, and in the crevices of rock formations. Water in the atmosphere accounts for only about 0.001% of the total Earth's water volume and is renewed every 16 days on average.

For more information on the water cycle, readers are referred to Bengtsson et al. (2014), Oliver (1995).

4.2.1 Impacts of Urbanization on Water Cycle

Urbanization alters precipitation-runoff relations compared with watersheds under natural conditions. Various effects of urbanization on water cycle and flood hazard have been intensively studied and there is a large amount of literature on different aspects of the subject ranging from land use change, development on floodplains and measures for risk reduction, to various modeling approaches (O'Driscoll et al. 2010). It is well documented that the natural water cycle cannot function properly in urban areas because buildings, concrete and other sealed surfaces prevent water from infiltrating into the ground. The major impacts of urbanization on floods have been characterized in terms of flood peak, magnitude, frequency and flooding-caused damage that described. In addition to these widely known facts, this chapter provides more in-depth information on effects of urbanization on flooding in urban areas via case studies.

4.2.1.1 Impact on Peak Flow, Peak Timing, Total Volume and Frequency

When an area is urbanized, a large fraction of the vegetation and top soil is replaced by impervious covers such as buildings, roads and business facilities. Consequently, the hydrological cycle of a watershed is significantly altered. Interception of precipitation by tree canopies is reduced due to vegetation removal and flow velocities in urban areas are increased due to decreased surface roughness (Dams et al. 2013). Infiltration of precipitation is much lower in urban areas than non-urbanized areas, and evaporation from the urban impervious surface is discontinuous and intermittent, having significant decreases with increased urban/residential development (Dow and DeWalle 2000). Watershed surface evapotranspiration is also decreased due to urbanization (Kondor and Nishiyama 2000). On average, urban watersheds lose 90% of storm rainfall to runoff, whereas non-urban forested watersheds retain 25% of the rainfall (Shang and Wilson 2009). For surface runoff, one of the most obvious changes caused by urbanization is the sharp rise in the peak flow during a flood. A recent study (James et al. 2014) showed that at 20% watershed imperviousness, the 2-year recurrence-period peak flow increased by a factor of 6. Another study (Hawley and Bledsoe 2011) compared storm runoff in two adjacent catchments; one is highly urbanized and the other is a recently developed peri-urban area containing two distinct areas of drainage: one with mixed natural and storm drainage pathways, the other entirely storm drainage. The comparison suggests that the relative increase in peak flows is greatest at low levels of urbanization. Meanwhile, relatively uniform topography and reduced roughness in urban areas and the introduction of storm water conveyance systems make a watershed 'flashy', meaning that the time to peak flow is decreased (Nirupama 2007; Saghafian 2008). In the Tsurumi River, Japan, the peak time reduced from 10 h in the 1960s to 2 h in the 1990s. This shortening is not only due to land use change but may also be attributed to the construction of artificial drainage systems in urban areas as well as channel engineering works. This reduction in the time to peak flow is also related to the increase in peak flow itself. Furthermore, urbanization results in an increase in the volume of direct runoff from an urbanized catchment compared with a similar sized catchment in a rural state when subjected to the same magnitude and frequency of storm conditions. Barron et al. (2011) indicated a 30–100% increase in runoff volume due to urbanization for the catchments they studied. Urbanization also increases the frequency of floods relative to a rural situation. Even rain events of relatively low intensity may produce runoff. Since the flood recurrence interval (return period) for a stream is the probability that a flood of a given magnitude will be equaled or exceeded in a given year, the increase in peak flow will lead to the reduction of recurrence interval for that peak flow. A study by Huang et al. (2008) revealed that recurrence intervals prior to urbanization of 200, 100, 50 and 25 years are decreased to approximately 88, 33, 16 and 8 years following urbanization for peak discharges in the watershed under investigation. It is worth mentioning that much available evidence in the literature on the long-term hydrological effects of urbanization has been obtained through the application of hydrological models (Fletcher et al. 2013).

4.2.1.2 Effect of Urbanization on Flood Inundation Depth

Lake Tega is located in the northern part of Chiba Prefecture, Japan with a drainage area of 148.85 km^2. Due to the so-called eastward diversion project in the seventeenth century, it became a retarding basin for floods from the Tone River which is the largest river in Japan in terms of discharge (Okuma 1981). As shown in Fig. 4.1, urban area in the watershed has expanded by five times and the population increased from 109,000 in 1960 to 504,000 in 2010 (Fig. 4.2).

To quantify how flood risk has evolved with land use change in the watershed, 2-D numerical simulations of flood inundation were performed for different periods of time based on land use data either obtained from Geospatial Information Authority of Japan or by digitizing old maps (Huang 2011). The numerical model employed is given below

$$(1-\lambda)\frac{\partial h}{\partial t}+\frac{\partial \beta M}{\partial x}+\frac{\partial \beta N}{\partial y}=0 \tag{4.1}$$

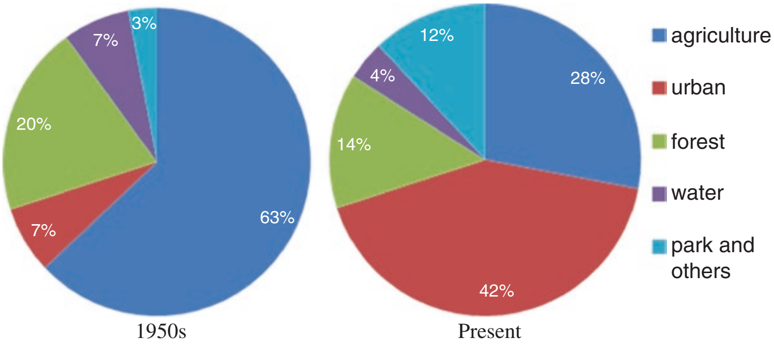

Fig. 4.1 Land use change in the watershed of Lake Tega

Fig. 4.2 Overflow of Lake Tega in 2013

$$(1-\lambda)\frac{\partial M}{\partial t}+\frac{\partial \beta UM}{\partial x}+\frac{\partial \beta VM}{\partial y}=-gh(1-\lambda)\frac{\partial (h+z)}{\partial x}-(1-\lambda)\frac{gn^2 M\sqrt{U^2+V^2}}{h^{4/3}} \tag{4.2}$$

$$(1-\lambda)\frac{\partial N}{\partial t}+\frac{\partial \beta UN}{\partial x}+\frac{\partial \beta VN}{\partial y}=-gh(1-\lambda)\frac{\partial (h+z)}{\partial y}-(1-\lambda)\frac{gn^2 N\sqrt{U^2+V^2}}{h^{4/3}} \tag{4.3}$$

where M, N are grid-average fluxes per unit width in x and y directions, respectively. λ is the percentage of area covered by buildings or houses in each grid and β is the percentage of impervious length along each grid interface. For the sake of numerical stability, both space-staggering and time-staggering are employed in discretizing the equations. The computational grid size was 10 m × 10 m. Manning coefficient (n) on each grid was determined according to land use type as shown in Table 4.1. For grid with mixed land uses, a composite Manning coefficient was calculated as below

$$n_c^2=\sum n_i^2 A_i / \sum A_i \tag{4.4}$$

Table 4.1 Values of the Manning coefficient used in the simulation

Land use	Urban area	Agricultural field	Forest	Road
Manning n	0.067	0.025	0.06	0.043

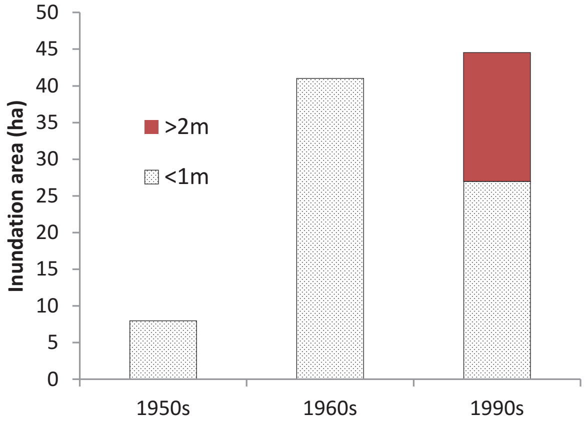

Fig. 4.3 Change in inundation area and depth

where A_i and n_i are the area and the Manning coefficient of land use type i, respectively.

As shown in Fig. 4.3, the simulation results for a lake overflow scenario based on historical records of lake's overflow revealed that potential inundation area increased significantly in the 1990s as compared to the 1950s due to urbanization. Furthermore, although the total inundation area in the 1990s was more or less the same as the 1960s, areas with potential flooding depth above 2 m appeared in the 1990s. In other words, flood inundation depth may increase with the level of urbanization. How does the potential distribution of flood inundation depth in an urban area vary with the level of urbanization has not been addressed up to now.

A related issue is that there are many underpasses along roads in urban areas (Fig. 4.4), and many of them are vulnerable to flooding. In 2008, a lady drove her car into an underpass on a road in Tochigi Prefecture and drowned because of high water depth. The same tragedy occurred in Aichi Prefecture in 2016. The water depth at the underpass was reported to be higher than 3 m. The total number of road underpasses in Japan is about 3500. According to an experiment, the water depth of 70–80 cm is the limit that a driver can open the front door of a submerged vehicle.

During the flood disaster occurred in the watershed of Lake Tega in 2013, an underpass on the National Road 365, as shown in Fig. 4.5, was also deeply inundated although it did not lead to any life loss.

Road networks are the most fundamental component of social infrastructure. They play an essential role in economy and account for a large percentage of land use in urban areas. However, the impacts of roads on urban flooding have received little attention (Huang 2000, 2012). On July 13, 2004, a heavy storm caused a levee breach in Ikarashi River in Niigata Prefecture, Japan. The levee breach caused

Fig. 4.4 Road underpass where flood inundation depth could be high

Fig. 4.5 An underpass on the National Road 365, which was flooded in 2013

flooding in a large area of Sanjo City, Niigata Prefecture (Huang 2006) and 15 people died in this flood disaster (Tamura, 2005). Flood inundation simulation with the 2-D model described above revealed that the flood water spread out mainly in two direction: toward the west and the south. Figure 4.6 shows the distribution of simulated flood depth 3 h after the levee breach. As seen from the figure, the flood

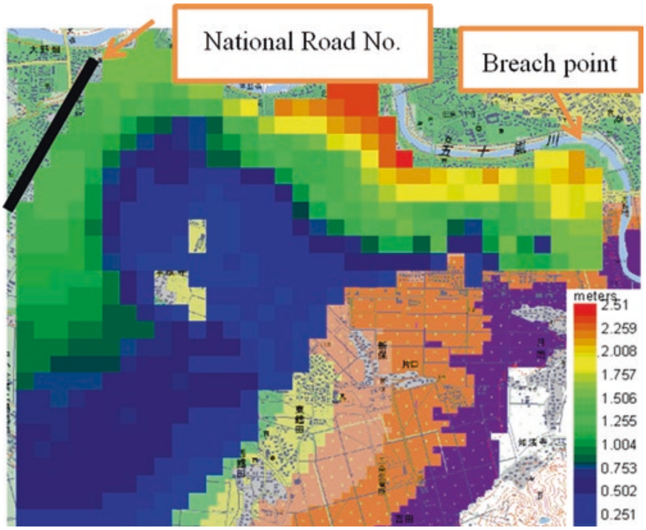

Fig. 4.6 Distribution of simulated flood depth 3 h after the levee breach

water moving toward the west was blocked by the National Road No. 8, which resulted in flood depth deeper than 1 m in areas adjacent to the road.

Another study case is Minami District in Niigata City. As shown in Fig. 4.7, it is an area enclosed by two rivers. It is a flat lowland and very vulnerable to flooding. The road network in the district consists of National Road No.8 and Prefectural Road No.146 running from the North to South, and National Road No.46 running from the West to East, and National Road No.460 running along the Southeast direction. For such a geographical setting, numerical simulations of inundation scenarios were performed. In the case of flood water coming out of the junction, the numerical simulation shows that the Southeast road could block flood waters from moving further to the South, resulting in high inundation depths in the narrow area surrounded by roads, as illustrated in Fig. 4.7.

4.3 Flood Damage

Flood disasters have wide impacts on human beings (e.g. their health and belongings), on society (e.g. public infrastructures, culture, industry production, competitive strength in economy), and on ecological systems (e.g. reduction of agriculture products and animal habitats). As a result, flood damage serves as an indicator of flood disaster impacts caused by the vulnerability to flooding. The estimation of flood damage was initialized by insurance companies, but has become increasing timely and valuable and desirable social data for better flood risk management because of its capability in summarizing all the potential losses after floods. There are a number of definitions of damage caused by disasters. In the case of flood

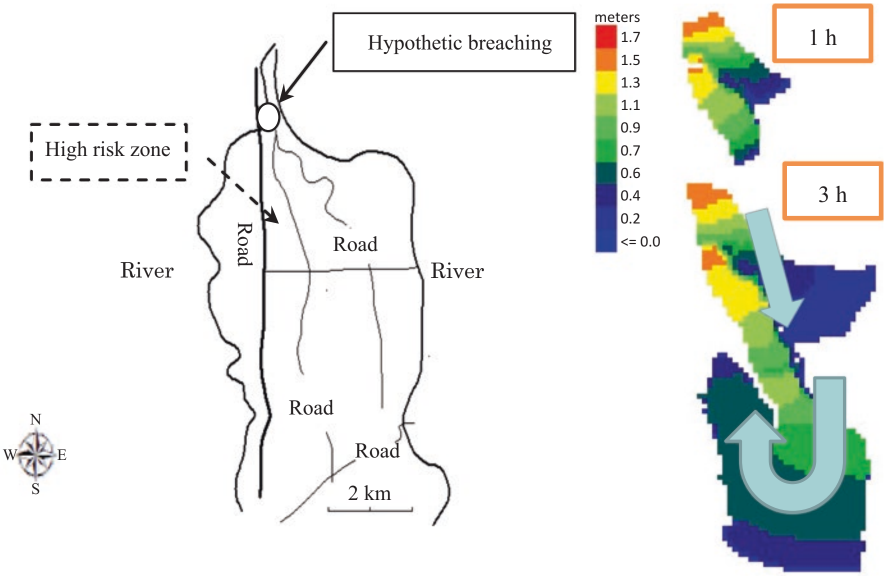

Fig. 4.7 Minami District and the distribution of simulated flood depth assuming a breaching at river junction

Table 4.2 Flood damage classification by Merz and Emmermann (2006)

	Direct damages	Indirect damages
Tangible	e.g. damage to residential building and contents, infrastructure, transportation facilities, erosion of agriculture	e.g. loss of life, injuries, anxiety, damage to history and cultural heritage
Intangible	e.g. disruption to the total transportation network, production losses out of the flood zone, companies'mitigation	e.g. crime, loss of trust in authorities

disaster, damage can be divided into four types: direct tangible, indirect tangible, direct intangible and indirect intangible. Some examples for the different types of damage are shown in Table 4.2. Being tangible or intangible depends on whether or not the damage can be assessed in monetary values or not.

Direct tangible damage refers to the physical damage to residential building and contents, infrastructure such as transportation facilities, and decline of agriculture yield. Direct intangible damage includes production losses out of the flood zone due to the disruption to the transportation network. A good example is the Thailand's Floods of 2011 in which there were 1.8 million households affected, 813 casualties, and 17,578 square kilometers of inundated farm lands. However, the impact was not limited to Thailand but spread to the world. In other words, there was an indirect and tangible damage in addition to the direct tangible damage at home. It was estimated that the flooding in Thailand in 2011 reduced the world's industrial production by 2.5%. In the global era, flooding on one side of the earth can affect the economy on the other side of the earth through global supply chain networks.

Indirect but tangible damage includes stress increase, fatigue due to clean-up and insurance application and crime rate increase. Indirect intangible damage includes loss of trust in authorities, societal disruption and decrease in investors' confidence.

In this work, we propose an extension of the above classification by adding a time dimension. In addition to the delineations by direct or indirect, tangible or intangible, the damage may be further differentiated in short and long terms. The short term impact includes recovery operation, inconvenience and moral damages while long term impacts includes psychological traumas and cultural loss. The Pitt Review "Learning Lessons from the 2007 floods" (2007) reported that the limited evidence available suggested that there are significant short and long-term impacts on psychosocial health. Mental health problems are estimated to account for 80% of all disability adjusted life-years attributable to floods in the UK (Fewtrell and Kay 2008). A review work by Stanke et al. (2012) revealed that there is a growing body of evidence suggesting that floods can have profound effects on people's wellbeing, psychosocial resilience, relationships and mental health, often over extended periods of time. However, the long term impacts of flooding on physical and mental health are still poorly understood and remains as a little-studied subject.

As shown in Fig. 4.8, in the Nakagawa-Ayase River Basin, a significant change in direct and tangible flood damage with urbanization is that even a small-scale rainfall event may cause flooding in urbanized areas. The causes of such a phenomenon have not been scientifically analyzed but can be considered as a reflection of poor urban planning. In urban flood management, it is a common practice to establish a management plan according to a chosen design rainfall expressed in terms of probability or return period. It usually targets a relatively large-scale rainfall event. The occurrence of flood damage in a watershed is often attributed to the

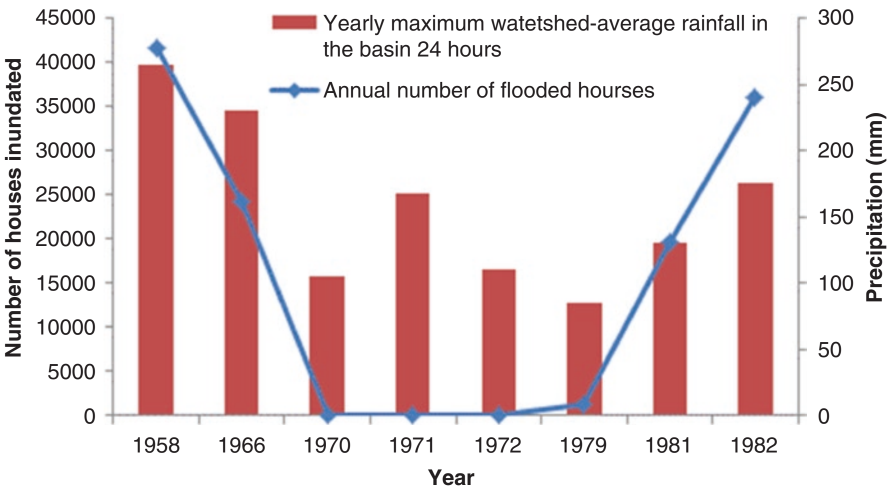

Fig. 4.8 Change in the relationship between rainfall intensity and the number of houses flooded due to urbanization in Nakagawa-Ayase River Basin. (Data source: Edogawa Rive Office)

insufficiency in flood protection standard. Therefore, the damage induced by a small-scale rainfall event poses a challenge to the current practice of flood management planning because such damage was caused by the rainfall much less than the level of protection. As a matter of fact, the development of rainwater storage and infiltration facilities in the Nakagawa-Ayase River Basin has been pursued for decades. The management goal for the river basin is to manage a total volume of flood water that is set to be 179,000,000 m^3 through river channel, retarding basin, diversion channel, storage and infiltration facility without flooding.

In 1992, a flood countermeasure known as "The Metropolitan Area Outer Underground Discharge Channel" for the Nakagawa-Ayase River Basin entered its construction phase. It is a diversion tunnel, 6.3 km long 10 m in diameter and 50 m below the ground. By the combination of vortex flow dropshaft and underground tunnel, it diverts water from the Nakagawa-Ayase River Basin to Edo River in case of heavy rainfall or large flood in the Nakagawa River and its operation stated from 2012. In July 2000, a rainfall of 159.5 mm caused flooding in the watershed and the total inundated area was 113.76 ha. In July 2014, a rainfall of 141 mm also caused flooding in the watershed but the total inundated area was 1.81 ha due to the operation of the diversion tunnel. For a number of large storm events, the reductions of direct and tangible damage estimated by the river administration were compiled in Fig. 4.9. The effectiveness of the facility to large-scale rainfall events is remarkable. In September 2015, a record high rainfall hit the watershed and the Outer Underground Discharge Channel attained the highest damage reduction since its operation. However, a comprehensive evaluation of the damage reduction by the facility in relation to land use change and its future trend in the watershed has not been conducted. Since the Nakagawa-Ayase River Basin has a bow-shaped topography, some locations are extremely vulnerable to flooding and the Metropolitan Area Outer Underground Discharge Channel does not operate for small-scale rainfall events, would the flood damage by small-scale rainfall event be totally eliminated

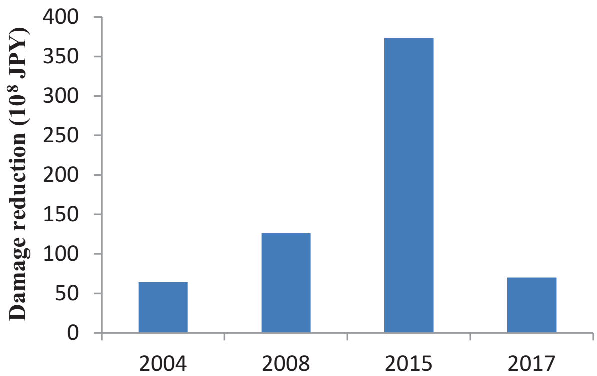

Fig. 4.9 Reduction of direct and tangible flood damage by the underground diversion channel in Nakagawa-Ayase River Basin. (Data source: Edogawa Rive Office)

remains a concern. Better collaboration between flood managers and urban planner can be considered as indispensible to minimize flood damage in the watershed.

In U.S., there is a National Response Framework (NRF) that functions as a guide to how the Nation responds to all types of disasters and emergencies. It is comprised of the core document, the Emergency Support Function (ESF), Support, and Incident Annexes, and the Partner Guides and aimed to coordinate the responsibilities of authorities and capture best practices for managing incidents that range from the serious but purely local, to large-scale catastrophic natural disasters or terrorist attacks. The concept is that planning makes it possible to manage the entire life cycle of a potential crisis, and help stakeholders learn their roles and governments at all levels develop detailed, robust, all-hazards response plans. However, it did not provide any guideline on post-disaster recovery. Following Hurricane Katrina, however, the USA Congress passed the Post-Katrina Emergency Management Reform Act of 2006. The Act requires FEMA to develop a National Disaster Recovery Strategy that addresses many of the shortfalls found in the National Response Framework, including a clarification of the federal roles in long-term recovery and proposed improvements to existing programs that better reflect local needs (Topping 2009). In light of such a progress, embedding flood damage estimation into urban planning could be considered as a strategy for better flood risk management. To develop such a new strategy, data and methodology for more accurate damage estimation are required.

4.4 Summary

Urbanization modifies the hydrological cycle of a watershed causing change in flood peak, peak timing, total volume and frequency. In addition to these effects, this chapter highlights the possibility of flood inundation depth may increase with urbanization. It also shows that even a small-scale rainfall event may cause flood damage in urbanized areas. For better flood risk management and damage reduction, better planning for urban development is needed that takes account of urbanization effects explicitly and adequately.

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References

Anderson DG (1968) Effects of urban development on floods in Northern Virginia: U.S. Geological Survey Water-Supply Paper 2001-C. p 22

Barron OV, Pollock D, Dawes W (2011) Evaluation of catchment contributing areas and storm runoff in flat terrain subject to urbanization. Hydrol Earth Syst Sci 15:547–559

Bates PD, De Roo APJ (2000) A simple raster-based model for flood inundation simulation. J Hydrol 236:54–77

Bengtsson L, Bonnet R-M, Calisto M (2014) The earth's hydrological cycle (Space Sciences Series of ISSI). Springer, Dordrecht

Campana NA, Tucci CEM (2001) Predicting floods from urban development scenarios: case study of the Dilúvio Basin, Porto Alegre, Brazil. Urban Water 3:113–124

Dams J, Dujardin J, Reggers R, Bashir I, Canters F, Batelaan O (2013) Mapping impervious surface change from remote sensing for hydrological modeling. J Hydrol 485:84–95

DeGroot W (1982) Stormwater detention facilities. In: ASCE conference proceedings, Henniker, New Hampshire, USA

Dow CL, DeWalle DR (2000) Trends in evaporation and Bowen ratio on urbanizing watersheds in eastern United States. Water Resour Res 36:1835–1843

Fewtrell L, Kay D (2008) An attempt to quantify the health impacts of flooding in the UK using an urban case study. Public Health 122:446–451

Fletcher TD, Andrier H, Hamel P (2013) Understanding, management and modeling of urban hydrology and its consequences for receiving waters; a state of the art review. Adv Water Resour 51:261–279

Hawley RJ, Bledsoe BP (2011) How do flow peaks and durations change in suburbanizing semi-arid watersheds? A southern California case study. J Hydrol 405:69–82

Hollis GE (1975) The effect of urbanization on floods of different recurrence interval. Water Resour Res 11(3):431–435

Huang GW (2006) Characterization of flood inundation in Sanjo City, Japan on July 13, 2004. J Hydrodyn Ser B 18(3):295–299

Huang GW (2011) Long-term impact of policy mismatch on watershed health. Int J River Basin Manag 9(1):79–84

Huang S, Cheng S, Wen J, Lee J (2008) Identifying peak-imperviousness-recurrence relationships on a growing-impervious watershed, Taiwan. J Hydrol 362(3):320–336

Huang GW (2000) Does road accelerate flooding? J Jpn Soc Hydrol Water Res 23(3):248–254. (in Japanese)

Huang GW (2012) From confining to sharing for sustainable flood management. Sustainability 4(7):1397–1411

James DM, Kim H, Kjeldsen TR et al (2014) Assessing the impact of urbanization on storm runoff in a peri-urban catchment using historical change in impervious cover. J Hydrol 515:59–70

Jeremie B, Tim DF, Justin FC, Matthew JB (2017) Stormwater infiltration and the 'urban karst' – a review. J Hydrol 552:141–150

Johnson SL, Sayre DM (1973) Effects of urbanization on floods in the Houston, Texas metropolitan area. Geological Survey, Water Resources Division, Austin, pp 3–73

Kondoh A, Nishiyama J (2000) Changes in hydrological cycle due to urbanization in the suburb of Tokyo metropolitan area. Jpn Adv Space Res 26(7):1173–1176

Leopold LB (1968) Hydrology for urban land planning – a guidebook of the hydrologic effects of urban land use: U.S. Geol Surv Circ 554:18

Mark JJ (2014) "Urbanization." Ancient History Encyclopedia. https://www.ancient.eu/urbanization/

Merz B, Emmermann R (2006) Dealing with natural hazards in Germany: from reaction to risk management. Gaia-Ecol Perspect Sci Soc 15(4):265–274

Morita M (2014) Flood risk impact factor for comparatively evaluating the main causes that contribute to flood risk in urban drainage areas. Water 6:253–270

O'Driscoll M, Clinton S, Jefferson A, Manda A, McMillan S (2010) Urbanization effects on watershed hydrology and in-stream processes in the Southern United States. Water 2:605–648

Nirupama N, Simonovic SP (2007) Increase of flood risk due to urbanization: a Canadian example. Nat Hazards 40(1):25–41

Okuma T (1981) Flood disaster and control in Tone River. Tokyo University Press (in Japanese)

Oliver HR, Oliver SA (1995) The role of water and the hydrological cycle in global change. Springer, Berlin

Pattison I, Lane SN (2012) The link between land-use management and fluvial flood risk: a chaotic conception? Prog Phys Geogr 36:72–92, 2012

Pitt Review (2007) Learning lessons from the 2007 floods. Cabinet Office 22 Whitehall London SW1A 2WH

Saghafian B, Farazjoo H et al (2008) Flood intensification due to changes in land use. Water Resour Manag 22(8):1051–1067

Shang J, Wilson JP (2009) Watershed urbanization and changing flood behavior across the Los Angeles metropolitan region. Nat Hazards 48:41–57

Shi PJ, Ge Y, Yuan Y, Guo WP (2005) Integrated risk management of flood disasters in metropolitan areas of China. Int J Water Resour Dev 21:613–627

Singh RB, Singh S (2012) Rapid urbanization and induced flood risk in Noida, India. Asian Geogr 28(2):147–169

Stanke C, Murray V, Amlôt R, Nurse J, Williams R (2012) The effects of flooding on mental health: outcomes and recommendations from a review of the literature. PLOS Currents Disasters, 30 May 2012, 1st edn. https://doi.org/10.1371/4f9f1fa9c3cae

Tamura K, Hayashi H, Kimura R (2005) Clarifying suffering of the elderly in the 2004 Niigata flood and the 2004 mid-Niigata prefecture earthquake. J Nat Dis Sci 27(2):67–84

Topping K (2009) Toward a National Disaster Recovery act of 2009. Nat Hazard Obs 33(3):1–9

Xu G, Xu Y, Xu H (2010) Advance in hydrologic process response to urbanization. J Nat Resour 25:2171–2178

Yao L, Chen L, Wei W (2017) Exploring the linkage between urban flood risk and spatial patterns in small urbanized catchments of Beijing, China. Int J Environ Res Public Health 14(3):239

Part II
Monitoring and Simulation of Water-Related Disaster

Chapter 5
Evaluation and Application of the Latest Satellite-Based Precipitation Products with a Distributed Hydrological Model in the Lower Mekong River Basin

Yishan Li, Wei Wang, Hui Lu, and Zhiguo Pang

Abstract Precipitation is a key driving variable for hydrological models. However, in many undeveloped areas, it is hard to obtain reliable and appropriate ground observed precipitation data for hydrology studies, such as the Lower Mekong River Basin (LMRB), which is the most important transboundary river basin in Southeast Asia with sparse coverage of ground level rain gauges. Satellite-based precipitation products could therefore be an alternative choice. In this study, data from the latest released satellite-based precipitation products, the Integrated Multi-satellitE Retrievals for Global precipitation measurement (IMERG) and version 7 of the Tropic Rainfall Measurement Mission (3B42V7), are evaluated and applied with a distributed hydrological model - Geomorphology Based Hydrological Model (GBHM), to examine the effectiveness of satellite-based precipitation products over the LMRB during the period 2014/4/1 to 2015/12/31. The pixel point comparison shows that both the IMERG and 3B42V7 are able to provide reliable precipitation estimate in the LMRB, while the IMERG performs slightly better than the 3B42V7.

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The hydrological application evaluation suggests that both of the IMERG and the 3B42V7 produced reasonable simulations however, the IMERG simulation outperformed the 3B42V7 simulation, with a higher Nash-Sutcliffe efficiency value at most gauges, besides, the 3B42V7-simulations produced serious overestimations of discharge at Nong Khai during July 2015. This may be due to the fact that the 3B42V7 overestimates the rainfall rate in Lao People's Democratic Republic, where the TRMM product was not calibrated because it lacks of available ground observations in the region. Our results demonstrate that the IMERG products can provide more accurate precipitation data than the 3B42V7 over the LMRB, and therefore can be reliably used as forcing data of hydrological simulations over the LMRB.

Keywords Mekong river · Hydrological simulation · Remote sensing · GPM · TRMM

5.1 Introduction

Precipitation is the key forcing variable to estimate land surface hydrological fluxes and states (Nijssen and Lettenmaier 2004). The spatial and temporal pattern, intensity and duration of precipitation have significant effects on hydrological cycles (Sorooshian et al. 2011). Floods, droughts and some other natural hazards are usually caused by anomalies in precipitation (Hong et al. 2004). Consequently, the accuracy of a hydrological simulation is heavily dependent upon the accuracy of precipitation data.

Precipitation data can be measured at local scale by rain gauges, simulated by atmospheric models and retrieved from remote sensing data at global scale. Traditionally, rain gauge observation is treated as the ground truth of precipitation data. However, the distribution of available gauges significantly varies around the world. Undeveloped regions like Africa, Southeast Asia and South America are lacking in rain gauges. Model simulation can provide global-covered rainfall data, but the performance of simulated precipitation data need improve, especially in the areas with complex and multiple landcover.

Thanks to the rapid development of remote sensing techniques, plenty of satellite-based precipitation products have been developed and released, such as the Tropical Rainfall Measuring Mission (TRMM), the Climate Prediction Center MORPHing technique (CMORPH), and the newest Global Precipitation Measurement (GPM), providing unprecedented opportunities for hydrological modeling and prediction, especially for those areas where meteorogical stations are scarce (Li et al. 2013). Owing to the advantages of high spatiotemporal resolution, spatially-distributed, readily accessible and long-recorded information, satellite-based precipitation products have been applied to a number of hydrological studies (Li et al. 2015). However, cloud conditions, retrieval algorithms, and land surface properties can all induce errors in the final precipitation estimation. Consequently, the errors associated with satellite-based precipitation products should be characterized before the data can be used in models (Turk et al. 2008). There are several works to evaluate and compare GPM and/or TRMM, for example, Li et al. compared multiple sets of precipitation data from the Yangze River, Xu et al. examined data from the Yalung Zangbo River, and so on. Recently, He et al. (MRC 2010) compared GPM and TRMM data in the upper Mekong River and found both products can give reliable rainfall estimation in the study region, while GPM captures precipitation events better than the TRMM. Until now, according to the former studies, there has been no comprehensive evaluation of GPM and TRMM over the Lower Mekong River Basin (LMRB). This is partly due to the fact that there are only a few rain gauges in this region and so it is difficult to collect ground rainfall observations promptly.

In this study, we evaluated the performance of the GPM and TRMM in the LMRB in two ways: firstly by making a direct comparison between satellite-rainfall data and ground observations, and secondly using an indirect method to compare the simulated discharge under a distributed hydrological model with that using GPM and TRMM data, separately. Since the simulated discharge is a temporal and spatial integration of rainfall, by using a physical processes-based hydrological model, we can evaluate the reliability of input rainfall through evaluating the simulation results of discharge. The results of our study will demonstrate the accuracy of the IMERG and 3B42V7 in this region, which may help potential users to select data appropriately, and will also provide information to the data producers to help them improve their products. Moreover, the hydrological simulation result will promote the remote sensing application in hydrology and related communities.

5.2 Study Area and Data

5.2.1 Study Area

This study focused on the LMRB, i.e. the lower reaches of the Mekong River Basin. Figure 5.1 shows the geographic information and elevation of the MRB. The Mekong river is the most important transboundary river in Southeast Asia, rising from the Tibetan Plateau in China and flowing through China's Yunnan Province, Myanmar, Lao People's Democratic Republic (PDR), Thailand, Cambodia and Vietnam, six countries in all, before finally discharging into the South China Sea (MRC 2010). It is the tenth largest river in the world, with a length of almost 4900 km, a total catchment area of 795,000 km^2 and an average discharge of 14,500 m^3/s (MRC 2010). The Mekong River flows for about 2200 km, with a decrease of almost 4500 m in elevation from the Tibetan Plateau to the Golden Triangle where the borders of Thailand, Lao PDR and Myanmar come together and where the river becomes very steep and narrow. As the river reaches the lower basin region, major tributary systems develop, which show obvious difference between the left bank and right bank. The left bank tributaries drain the high-rainfall areas of

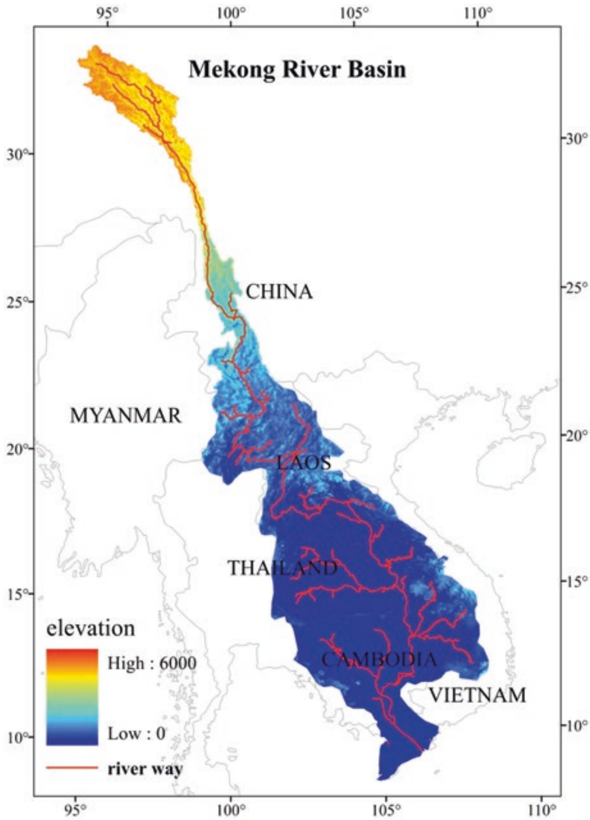

Fig. 5.1 The study area, including elevation and main stream information

Lao PDR, while the right bank tributaries drain a large part of Northeast Thailand, which has a lower rainfall rate. The Mekong River then joins the largest freshwater lake in Southeast Asia, Tonle Sap Lake at Phnom Penh, where the main stream breaks into a number of branches and finally rushes out into the ocean.

5.2.2 Satellite Precipitation Products

The TRMM 3B42V7 and GPM IMERG precipitation data are selected in this paper as the precipitation forcing data. TRMM 3B42V7 data are generated by combining information from both passive microwave and infrared observations with high spatial (0.25°) and temporal (3 h) resolutions, and have been calibrated against ground rain gauge observation at the monthly scale to remove the bias of satellite retrievals (Huffman et al. 2007). The GPM mission is composed of an international network of satellites that provide the next generation of global rain and snow observations (Guo et al. 2016). The IMERG precipitation data estimates come from the various precipitation-relevant satellite passive microwave sensors comprising the GPM constellation and are computed using the 2017 version of the Goddard Profiling Algorithm (GPROF2017), gridded, inter-calibrated to the GPM Combined Instrument product, and are then combined into half-hourly 0.1° × 0.1° fields (Huffman et al. 2012).

5.2.3 Land Surface Data

In order to develop a distributed hydrological model for the MRB, several land surface data are needed, including digital elevation model (DEM) data, soil data, land cover data and vegetation data.

DEM data, provided by USGS at 90 m resolution, is used to generate a digital river channel and network. The river network was generated using AcrGIS functions, and statistical values related to river properties such as river length, slope, density were also calculated. In order to be consistent with th resolution of hydrological model, the river network at 90 m resolution was re-projected into the calculation grid of the hydrological model at a 10 km × 10 km resolution.

Soil properties are very important parameters for runoff generation, evapotranspiration estimation, and routing processes. Soil type and soil depth data were obtained from the FAO digital soil map of the world and used to derive soil properties, such as hydraulic and thermal conductivity.

Land use and land cover data were downloaded from the USGS 1-km Global Land Cover Characteristics Database version 2.0. The dynamic of vegetation is represented by using NDVI data provided by MODIS.

5.2.4 Meteorological Forcing Data and Discharge Data

The other forcing climate data, including air temperature (mean, maximum and minimum), wind speed and sunshine duration, are derived from the ECMWF ERA-interim dataset. The mean air temperature is calculated by taking the average of the maximum and minimum ERA-interim 2-m temperature. The relative humidity is calculated using the specific humidity data and mean temperature data from ERA-interim dataset. All of the ERA-interim data are processed into the scale fit for the model.

The *in situ* observation discharge data for the MRB were obtained from the Mekong River Commission (MRC). The upper part of the Mekong River, also known as the Lancang River, has been developed over the last several decades. More than ten dams and reservoirs have been constructed and are currently operating along the Lancang River. Consequently, the flow regime of the Lancang River has been highly impacted. Conversely, there are almost no big reservoirs located along the main stream of the LMRB, and the flow regime is a largely natural one. In order to remove the impacts of upstream dam operation on the LMRB hydrological simulation, the observed stream flow at Chiang Sean station, which is the upmost station in the LMRB, was input into the hydrological model as the discharge of upstream. Discharge observed at Laung Prabang, Mukdahan, Pakse and Strung Treng are used as validation data to compare the 3B42V7 simulation and IMERG simulation.

5.3 Model Description and Set Up

The hydrological model used in this work is Geomorphology Based Hydrological Model (GBHM) (Yang et al. 2002a, b), the model and its methods has been successfully applied to many different types of rivers, ranging from catchment-scale (Cong et al. 2009; Gao et al. 2008; Jijun et al. 2008; Yang et al. 2004) to continental-scale [16]. The GBHM consists of four key characteristics: a gridded discretization scheme, a sub-grid parameterization scheme, a hillslope based hydrological modeling module, and a kinematic wave flow routing module (Yang et al. 2002a, b).

The digital basin is defined using DEM (YANG et al. 1997). The digital basin is sub-divided into a number of cascade-connected flow intervals following the flow distance from outlet to upper source, and using the area and width functions to group the topography and divide the catchments into a series of flow interval hillslopes (Yang et al. 2002a, b). The hillslope is the fundamental computation unit in the model, providing lateral inflow estimates to the same portion of the main stream (see Yang et al. 2002a, b for further details). The catchment parameters related to topography, land use and soil are then calculated for each simulation unit. By establishing a digital basin, the study basin can be divided into a discrete grid system. The grid is represented by a number of geometrically symmetrical hillslopes. The complex, two-dimensional water kinematics can be simplified to a single dimension by applying this flow-interval and hillslope-river based scheme of sub-grid parameterization. A physically based model is used to simulate the hydrological processes of snowmelt, canopy interception, evapotranspiration, infiltration, surface flow, subsurface flow and the exchange between the groundwater and the river for each hillslope. Finally, a nonlinear, numerical river routing scheme is used to calculate the catchment runoff. The model structure is shown in Fig. 5.2 (Wang et al. 2016).

In order to stay consistent with the time period of the IMERG, the study period is selected as 2014/4/1–2015/12/31, i.e. 21 months. The 3B42V7 and IMERG precipitation data were interpolated to 10 km resolution in the GBHM model processing, the Chiang Sean gauge's discharge input data were hourly scale to control the upper discharge. Due to the lack of observation data in the Mekong River, and the short study period, it is very difficult to calibrate the model used in this study. The parameters set and the model calibration used were utilized in a former Mekong-focused study (Wang et al. 2016). The discharge station information is shown in Table 5.1.

5.4 Evaluation Matrix

Three indices were used to measure the model performance for the two precipitation data simulations: the modified Nash-Sutcliffe efficiency coefficient (NASH), the ratio of the absolute error to the mean (RE) and the relative Root-mean-square error (RMSE). These indices were used to evaluate the agreement between the simulated

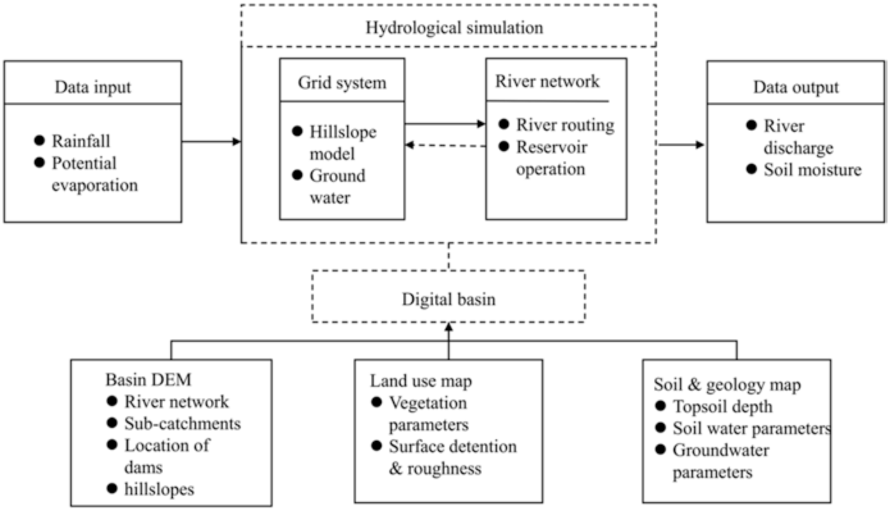

Fig. 5.2 The structure of the Geomorphology Based Hydrological Model

Table 5.1 Discharge station information

Station	Drainage area 10^4 km^2 (ratio)	Average runoff m^3/s (ratio %)
Chiang Sean	18.9 (23.8)	2688 (18.6)
Luang Prabang	26.8 (33.7)	3913 (27.0)
Mukdahan	39.1 (49.2)	7782 (53.7)
Pakse	54.5 (68.6)	9880 (68.2)
Stung Treng	63.5 (79.9)	13,133 (90.1)

and observed hydrographs at monthly and daily scales. The equations used to calculate these indices are as follows:

$$NASH = 1 - \frac{\sum_{i=1}^{T}\left(obs_i - sim_i\right)^2}{\sum_{i=1}^{T}\left(obs_i - \overline{obs}\right)^2} \tag{5.1}$$

Equation 5.1 is the NASH efficiency coefficient formula. NASH efficiency coefficients range from negative infinity to 1. The closer to 1, the more accurate the discharge hydrograph simulation.

$$RE = \frac{\overline{sim} - \overline{obs}}{\overline{obs}} \times 100\% \tag{5.2}$$

Equation 5.2 is the formula for relative error. The smaller the RE, the more accurate the discharge simulation.

$$RRMSE = \frac{\sqrt{\frac{1}{n} * \sum_{i=1}^{n} \left(obs_i - sim_i\right)^2}}{\overline{obs}} \tag{5.3}$$

Equation 5.3 is the relative root-mean-square error (RRMSE). A smaller RRMSE indicates a more accurate simulated discharge result. The $\overline{sim}$ and $\overline{obs}$ in these equations represent the mean simulated and observed discharges, respectively. i refers to the time (the number of day or month). n refers to the total number of days or months.

5.5 Results

5.5.1 Direct Evaluation of the IMERG and 3B42V7

There are around 50 rain gauges located in the LMRB. However, during our study period, only 34 gauges provided rainfall observations. Figure 5.3 shows the distribution of these 34 stations. It is clear that most stations are located around the LMRB. These stations are operated by Thailand and Vietnam. There are few stations in Lao PDR, with almost no stations in Cambodia. Such a sparse distribution of rain gauges fails to provide reliable rainfall information for regional application. However, data from these stations can be used to evaluate the IMERG and 3B42V7 through the point-pixel comparison.

Figure 5.4 shows a scatter plot for the IMERG and 3B42V7 against ground rain gauge observations for the study period as a whole. It is obvious that both products perform similarly in the LMRB, i.e. they both provide good estimations for low rainfall occurrences but underestimate heavy rainfall occurrences. Quantitatively, the IMERG has a slightly lower RRMES and a higher correlation coefficient than the 3B42V7 (Table 5.2).

5.5.2 Evaluation of Discharge Simulation

Figure 5.5 shows the comparison of the IMERG and 3B42V7 simulations against observations at the five discharge stations, while Table 5.3 summarises the models' performance when driven by different precipitation data. From Fig. 5.5 it can be found that (1) both the IMERG and 3B42V7 are able to drive the GBHM and can get reliable discharge simulations at the monthly scale; (2) in most discharge stations, the discharge driven by the IMERG-simulation is closer to the observed discharge than that driven by the 3B42V7-simulaiton. Such findings are as expected, since both the TRMM and GPM are calibrated with ground observations at the monthly

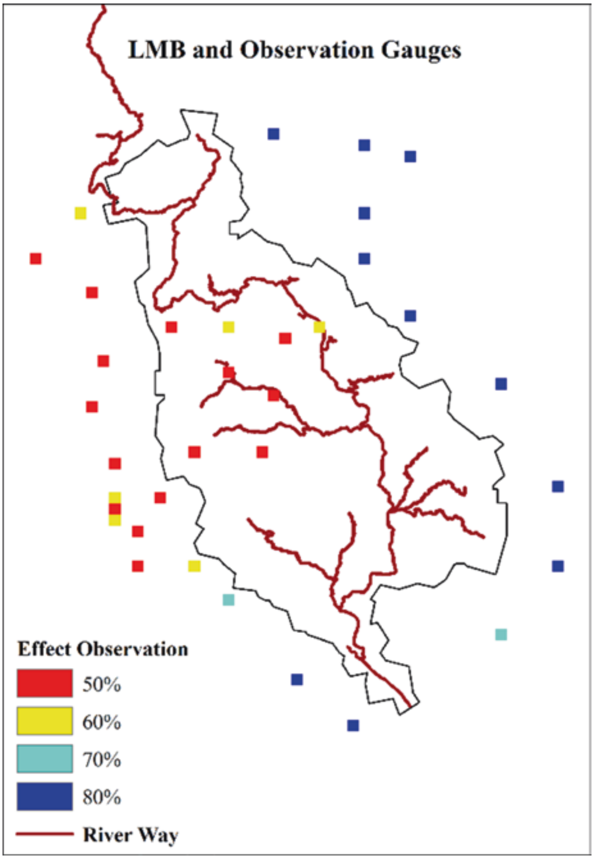

Fig. 5.3 Distribution of rain gauges with observation in the study period

scale, and the GPM is developed on the basis of the TRMM with more accurate sensors and greater accumulated experience.

More specifically, from the evaluation indexes shown in Table 5.3, it is clear that both the IMERG and 3B42V7 simulations have monthly NASH coefficients larger than 0.8, except for the 3B42V7 simulation at Nong Khai station. From the view of RRMSE, both simulations are performing well, with RRMSE less than 0.3 for most stations. Moreover, for all five stations, the IMERG simulation shows higher NASH coefficients and lower RRMSEs than the 3B42V7 simulation. This indicates that the new generation satellite rainfall product performs as well as expected.

Table 5.3 also shows the statistical results at the daily scale. In general, the daily discharges were also well simulated by both the IMERG and 3B42V7. Compared with those simulated at the monthly scale, the NASH coefficients of the daily simulations decreased slightly (0.05~0.17) and the RRMSEs increased from 0.3 to 0.4, with only one exception, the Nong Kai station. Figure 5.6 shows the comparison of simulated and observed discharges at the daily scale. It is obvious that the simulation results, both IMERG and 3B42V7, are generally in agreement with observa-

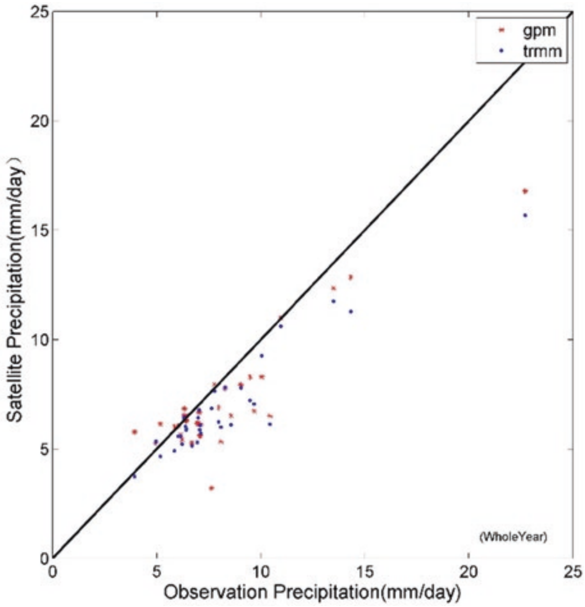

Fig. 5.4 Performance of the IMERG and 3B42V7 at 34 gauges during the study period

Table 5.2 Statistic matrix for IMERG and 3B42V7 evaluation

Metrics	3B42V7	IMERG
RRMSE	2.171	1.952
RB	0.142	0.150
CC	0.379	0.507

tions. This means that the satellite precipitation data, which are calibrated at the monthly scale, are able to drive hydrological models to produce reliable discharge simulations in the LMRB even at the daily scale.

From both Table 5.3 and Fig. 5.6, we find that the 3B42V7 fails to simulate discharge at Nong Khai station, while the IMERG provides a modest simulation. In order to identify the reasons of this difference we compared the original 3B72V7 precipitation data with that of the IMERG. Figures 5.7 and 5.8 show the monthly average rainfall of the 3B42V7 and IMERG and the differences between them in July and August of 2015, respectively. From these two sets of maps it is clear that there are small difference in most regions of MRB, except in the sub-basins around Nong Khai station. Both of the two satellite-based products suggest that the rainfall center is around Nong Khai during July and August, while the rainfall center of 3B42V7 is on upstream of Nong Khai against to the rainfall center of IMERG is located at downstream of Nong Khai. From the differences shown in the maps in Figs. 5.7 and 5.8, the 3B42V7 demonstrates more rainfall in the region from Luang Prabang to Nong Khai than IMERG. While the 3B42V7 demonstrates less rainfall in the region from Nong Khai to Mukdahan than IMERG. However, there are almost

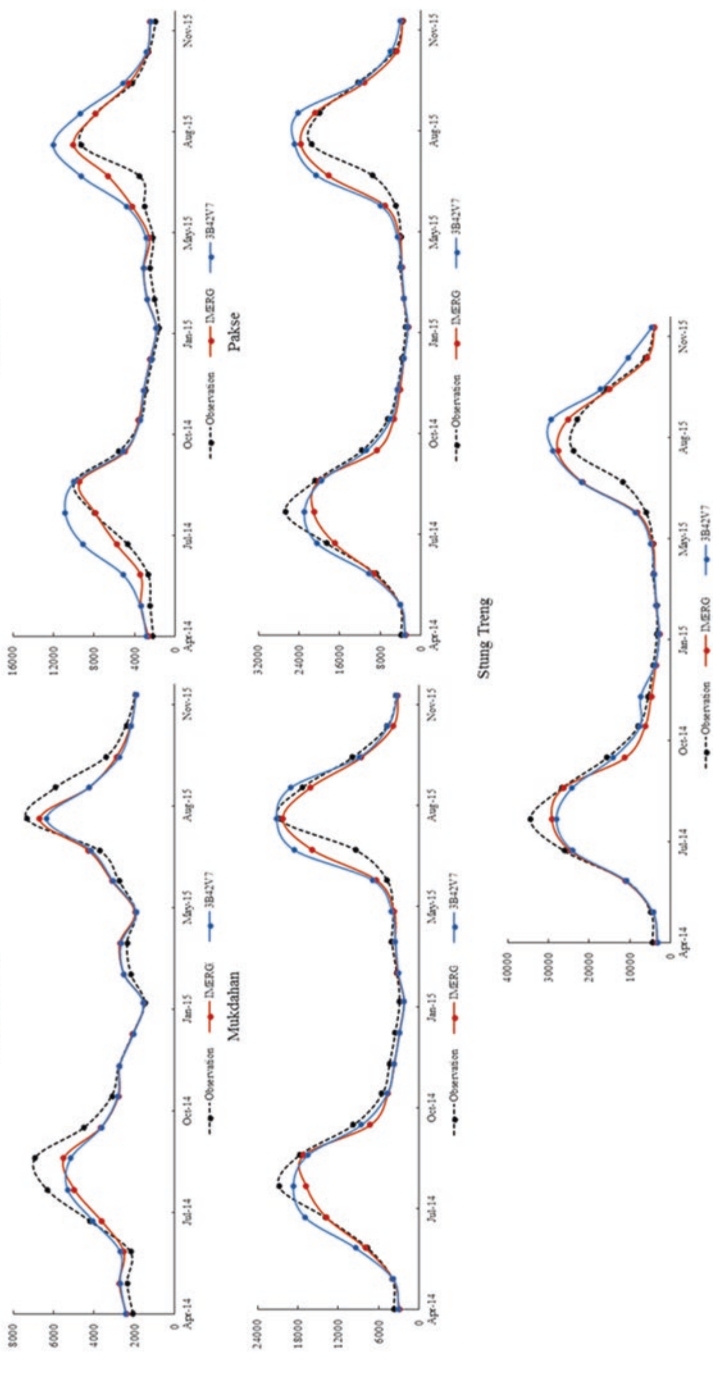

Fig. 5.5 Comparison of monthly discharge at the five discharge stations

Table 5.3 Discharge simulation results of the two data force experiments

Forcing data	Stations	Evaluation Index				
		RE (%)	NASH-monthly	RRMSE-monthly	NASH-daily	RRMSE-daily
3B42V7	Luang Prabang	−7.0	0.84	0.203	0.79	0.276
	Nong Khai	**31.4**	**0.36**	0.616	**0.01**	0.689
	Mukdahan	−4.5	0.85	0.278	0.65	0.460
	Pakse	9.1	0.83	0.308	0.66	0.483
	Stung Treng	7.1	0.86	0.297	0.70	0.470
IMERG	Luang Prabang	−6.5	0.85	0.195	0.77	0.266
	Nong Khai	12.4	0.87	0.220	0.64	0.412
	Mukdahan	−4.3	0.90	0.223	0.74	0.401
	Pakse	−1.0	0.88	0.262	0.73	0.434
	Stung Treng	0.1	0.90	0.249	0.79	0.397

Bold values in the table represents abnormal results which are obvious unreliable and problematic
RE ratio of the absolute error to the mean, *NASH* modified Nash-Sutcliffe efficiency coefficient, *RRMSE* relative Root-mean-square error

no rain gauges in this region, so it is hard to say which product is more accurate indirectly. Consequently, we can only evaluate the performance of rainfall products indirectly by comparing the discharge simulations.

From Table 5.3, it is clear that the 3B42V7 simulation shows a much bigger RE (31.4%) at Nong Khai station than the IMERG simulation does (12.4%). Figure 5.6 suggests that the 3B42V7 simulation overestimated discharge mainly during the raining season. However, both Fig. 5.6 and Table 5.3 demonstrate that the 3B42V7 simulation has a comparable accuracy to the IMERG simulation at Mukdahan station. From Figs. 5.7 and 5.8 we can identify that the 3B42V7 simulation obviously underestimates rainfall in the region from Nong Khai to Mukdahan. It is speculated that the overestimations and underestimations compensate for each other, thus making the 3B42V7 simulation performance comparable to the IMERG simulation at Mukdahan station. By combing the above-mentioned findings, we conclude that (1) the IMERG has a good rainfall estimation in the region from Luang Prabang to Mukdahan, and (2) the 3B42V7 overestimates rainfall in the region from Luang Prabang to Nong Khai and underestimates rainfall in the region from Nong Khai to Mukdahan.

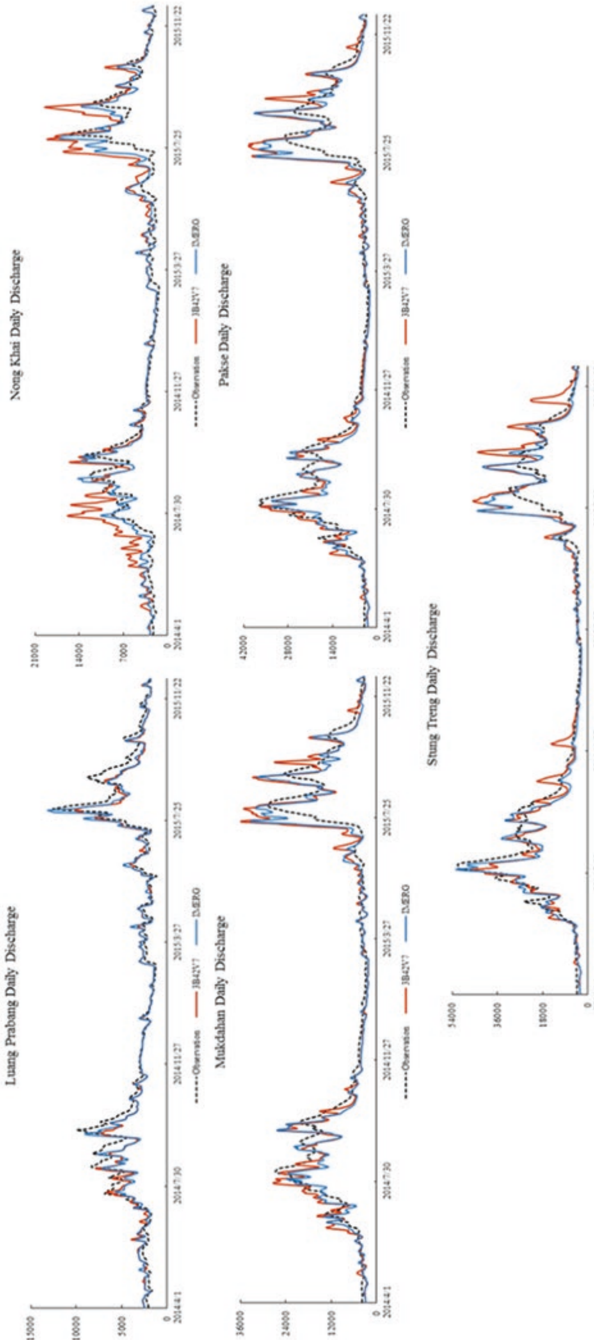

Fig. 5.6 Comparison of daily discharge at the five discharge stations

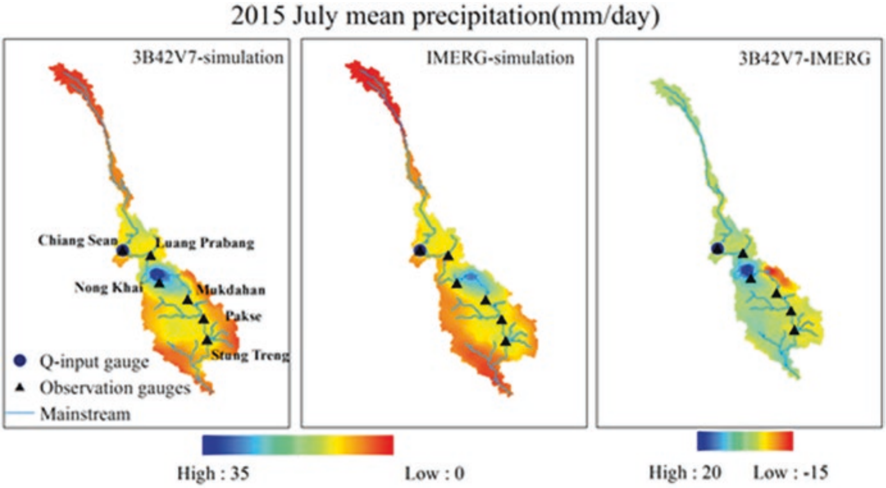

Fig. 5.7 Averaged rainfall of the 3B42V7 (left), IMERG (middle) simulations, and the differences between them (left) in July 2015

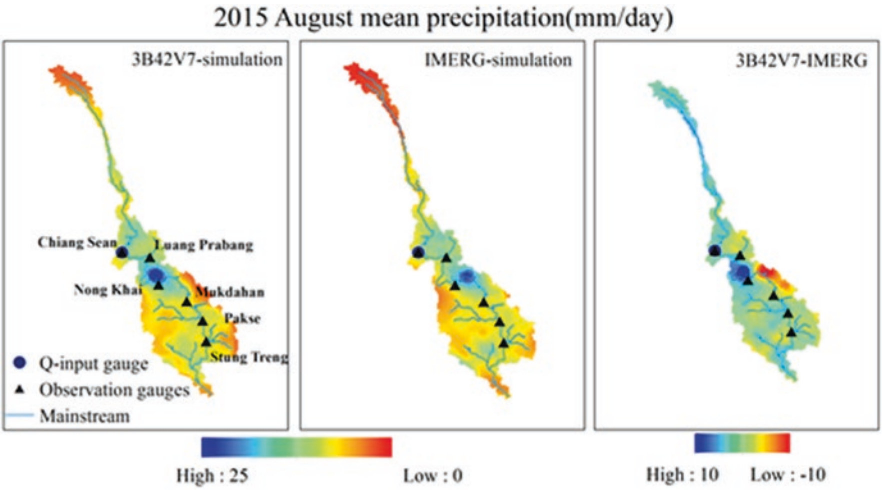

Fig. 5.8 Averaged rainfall of the 3B42V7 (left), IMERG (middle) simulations, and the differences between them (left) in August 2015

5.6 Conclusions

Precipitation is one of the most important inputs of land surface models, hydrological models and ecological models. In regions like the LMRB, where rain gauges are sparsely and unevenly distributed, satellite-based precipitation data can provide a valuable and unique data source for hydrological research.

This study presents a first evaluation of the TRMM 3B42V7 and GPM IMERG in the LMRB, both through a direct point-pixel comparison and an indirect discharge comparison. The point-pixel comparison, conducted over 34 rain gauges, shows that the 3B42V7 and IMERG perform similarly in rainfall estimations, while statistically, the IMERG is slightly better than the 3B42V7, with smaller RRMSEs and bigger correlation coefficients.

For discharges simulated at most stations, both the IMERG and 3B42V7 generally demonstrated good results at the monthly scale, with a NASH higher than 0.8 and RRMSE less than 0.3. The results at the daily scale were less accurate than those at the monthly scale, but still acceptable with a NASH around 0.6.

The 3B42V7 simulation showed obvious overestimation of discharge at Nong Khai station, with a 0.01 daily NASH and 0.68 RRMSE. At the same time, the IMERG simulation performed well, with a daily NASH of 0.62 and RRMSE of 0.412. This difference indicates that the IMERG outperforms the 3B42V7 in this region. A more detailed analysis found that the 3B42V7 overestimated rainfall in the region from Luang Prabang to Nong Khai and underestimated rainfall in the region from Nong Khai to Mukdahan.

Some limitations exist in this study. Although our study shows that the IMERG provides a better input rainfall product than the 3B42V7 for the GBHM, this trend should be tested in other cases, such as using different remote sensing-based rainfall data for different distributed hydrological models in different basins. Another uncertainty may lie in the short period of this study. To achieve more stable and reliable evaluation results, a longer simulation period is preferred. This will become available as GPM data is continuously accumulated.

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References

Cong Z, Yang D, Gao B, Yang H, Hu H (2009) Hydrological trend analysis in the Yellow River basin using a distributed hydrological model. Water Resour Res 45(7)

Gao B, Yang DW, Liu ZY, Zhu CB (2008) Application of a distributed hydrological model for the Yarlung Zangbo river and analysis of the river runoff. J China Hydrol 28(3):40–44

Guo H, Chen S, Bao A, Behrangi A, Hong Y, Ndayisaba F, ... Stepanian PM (2016) Early assessment of integrated multi-satellite retrievals for global precipitation measurement over China. Atmos Res 176: 121–133

Hong Y, Hsu KL, Sorooshian S, Gao X (2004) Precipitation estimation from remotely sensed imagery using an artificial neural network cloud classification system. J Appl Meteorol 43(12):1834–1853

Huffman GJ, Bolvin DT, Nelkin EJ, Wolff DB, Adler RF, Gu G, … Stocker EF (2007) The TRMM multisatellite precipitation analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. J Hydrometeorol 8(1):38–55
Huffman GJ, Bolvin DT, Braithwaite D et al (2012) Developing the integrated multi-satellite retrievals for GPM (IMERG)[J]. Acta Paulista De Enfermagem 25(1):146–150
Jijun X, Dawen Y, Zhiguo C, Yong J (2008) Flood forecasting in the three-gorge reach based on a distributed hydrological model (I): modeling and calibration. J China Hydrol 28(1):32–37
Li Z, Yang D, Hong Y (2013) Multi-scale evaluation of high-resolution multi-sensor blended global precipitation products over the Yangtze River. J Hydrol 500:157–169
Li Z, Yang D, Gao B, Jiao Y, Hong Y, Xu T (2015) Multiscale hydrologic applications of the latest satellite precipitation products in the Yangtze River basin using a distributed hydrologic model. J Hydrometeorol 16(1):407–426
MRC (2010) IWRM-based Basin Development Strategy for the Lower Mekong Basin. Fourth draft. Mekong River Commission
Nijssen B, Lettenmaier DP (2004) Effect of precipitation sampling error on simulated hydrological fluxes and states: anticipating the Global Precipitation Measurement satellites. J Geophys Res Atmos 109(D2)
Sorooshian S, AghaKouchak A, Arkin P, Eylander J, Foufoula-Georgiou E, Harmon R, … Skofronick-Jackson G (2011) Advanced concepts on remote sensing of precipitation at multiple scales. Bull Am Meteorol Soc 92(10):1353–1357
Turk FJ, Arkin P, Sapiano MR, Ebert EE (2008) Evaluating high-resolution precipitation products. Bull Am Meteorol Soc 89(12):1911–1916
Wang W, Lu H, Yang D, Sothea K, Jiao Y, Gao B, … Pang Z (2016) Modelling hydrologic processes in the Mekong River Basin using a distributed model driven by satellite precipitation and rain gauge observations. PLoS One 11(3):e0152229
YANG D, HERATH S, MUSIAKE K (1997) Analysis of geomorphologic properties extracted from DEMs for hydrologic modeling. Proc Hydraul Eng 41:105–110
Yang D, Herath S, Musiake K (2002a) A hillslope-based hydrological model using catchment area and width functions. Hydrol Sci J 47(1):49–65
Yang D, Oki T, Herath S, Musiake K, Singh VP (2002b) A geomorphology-based hydrological model and its applications. Mathematical models of small watershed hydrology and applications, 300
Yang D, Musiake K (2003) A continental scale hydrological model using the distributed approach and its application to Asia[J]. Hydrol Process 17(14):2855–2869
Yang D, Koike T, Tanizawa H (2004) Application of a distributed hydrological model and weather radar observations for flood management in the upper Tone River of Japan. Hydrol Process 18(16):3119–3132

Chapter 6
Assessment of Climate Change Impacts on Urban Rainfall Extremes for Achieving Sustainable Urban Water Development in Hanoi, Vietnam

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Abstract In recent decades, the increased frequency of disaster events, particularly hydro-meteorological disasters, have threatened human lives and infrastructure. In the context of climate change, urban water management became more complicated because of erratic or heavy rain events or prolonged droughts. Now, sustainable water management and planning requires to visualize the potential impact of climate change on extreme rainfall pattern in order to reduce the climatic vulnerability. This chapter evaluates the impact of climate change on extreme rainfall intensities under different greenhouse gases emission RCP (Representative Concentration Paths) considering future period of 2070–2099 over a baseline period of 1976–2005. The impacts were assessed using rainfall output of 5 General Circulation Models (GCM) under RCP 8.5 (high) and RCP 4.5 (medium) emission scenarios. Bilinear interpolation and quantile mapping technique were applied to extract rainfall data from grid points onto station points and to correct bias of GCM simulations in comparison with the observational data respectively. To derive the rainfall IDF (Intensity-Duration-Frequency) curves, daily rainfall output was temporally downscaled using scaling method. In the study, IDF curves were developed and the performances of the downscaling method were evaluated. The results indicate that the mean of corrected monthly rainfall and the frequency of wet days are considerably closer to observation than the raw rainfall estimates. In addition, the bias correction method accurately captured extreme rainfall values for all 5 GCM

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and indicated that by the end of the century, under different scenarios the rainfall intensity is increasing for all the durations and the return periods. The results will assist the water manager and urban planner to design the sustainable and robust water infrastructure.

Keywords Urban water planning · Sustainable water management · Rainfall IDF · Climate change · Bias correction · Downlscaling

6.1 Introduction

Water is a basic necessity and valuable resource that needs to be managed and used sensibly, which is gradually transforming into a crisis that is responsible for a bad health condition, destroying livelihoods for many and inflicting unnecessary suffering for poor (Connor 2015; Hanjra and Qureshi 2010). It is one of the biggest challenges our generation is facing (IPCC 2014). To overcome this crisis, development of clean potable water, managing wastewater efficiently, providing basic sanitation facilities, developing robust water management in both urban and rural areas and integrating sustainability in our daily life is necessary to achieve water sustainability (Conca 2006; UNEP 2012; Tremblay 2010). Specially the condition is deteriorating in urban areas, where industrialization, growing human population, and urbanization exerting a significant amount of pressure on the water bodies that keep ecosystems flourishing and nourished. In urban region around the world, the water systems such as rivers, lakes, ponds and, aquifers are drying up due to changes in climate or pollution due to anthropogenic activities (Saraswat and Kumar 2016; Saraswat et al. 2016). The climate change is altering the patterns of water cycle along with the weather, which is causing floods in some region and droughts in others at the same time. The climate change has been described as the significant changes in the weather patterns, temperature, precipitation (intensity, frequency and duration) and several others (Saraswat et al. 2017; USEPA 2015). In year 2014, the IPCC assessment report analyzed that the intense rainfall events are seen worldwide and the number of such events increased, particularly on land regions, which induced heavy discharge in catchments (IPCC 2014). The heavy discharge can lead to greater risks of flooding at a regional scale and national scale (IPCC 2014). It is recognized by IPCC that the water-related issues such as flooding and water scarcity is major issues to deal with in the twenty-first century (Adusumalli and Arora 2015). It is also expected that 60–70% of the world's population may even face water scarcity due to the increasing trend of climate change and urbanization (UNDESA 2016).

Most of the time, due to communication and coordination inefficiencies of system urban planners and water manager unable to coordinate effectively on designing of approaches, results in disaster for sustainable urban planning. In this chapter, we argue that the assessment of climate change impact on rainfall IDF (Intensity-Duration-Frequency) curves will be helpful and support urban water management, which should be an integral part of sustainable urban development and planning. Flood risk in urban area is a serious challenge for an effective urban planning and development. Recently, the approaches to urban water management and flood risk control have been changed from “hard measures” to more “integrated management” measures such integration of stormwater management, rainwater harvesting, structural development and also ‘soft’ measures all together, in which ecosystem services for flood regulation play an important role (Mishra et al. 2017; Mai and Herath 2014). In urban regions, the rapid and unplanned urbanization is one of the major thrusts for deteriorating urban water management and water security (Mishra et al. 2017; Saraswat et al. 2017). Urbanization leads to the creation of impervious surfaces, which lead to an increase in surface runoff volume and contributes to downstream flooding (Saraswat et al. 2016; Yan et al. 2015), eventually, the loss of recharge affects residential and municipal water supplies. Due to this the environmental problems such as clean water provision, wastewater production, and treatment as well as disasters such as flooding and land subsidence, have become commons in many cities (Mishra et al. 2017; Jago-on et al. 2009). In many urban areas, the sustainable use of water is approaching or exceeding the limits (Mishra et al. 2017; Hatt et al. 2007).

River basins also comprise complex-adaptive systems, and the socio-ecology of rivers needs particular attention for an integrated management (Chakraborty and Chaktraborty 2017). There is a need to carry out management of the freshwater landscapes through the biotic elements the freshwater systems possess, especially so, as it is an often ‘forgotten’ aspect of water resource management. These biotic elements should not be ‘synthetic’, that is, brought in as a quick fix solution for restoration, but should (ideally) be a part of the natural succession of the freshwater systems. It is high time that the urban areas as well as rural areas surrounding urban areas incorporate biotic elements as ‘indicators’ of healthy freshwater environments. These cases also strongly suggest that a biospheric understanding rather than a (scientific) approach that tries to synthetize nature (through, for example, water purification) can be a better solution for sustainable water environments in the urban areas. The importance of rural-urban linkage is no less important feature here as freshwater environments such as rivers and streams pass through irrespective of these landscapes. Also, the rural environments upstream serve as part of the urban watershed and affected by urban land use, creating rivers whose biospheric components are greatly compromised. The example of Lake Kasumigaura near Tokyo, Japan can be raised in this regard. Kasumigaura is a shallow lake (with average depth of about 4 m) with healthy fisheries until around 1970s, when large scale concretization of bed and banks of the Lake and its tributary rivers caused the aquatic vegetation to decrease, with resultant increase in the pollution level of the lake. This is another instant where not accounting the biological properties of the water landscapes has caused a big problem for the lake’s fisheries. The restoration of Kasumigaura with water purification technology has yielded no result and the lake continues to have deterioration in its water quality, with noted eutrophication events. This led to decrease of native and traditional fisheries like smelt harvest and reduce the fisheries to introduced species only (Takeuchi et al. 2003). Nymphoides peltata or Asaza is vegetation that is especially suffered from the concretization of the bed and banks of the lake and rivers around Kasumigaura (ibid). It is another biotic agent that can show the ‘health’ of the water landscape. The case suggests that biotic components of the freshwater system in question are a viable way to achieve the integrated management.

This research is addressing the challenge of extensive urban floods due to an increase of rainfall intensities in urban areas brought about by climate change (Pereira et al. 2009). Due to climate change, the water resources will be affected in both quantity and quality, and hence water, stormwater, and wastewater facilities infrastructure and urban water management will face a greater risk of damage (Saraswat et al. 2016). Therefore, to achieve sustainable water management, it is important to quantify and visualize the climate change impacts on urban water infrastructure, which is expected to deteriorate water management by altering rainfall patterns (Saraswat et al. 2017). The result will be more floods in the rainy season and water scarcity in dry season. Recently, it has been observed that the frequency of natural disaster events is increasing, particularly hydro-meteorological disasters which, directly threatened the human lives, economies and infrastructure. In the context of climate change, water management is becoming more complicated because of erratic or heavy precipitation, rainfall events or prolonged droughts (Yilmaz et al. 2014). Sustainable water management and planning requires the quantifying the potential effects of climate change on extreme rainfall pattern to help in reducing the climatic vulnerability. Specially, change in spatial and temporal distribution of extreme rainfall events in future need to be precisely understood in preparing urban drainage master plans which include design of stormwater drains in the city, bigger storage in the upper region, river bank wall, channel widening and and many other structures involving hydrologic flows (Westra et al. 2014; Prodanovic and Simonovic 2007; et al. 2012).

Rainfall intensity-duration-frequency (IDF) curve presents the probability of a given rainfall intensity and duration expected to occur at a particular location. The rainfall IDF, which was first introduced by Bernard in 1932, is widely used by water scientists and civil engineers during planning and design of various hydraulic strucutres. Design standards for considering specific return period values depend on type of water infrastructure as well as their location. Climate change is widely projected to increase frequency and intensity of extrme rainfall events resulting larger design rainfall value in the future for the same return period. Thus, conventional (stationary) frequency analysis method of estimating extreme rainfall will be inadequate and require revision of existing guidelines and standards to accommodate higher value of rainfall in planning and designing various hydraulic infrastructures. In this case, the rainfall IDF relationships may be used advantageously for urban water management and planning. De Paola et al. (2014) estimated the rainfall IDF for three cities, including Addis Ababa (Ethiopia), Dar Es Salaam (Tanzania) and Douala (Cameroon), using rainfall observations and rainfall estimates derived from the CMCC (Centro Euro-Mediterraneo sui Cambiamenti Climatici) model. The temporal disaggregation method was used to obtain the rainfall amounts over smaller time scale. The evaluation of rainfall IDF was conducted and then the projection of rainfall IDF was estimated to verify the change of extreme values under climate change. Akpan and Okoro (2013) developed two sets of rainfall IDF models for the Calabar City (Nigeria), and estimated the relationship between rainfall intensity and duration for specific frequencies and associated rainfall intensity and frequency for specific durations, using a rainfall dataset from 2000 to 2009. These models are used to predict the possibility of a certain amount of rainfall that may be used in planning and designing of the infrastructure in Nigeria. Logah et al. (2013) analyzed rainfall data of four stations in Greater Accra Region to develop the rainfall intensity – duration – frequency curves by fitting the rainfall intensity to Gumbel distribution for various durations. Le et al. (2006) used 4 empirical functions including the Talbot, Bernard, Kimijima and Sherman equations to construct rainfall IDFs for several stations in Vietnam. Their study compared the results between these 4 methods and then chose the appropriate equation for Vietnam. In addition, their study also proposed a method to generalize the IDF curve for ungauged rainfall locations over Vietnam. Wang et al. (2014) applied PRECIS regional climate model for investigating the potential impact of climate change on rainfall IDF over Ontario, Canada. Their results reported that all rainfall extreme events for different durations and return periods return periods are likely to increase over 2030s, 2050s and 2080s.

Nguyen et al. (2007) constructed rainfall IDF curves using temporally and spatially downscaled rainfall data under the A2 scenario. In their study, SDSM (Statistical DownScaling Model) method combined with bias correction was employed to obtain adjusted daily rainfall estimates at several rain gauge stations in Quebec. Later, using scaling method, sub-daily rainfall values were produced by applying Generalized Extreme Value (GEV) distribution on daily data. Rodríguez et al. (2014) studied the impact of climate change on rainfall IDF over Barcelona (Spain). This change was analyzed from the output of five General Circulation Models (GCM) under three scenarios, including A1B, A2 and B2. Willems and Vrac (2011) took into account the change of rainfall IDF for Belgium based on several rainfall data series. The results indicated that the increase in extreme rainfall could be 30% by the end of the century. In recent climate change impact studies, use of quantile mapping technique is widely popular for minimizing biases in the GCM rainfall output. In this technique, observation and GCM rainfall data of past period (usually 30 years) are compared and checked for any significant biases in their values (Hansen et al. 2007; Mpelasoka and Chiew 2009; Kuo et al. 2015). Accordingly, differences in statistics like mean rainfall, maximum rainfall and number of rainy (wet) days and rainfall over the study period are estimated and corrected future GCM is obtained. Mishra and Herath (2014) applied quantile mapping technique to correct biases in MRI-GCM (Meteorological research Institute) rainfall for the assessment of climate change impact on flood-frequency in the Bagmati river basin, Nepal. Mirhosseini et al. (2012) applied scaling factor to correct the GCM output by comparing monthly rainfall CDF (Cumulative Distribution Function) of historical model and observation values. Srivastav et al. (2014) applied equidistance-quantile matching technique for updating rainfall IDF curves at four locations in Canada fitting GCM annual maximum rainfall and sub-daily observed data. Ogarekpe (2014) compared rainfall IDF curves derived from three models, including exponential, logarithmic and power models for Calabar, Nigeria. Their study indicates that the logarithmic model best produces intensity values compared to the observations and is appropriate for applying to design of hydraulic structures.

This study predicts rainfall IDF curves using spatial and temporal downscaled GCM data. Overall, objective of this research is to assess climate change impact on rainfall IDF curves in Hanoi, Vietnam. The assessment of climate change impacts on rainfall IDF curves includes the following major steps: (i) extraction of multiple GCM participation output over the Hanoi station for different emission scenarios; (ii) bias correction of GCM rainfall output for current and future climate periods; (iii) derivation of short-duration rainfall intensities for different return periods; and (iv) development and comparative analysis of rainfall IDF curves. Multiple GCM and scenarios were used to reflect the uncertainty associated climate change. Daily rainfall output of 5 GCM (ACCESS1-0, GFDL-CM3, GFDL-ESM2G, MRI-CGCM3.2 and NoESM1-M) was used for the climate change impact assessment. Representative Concentration Paths (RCP) 4.5 and 8.5 indicating medium and high greenhouse emission scenarios were considered for the study (IPCC 2014). Quantile mapping technique enabled to correct the biases in the GCM rainfall data. The simple scaling method was applied to derive annual maximum 15 min, 30 min, 1 h, 1.5 h, 2 h, 4 h, 8 h and 12 h rainfall intensities for each of the year over 1976–2005 (current) and 2070–2099 (future) periods. Finally, using frequency analysis, 2-, 5-, 10-, 25, 50- and 100 years rainfall IDF curves were developed for current and future climate. The chapter will provide an insight to the water planners and managers to re-examine urban development processes for municipal water and wastewater services by visualizing climate change impacts on infrastructure design, capital investment projects, service planning, and operation and maintenance (Saraswat et al. 2017; Saraswat and Kumar 2016). This study is an attempt to quantify the potential effects of climate change (specifically for precipitation) and using the rainfall characteristics to design robust water infrastructures and sustainable management.

6.2 Study Area and Data Collection

6.2.1 Study Area

The study area is capital city Hanoi, Vietnam, which is also a political and economic center of the country. Hanoi is located at 21°01′N and 105°51′E. The topography of Hanoi is very diverse with three main terrain zones, including the delta, hills and mountains; the delta accounts for over 80% area of the city. The river system in and around Hanoi city consists of many tributary rivers of the Red River and the Thai Binh River basin system. The river system is mainly characterized as sloping with narrow riverbeds and complicated meanders. Therefore, the capacity to drain water away is quite low. Specifically, when heavy rainfall occurs, it can cause a significant rise in the river level. The annual mean temperature in the central delta of Hanoi is approximately 23–24 °C and in the mountain zones it is slightly lower. The temperature difference between the hottest and coldest months is relatively large; the highest temperature is greater than 28 °C in the summer and the lowest temperature is less than 18 °C in the winter. The amount of annual rainfall in this area ranges from 1400 mm to 2000 mm. The rainy season in the city extends from the middle of April to the end of October. The total rainfall during the rainy season accounts for more than 80% of the annual rainfall. The average annual number of rainy days is approximately 150, of which there are 7 to 8 days when daily rainfall is over 50 mm and 1–2 days when daily rainfall is over 100 mm per day. Extremely heavy rainfall sometimes occurs in the first 2 months of the winter. Heavy rainfall events in 1984, 1996 and 2008, caused serious inundation in the study area.

6.2.2 Data Collection

6.2.2.1 Observation Data

In this study, daily rainfall observations from the Hanoi station covering the period of 1961–2005 were collected for bias correction of the GCM output. In addition, rainfall data of several short duration extreme events were collected from this station. The dataset consists of rainfall in several durations including 15 min, 30 min, 1 h, 1.5 h, 2 h, 4 h, 8 h and 12 h. Both daily and shorter-duration rainfall datasets are provided by the Vietnam institute of meteorology, hydrology and climate change.

6.2.2.2 GCM Data

There are a number of GCM and emission scenarios, providing predictions of future changes in climate. Due to a great amount of uncertainty associated with the scenarios and projections, use of multiple GCM is recommended to provide the range of recommendations for addressing various climate change impacts. Various studies are available to select GCM and scenarios. Broadly, future climateprojections are defined by four greenhouse emission scenarios withone mitigation scenario (RCP 2.6), two medium stabilization scenarios (RCP 4.5/RCP 6) and one very high baseline emission scenario (RCP 8.5). The RCP 2.6 scenario is considered largely idealistic as world leaders have not yet reached toconsensus emission mitigation strategies towards restricting this level. Climate projections for RCP 4.5 and RCP8.5 emission sceanarios, which represent medium stabilization scenario and the high emission scenario and cover most likely range of radiative forcing, were considered for estimating future rainfall extremes. Tens of GCMs have been developed globally for these emission scenarios. McSweeney et al. (2015) compared rainfall characteristics of various CMIP5 (Coupled Model Intercomparison Project Phase 5) GCMs to identify a set of 8–10 suitable GCMs across multiple regions: Southeast Asia, Europe and Africa. Accordingly, rainfall output of 5 GCMs with RCP 4.5 and RCP 8.5 emission scenarios were selected for analysing climate change impact on extreme rainfall over Hanoi. Table 6.1 provides brief description of Information about these models are described in Table 6.1 below, which is edited for this study based on the report issued by CSIRO and Bureau of Meteorology (2015).

Table 6.1 Information of CMIP5 models using in this study

CMIP5 Model ID	Institute and Country of Origin	Atmosphere horizontal resolution (°Lat × °Lon)	Historical	RCP4.5	RCP8.5
ACCESS1-0	CSIRO, Australia	1.9 × 1.2	1961–2005	2070–2099	
GFDL-CM3	NOAA, USA	2.5 × 2.0			
GFDL-ESM2G					
MRI-CGCM3	MRI, Japan	1.1 × 1.1			
NorESM1-M	NCC, Norway	2.5 × 1.9			

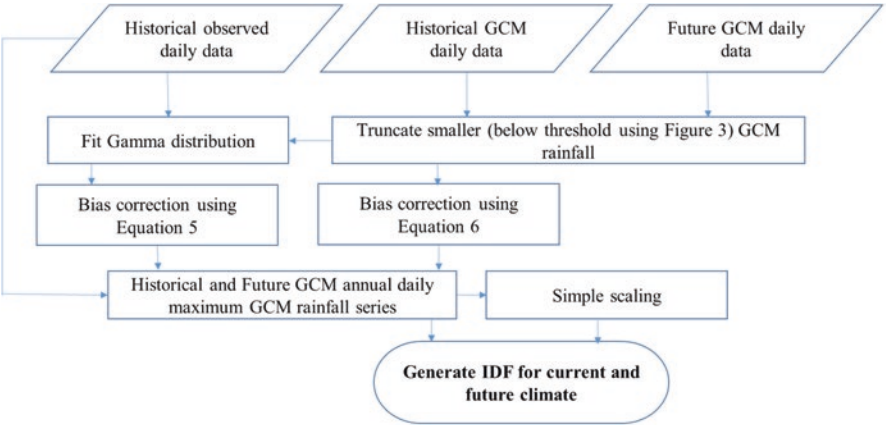

Fig. 6.1 Framework for generating rainfall IDF curves under climate change

6.3 Methodology

There are two major components under the research methodology (Fig. 6.1). These are statistical downscaling and establishment of rainfall IDF curves for different return periods. Bilinear interpolation and conventional quantile mapping bias correction techniques were applied for the spatial downscaling. The simple scaling method was applied for the temporal downscaling. Short durations rainfall intensities for various return periods were derived using Gumbel distribution.

6.3.1 Downscaling

6.3.1.1 Spatial Downscaling

Spatial downscaling consisted of two major steps. These are interpolation and bias correction of GCM rainfall output. Various methods are available for interpolating scanty data. Inverse weighted distance, Thiessen polygon and bilinear techqunique are popular interpolation technique to address coarse resolution resolution data

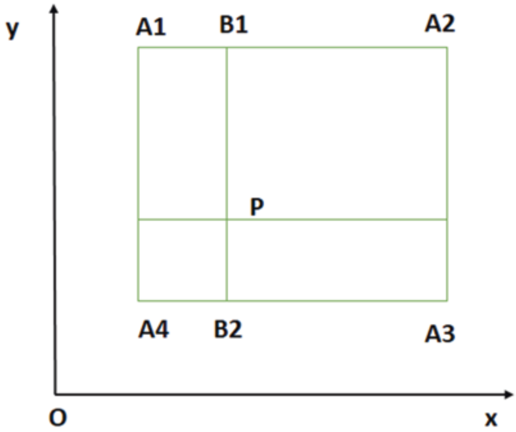

Fig. 6.2 The bilinear interpolation method

problem. Bilinear interpolation is widely used for gridded time series from RCM or GCM output (WaSiM 2012; Sluiter 2009; Yuan et al. 2016). The gridded data are treated as station data by considering four nearest quadrants. In this method, distance-weighted average of the four nearest values is used to estimate a new value. Geographical location of observation rainfall station and surrounding GCM grid cells are required to calculate their distances from the observation station. Accordingly, GCM data was derived from grid points. In Fig. 6.2, A1, A2, A3 and A4 are four nearest point around the interest point P. The interpolation in x direction is performed at first to derive B1 and B2. Then, another in y direction is carried out to obtain the value at the desired point P.

Climate outputs from GCM is usually not the same as the climate from observations. Hence, GCM rainfall outputs without performing some form of bias correction are not suggested for climate change impact assessments (Sharma et al. 2007; Hansen et al. 2007). Bias correction is applied to derive realistic GCM outputs by comparing and establishing a relationship between climate model outputs and observations at a station. Quantile mapping technique enabled to minimize the rainfall frequency and intensity bias in GCM data. In the beginning, problem of excessive rainy days are corrected by truncating GCM rainfall below a threshold value. This threshold value is estimated by comparingnon-exceedance probability of zero rainfall value in the observation and GCM rainfall data series (Fig. 6.3). Later, truncated values are adjusted by applying inverse CDF of the GCM data with observational shape and scale parameters. Threhold values estimated at monthly scale were applied for correcting GCM rainfall data.

The gamma PDF (Probability Density Function) and CDF can be expressed by the Eqs. (6.1) and (6.2), respectively; the shape and scale parameters can be calculated by functions (6.3) and (6.4), respectively.

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \tag{6.1}$$

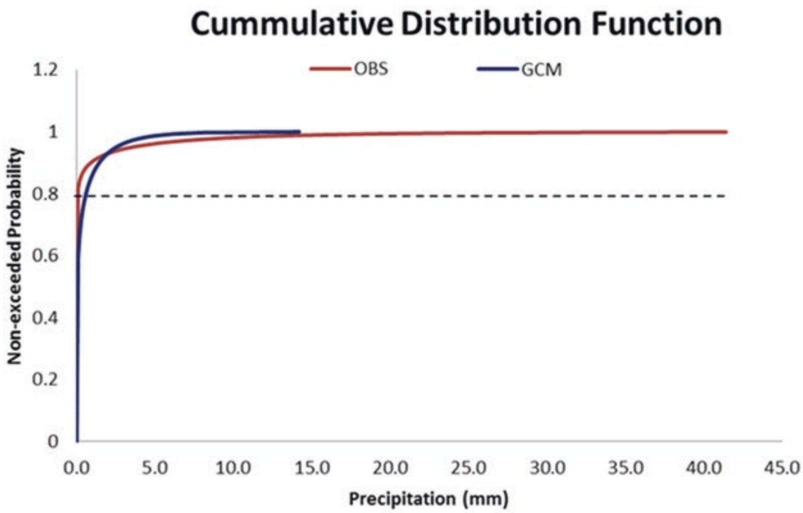

Fig. 6.3 Determining the threshold value for frequency correction, Hanoi during 1961–1975. (Note: OBS is observed value)

$$F(x) = \int_{x}^{0} f(t)\,dt \tag{6.2}$$

$$\alpha = \left(\frac{\overline{x}}{\sigma}\right)^2 \tag{6.3}$$

$$\beta = \frac{\sigma^2}{\overline{x}} \tag{6.4}$$

where x is daily rainfall, $\overline{x}$ is mean and σ is standard deviation of considered data series. Equations (6.5) and (6.6) illustrate the transformation of the bias correction method to match GCM rainfall distribution with observation rainfall distribution for baseline and future periods, respectively. The corrected GCM rainfall for the baseline period was estimated by calculating the inverse CDF of the GCM, with shape and scale parameters from the observation dataset. In terms of the future correction, a scaling factor was added by taking the ratio of the inverse CDF of future GCM rainfall to the observational and baseline GCM rainfall distribution parameters.

$$x_{GCM_{baseline-corrected}} = F_{obs}^{-1}\left[F_{GCM_{baseline-raw}}\left(x_{GCM_{baseline-raw}}\right)\right] \tag{6.5}$$

$$x_{GCM_{future-corrected}} = x_{GCM_{future}} \frac{F_{obs}^{-1}\left[F_{GCM_{future}}\left(x_{GCM_{future}}\right)\right]}{F_{GCM_{baseline}}^{-1}\left[F_{GCM_{future}}\left(x_{GCM_{future}}\right)\right]} \tag{6.6}$$

where, F is CDF and F^{-1} is its inverse.

In this study, we chose period of 1976–2005 as baseline period. At first, quantile-mapping technique was applied to remove systematic bias for this baseline. Later, the method is also employed to correct bias for an independent period covering 15 years from 1961 to 1975. We chose this period for independent testing of Eq. 6.6 because of the limit in observation and model historical simulation.

6.3.1.2 Temporal Downscaling

High-temporal-resolution (e.g., 15 min, 30 min, and 1-h) data are needed to create the IDF curves. Since the available data are available at daily intervals, it is necessary to temporally downscale the daily maximum rainfall intensity to hourly or sub-hourly rainfall intensities for different return periods. For the purpose of constructing rainfall IDF curves for the future period, scaling theory was applied to produce short-duration rainfall intensity of daily rainfall data. The scaling property is proven by many studies and is applied to rainfall intensity by Menabde et al. (1999), Nhat et al. (2007), and Mishra and Herath (2011). Scaling properties of extreme rainfall are analyzed for different durations as due to significant variation in statistical moments over different durations. Scaling approach enables to derive data from coarse temporal resolution to fine resolution. This way scaling technique helps to derive hourly extreme rainfall from daily values. Based on empirical analysis, Menabde et al. (1999) proposed that random variable I_d and I_D representing annual maximum rainfall intensities over d and D *time duration* respectively can have the following relationship (Eq. 6.7).

$$I_d = \left(\frac{d}{D}\right)^{-\eta} I_D \tag{6.7}$$

The equality and η in Eq. 6.7 refers to identical probability distribution function and scaling exponent respectively. The relationship between the moments of order q can be obtained by raising both sides of equation to power q and taking the expected values of both sides (Eq. 6.8).

$$E\left[I_d^q\right] = \left(\frac{d}{D}\right)^{-\eta(q)} E\left[I_D^q\right] \tag{6.8}$$

Estimation of scaling exponent η includes (i) log-log graph of moments $E\left[I_D^q\right]$ *versus* durations of different order q; and (ii) linear graph of slopes (*of moments versus duration lines*) and moment order q. If the resulting graph is a straight line i.e., value of η (slope) remains same for different values of q, it is of simple scaling otherwise it is of multi-scaling.

6.3.2 Rainfall IDF Curves Construction

The rainfall IDF curve is constructed by using short-durations rainfall observations from the Hanoi station. The Gumbel distribution is chosen for conducting frequency analysis. The cumulative distribution function can be expressed as below:

$$F_d(i) = exp\left(-exp\left(-\frac{i-\mu_d}{\sigma_d}\right)\right) \tag{6.9}$$

where, $\boldsymbol{i}$ is rainfall intensity, $\boldsymbol{\mu_d}$ and $\boldsymbol{\sigma_d}$ are the location and scale parameters respectively, and $\boldsymbol{F_d(i)}$ is the non-exceedance probability of intensity $\boldsymbol{i}$ in duration $\boldsymbol{d}$.

To obtain the rainfall intensity i from a given probability or return period, we find the inverse of function (6.9) by taking the natural logarithm of the left side twice. After doing this step, function (6.10) is derived:

$$i = \mu_d - \sigma_d * \left(ln\left(-ln\left(\mathbf{1}-\frac{\mathbf{1}}{T}\right)\right)\right) \tag{6.10}$$

where, T is the return period. The relationship between the return period T and the non-exceedance probability $\boldsymbol{F_d}$ is shown in function (6.11):

$$T = \frac{\mathbf{1}}{\mathbf{1}-F_d} \tag{6.11}$$

6.4 Results and Discussion

6.4.1 Validation of Quantile-Mapping Technique

Figure 6.4 shows the comparison between the monthly observed total rainfall from 1976 to 2005 and the five bias-corrected GCM results as well as their average number of monthly rainy days The quantile mapping technique produces total rainfall estimates which are very close to the observations in every month of the year. Furthermore, in terms of frequency calibration, this bias correction method is obviously accurate. The best performance of frequency bias correction method is shown for ACCESS1-0 and NorESM1-M. However, there is a small difference between the number of observed rainy days and from the bias corrected GCM outputs. There are 3–5 more and sometime fewer days than observations. Overall, the bias correction method produces good results in adjusting rainfall from raw GCM outputs, specifically in the amount of rainfall for dependent period.

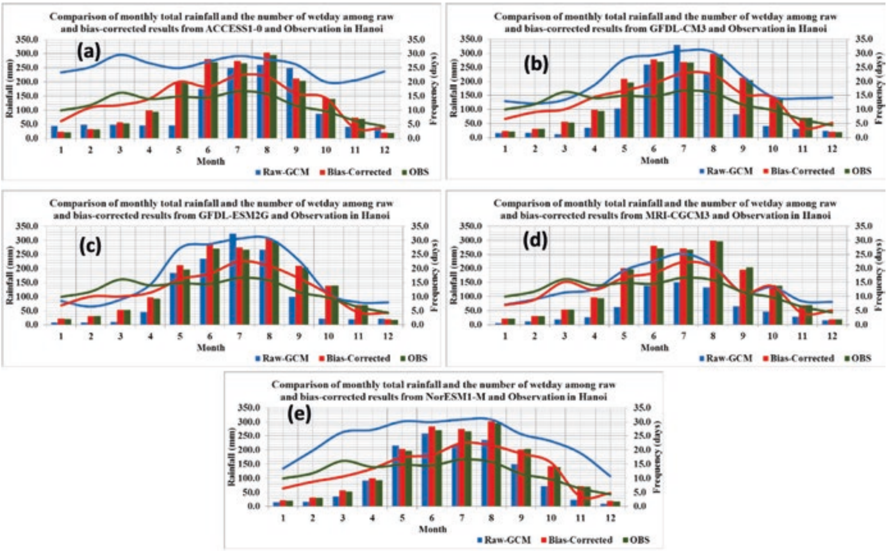

Fig. 6.4 Comparison of monthly total rainfall (column) and the number of wet days (line) among bias corrected GCM (red), raw GGMs (blue) and Observation (green) for period of 1976–2005; (**a**) ACCESS1-0, (**b**) GFDL-CM3, (**c**) GFDL-ESM2G, (**d**) MRI-CGCM3, (**e**) NorESM1-M

Quantile mapping performed well in predicting the amount of rainfall and the number of rainy days. In addition, it also performs well in capturing extreme events at the Hanoi station base on Q-Q plots of rainfall greater than the 95th percentile (Fig. 6.5). The most rainfall extreme values obtained from bias corrected models are relatively close to observations. For the highest value, three models including GFDL-CM3, MRI-CGCM3 and NorESM1-M show better fit than other models.

We also examined performance of bias correction technique for an independent period of 1961–1975 in order to assess the ability to apply it for removal of model bias for future period. For the annual cycle, rainfall, it is indicated from Fig. 6.6 that monthly total rainfall is improved significantly after eliminating systematic bias for instance in the summer. Specifically, the efficiency of bias correction technique is much clearer for September to November. The amount of rainfall in these 3 months range from 50 mm to around 250 mm meanwhile rainfall from raw GCM such as GFDL-CM3, GFDL-ESM2G and MRI-CGCM3 is usually around 100 mm. The adjusted result captures very well this characteristic. It is also similar to the number of wet days that bias – corrected method produces frequency of rainy days with higher agreement to observation. For extreme value (Fig. 6.7), bias correction method also performs conducive skill in matching raw GCM output to observation, specifically for the MRI-CGCM3 model. For other models, the two highest values are quite larger than previous observation. In summary, quantile – mapping demonstrates an advance skill in removal of bias for an independent period.

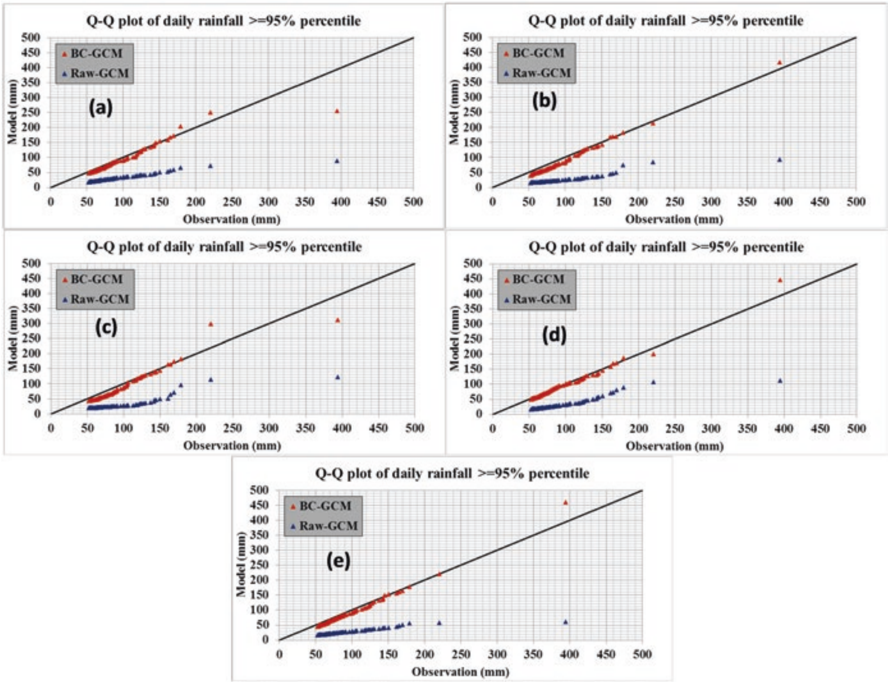

Fig. 6.5 Q-Q plot comparing rainfall greater than 95th percentile from bias corrected GCM and Observation (Red) and comparing raw GCM and Observation (blue) for period 1976–2005; (**a**) ACCESS1-0, (**b**) GFDL-CM3, (**c**) GFDL-ESM2G, (**d**) MRI-CGCM3, (**e**) NorESM1-M

6.4.2 Rainfall Intensity – Duration – Frequency Curves

Table 6.2 and Fig. 6.8 show rainfall intensity for nine different durations and six return periods at the Hanoi station. This result is obtained by using the Gumbel distribution for frequency analysis of observational short-duration rainfall datasets from 1976 to 2005. For the 100-year return period, average rainfall intensity in 15 min is 206 mm/h, in 1 h is 148.3 mm/h and in 24 h is 18.7 mm/h. There was one time that heavy rain with the amount of rainfall greater than 18.7 occurred, in 1984. For the 25-year return period, rainfall intensities are 175.4 mm/h, 121.3 mm/h and 14.5 mm/h in 15 min, 1 h and 24 h, respectively. For the 2-year return period, rainfall intensity in 15 min is 113.5 mm/h. The corresponding rainfall intensity in 1 h and 24 h are 66.6 and 6.1 mm/h, respectively.

For future rainfall IDF (Figs. 6.9 and 6.10), results from five GCM were combined by finding the ensemble mean. Rainfall intensity for different durations and return periods under both RCP4.5 and RCP8.5 scenarios are presented in Tables 6.3 and 6.4. These results indicate that rainfall intensity under RCP4.5 may increase much more than RCP8.5 for most durations and return periods. For the 100-year return period, rainfall intensity increases 42.6% in comparison with the baseline

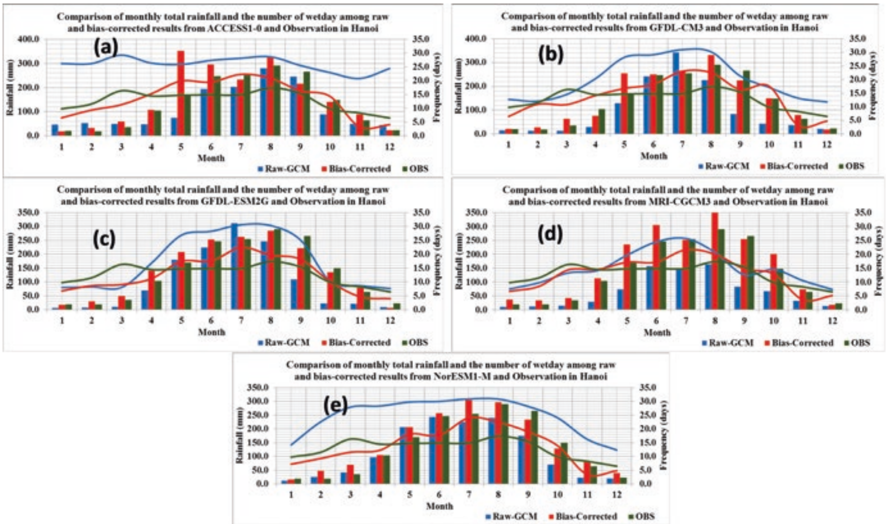

Fig. 6.6 Comparison of monthly total rainfall (column) and the number of wet days (line) among bias corrected GCM (red), raw GGMs (blue) and Observation (green) for independent period of 1961–1975; (**a**) ACCESS1-0, (**b**) GFDL-CM3, (**c**) GFDL-ESM2G, (**d**) MRI-CGCM3, (**e**) NorESM1-M

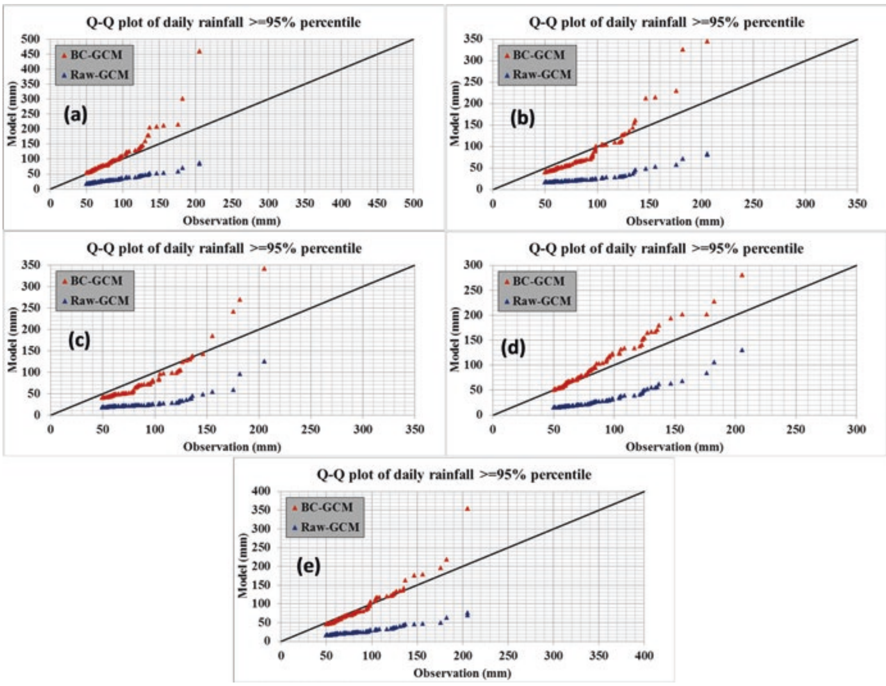

Fig. 6.7 Q-Q plot comparing rainfall greater than 95th percentile from bias corrected GCM and Observation (Red) and comparing raw GCM and Observation (blue) for independent period 1916–1975; (**a**) ACCESS1-0, (**b**) GFDL-CM3, (**c**) GFDL-ESM2G, (**d**) MRI-CGCM3, (**e**) NorESM1-M

period under RCP4.5. The corresponding increasing value under RCP4.5 is 38.8%. This implies that by the end of century, heavy rain may occur with extremely high intensity under both scenarios. However, the frequency of this event is very rare. For the 2-year return period, in 15 min, rainfall intensity increases 5.4% under RCP8.5 and up to 7.2% under RCP4.5. With this amount of increase, total rainfall after 15 min may be 121 mm and 119.6 mm by the end of century under RCP4.5 and RCP8.5, respectively.

6.5 Conclusions

In this chapter, the study argued that for sustainable urban planning and effective urban water management the analysis of future rainfall and its extreme events is very useful in order to design strong infrastructure and reduce flood risks and climatic vulnerability. For the same, the study developed the rainfall IDF curve to evaluates the impact of climate change on extreme rainfall intensities under medium and high greenhouse gases emission (RCP 4.5 and RCP 8.5 respectively) for the future period of 2070–2099 over a baseline of 1976–2005 using rainfall output of 5

Table 6.2 Rainfall intensity in several durations (D) and return periods (T) from observation for 1976–2005

T (↓)D(→)	15’	30’	1 h	1.5 h	2 h	4 h	8 h	12 h	24 h
2 years	113.5	90.5	66.6	49.3	40.3	23.2	13.7	10.2	6.1
5 years	138.2	116.2	88.5	65.8	54.6	32.4	20.3	15.1	9.5
10 years	154.6	133.3	103.0	76.8	64.1	38.5	24.6	18.4	11.7
25 years	175.4	154.8	121.3	90.6	76.0	46.2	30.1	22.6	14.5
50 years	190.7	170.7	134.8	100.8	84.9	51.9	34.2	25.6	16.7
100 years	206.0	186.5	148.3	111.0	93.7	57.5	38.2	28.7	18.7

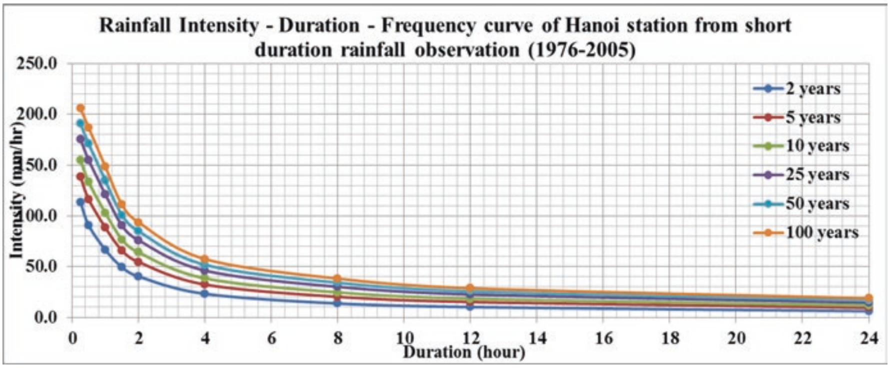

Fig. 6.8 Rainfall IDF curve of Hanoi station from observation data for 1976–2005

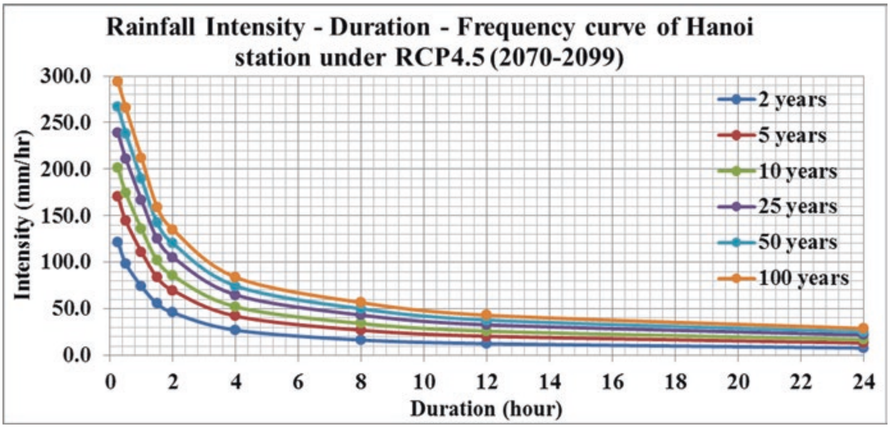

Fig. 6.9 Rainfall IDF Curve of Hanoi station for 2070–2099 under RCP4.5

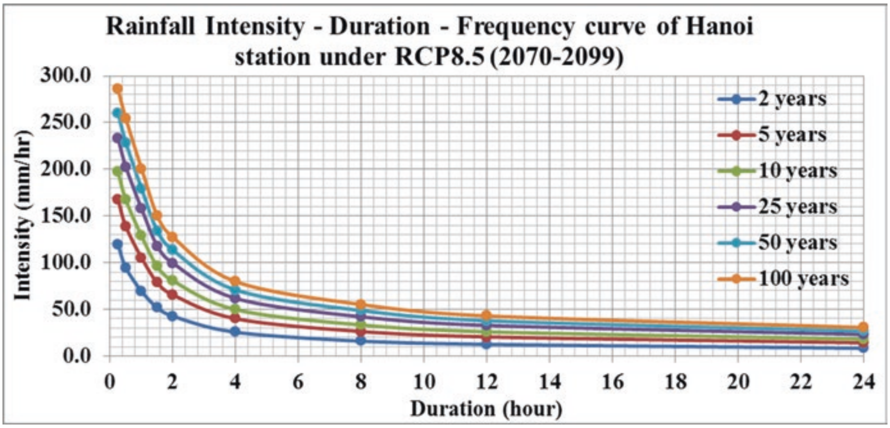

Fig. 6.10 Rainfall IDF curve of Hanoi station for 2070–2099 under RCP8.5

Table 6.3 Change of rainfall intensity in several durations (D) and return period (T) by the end of century under RCP4.5

T (↓), D (→)	15’	30’	1 h	1.5 h	2 h	4 h	8 h	12 h	24 h
2 years	7.2	8.8	11.0	12.4	13.8	16.8	20.6	23.4	28.4
5 years	23.4	24.2	25.6	26.8	27.6	30.2	33.4	35.8	40.0
10 years	30.2	30.8	31.6	32.6	33.4	35.6	39.0	40.8	45.0
25 years	36.2	36.6	37.4	38.0	38.6	40.8	43.6	45.4	49.4
50 years	39.8	39.6	40.4	41.2	41.6	43.8	46.2	48.0	52.0
100 years	42.6	42.4	43.0	43.4	44.2	45.8	48.2	50.2	54.0

Table 6.4 Change of rainfall intensity in several durations (D) and return period (T) by the end of century under RCP8.5

T (↓), D (→)	15’	30’	1 h	1.5 h	2 h	4 h	8 h	12 h	24 h
2 years	5.4	4.4	4.2	5.0	6.0	10.2	17.2	23.2	38.0
5 years	21.4	19.4	19.0	19.2	20.0	23.6	30.0	35.6	50.0
10 years	27.6	25.6	25.0	25.0	25.8	29.2	35.4	40.8	54.6
25 years	33.2	31.0	30.2	30.2	30.8	33.8	39.8	45.4	58.8
50 years	36.6	34.0	33.0	33.2	33.6	36.4	42.6	47.8	61.4
100 years	38.8	36.4	35.4	35.4	35.8	38.6	44.4	49.8	63.2

GCM. The bilinear interpolation and quantile mapping were applied and observational data is used to correct the bias of GCM simulations. The results of the research are of significant practical importance of design, operation, and maintenance of stormwater management, flood risk management, rainwater harvesting and water-related infrastructures in the capital city of Vietnam, Hanoi. It indicated that the methodology used accurately capture extreme values of rainfall for all 5 GCM and by the end of the century, rainfall intensity may increase in all durations and return periods under both RCP 4.5 and RCP 8.5 scenarios. Also, the results indicated that the mean of corrected monthly rainfall and the frequency of wet days are considerably closer to observation than the raw rainfall estimates. In addition, the bias correction method accurately captured extreme rainfall values for all 5 GCM and point out that by the end of the century, under different scenarios the rainfall intensity is increasing for all the duration and the return periods.

The results support the argument that the urban water management should be an integral part of sustainable urban development planning and development of rainfall IDF curves is very important in designing the sustainable water system, effective water management and sustainable urban infrastructures. The developed IDF curves are extremely useful in the sustainable development planning of the Hanoi, Vietnam, this will help the urban planners, local policymakers and water managers in designing sustainable water infrastructures such as stormwater infrastructure, storage structures, rainwater harvesting structures, flood management solutions and others. From the policy perspective, the developed rainfall IDF curves assist the local policymakers and urban planners to understand and visualize the future impacts of extreme rainfall events and climate change on current infrastructure and provides an opportunity for informed decisions. This helps the inclusion of the strong stormwater facilities, flood management, robust and sustainable water urban infrastructure in urban development policies.

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Reference

Adusumalli M, Arora K (2015) Towards sustainable community and institutional response to climate extremes: a situational analysis of institutions, communities and their response to climate change induced disasters in Uttarakhand. Euro Sci J Spec Edn, pp 66–86

Akpan SU, Okoro BC (2013) Developing rainfall intensity–duration–frequency models for Calabar City, south-south, Nigeria. Am J Eng Res (AJER) 02(06):19–24

Bernard MM (1932) Formulas for Rainfall Intensities of Long Durations. Trans ASCE 96:592–624

Chakraborty S, Chakraborty A (2017) Satoyama landscapes and their change in a River Basin context: lessons for sustainability. Issues Soc Sci 5(1):38–64. https://doi.org/10.5296/iss.v5i1.10892

Conca K (2006) The new face of water conflict, vol 3. Woodrow Wilson International Center for Scholars, Washington, DC

Connor R (2015) The United Nations world water development report 2015: water for a sustainable world, vol 1. UNESCO Publishing, Paris

CSIRO and Bureau of Meteorology (2015) Climate change in Australia information for Australia's natural resource management regions: technical report, CSIRO and Bureau of Meteorology, Australia

De Paola F, Giugni M, Topa ME, Bucchignani E (2014) Intensity-duration-frequency (IDF) rainfall curves, for data series and climate projection in African cities. SpringerPlus 3:133. https://doi.org/10.1186/2193-1801-3-133

Hanjra MA, Qureshi ME (2010) Global water crisis and future food security in an era of climate change. Food Policy 35(5):365–377

Hansen JW, Challinor A, Ines A, Wheeler T, Moron V (2007) Translating climate forecasts into agricultural terms: advances and challenges. Clim Res 33(1):27–41

Hatt BE, Fletcher TD, Deletic A (2007) Treatment performance of gravel filter media: implications for design and application of stormwater infiltration systems. Water Res 41(12):2513–2524

IPCC (2014) Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC, Geneva. pp 151

Jago-on KAB, Kaneko S, Fujikura R, Fujiwara A, Imai T, Matsumoto T, …, Taniguchi M (2009) Urbanization and subsurface environmental issues: an attempt at DPSIR model application in Asian cities. Sci Total Environ 407(9):3089–3104

Kuo CC, Gan TY, Gizaw M (2015) Potential impact of climate change on intensity duration frequency curves of central Alberta. Clim Chang 130:115. https://doi.org/10.1007/s10584-015-1347-9

Le MN, Tachikawa Y, Takara K (2006) Establishment of intensity-duration-frequency curves for precipitation in the monsoon area of Vietnam. Ann Disaster Prev Res Inst Kyoto Univ, No. 49 B, 2006

Logah F, Kankam-Yeboah K, Bekoe E (2013) Developing short duration rainfall intensity frequency curves for Accra in Ghana. Int J Latest Res Eng Comput (IJLREC) 1:67–73

Mai KN, Herath S (2014) Urban water balance recovery by network of distributed rain-water infiltration and storage facilities–Case study of Japanese urban catchment. United Nations University. Retrieved October 30, 2017, from https://www.researchgate.net/profile/Ngoc_mai_Kim/publication/291957259_Urban_water_balance_recovery_by_network_of_distributed_rain-water_infiltration_and_storage_facilities_-_Case_study_of_Japanese_urban_catchment

McSweeney CF, Jones RG, Lee RW, Rowell DP (2015) Selecting CMIP5 GCMs for downscaling over multiple regions. Clim Dyn 44:3237–3260. https://doi.org/10.1007/s00382-014-2418-8

Menabde M, Seed A, Pegram G (1999) A simple scaling model for extreme rainfall. Water Resour Res 35(1):335–339

Mirhosseini G, Srivastava P, Stefanova L (2012) The impact of climate change on rainfall intensity-duration-frequency (IDF) curves in Albama. Reg Environ Chang. https://doi.org/10.1007/s10113-012-0375-5

Mishra BK, Herath S (2011) Rainfall intensity duration frequency curves under climate change scenario in urban Kathmandu valley. NEA-JC Newslett 6(2):19–22

Mishra BK, Herath S (2014) Assessment of future floods in the Bagmati River basin of Nepal using Bias-corrected daily GCM precipitation data. J Hydrol Eng. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001090

Mishra BK, Regmi RK, Masago Y, Fukushi K, Kumar P, Saraswat C (2017) Assessment of Bagmati River pollution in Kathmandu Valley: scenario-based modeling and analysis for sustainable urban development. Sustain Water Qual Ecol 9:67–77

Mpelasoka FS, Chiew FHS (2009) Influence of rainfall scenario construction methods on runoff projections. J Hydrometeorol 10(5):1168–1183

Nguyen V-T-V, Nguyen T-D, Cung A (2007) A statistical approach to downscaling of sub-daily extreme rainfall processes for climate-related impact studies in urban areas. Water Sci Technol Water Supply 7(2):183–192

Nhat LM, Tachikawa Y, Sayama T, Takara K (2007) Regional rainfall intensity duration-frequency relationships for ungauged catchments based on scaling properties. Ann Disaster Prev Res Inst Kyoto Univ 50B:33–43

Ogarekpe NM (2014) Development and comparison of different intensity duration frequency models for Calabar, Nigeria. Niger J Technol (NIJOTECH) 33(1):33–42

Pereira LS, Cordery I, Iacovides I (2009) Coping with water scarcity: addressing the challenges. Springer, Dordrecht

Prodanovic P, Simonovic SP (2007) Development of rainfall intensity duration frequency curves for the city of London under the changing climate. Water Resour Res Rep, London

Rodríguez R, Navarro X, Casas MC, Ribalaygua J, Russo B, Pouget L, Redaño A (2014) Influence of climate change on IDF curves for the metropolitan area of Barcelona (Spain). Int J Climatol 34:643–654. https://doi.org/10.1002/joc.3712

Saraswat C, Kumar P (2016) Climate justice in lieu of climate change: a sustainable approach to respond to the climate change injustice and an awakening of the environmental movement. Energy Ecol Environ 1(2):67–74

Saraswat C, Kumar P, Mishra BK (2016) Assessment of Stormwater Run-off Management Practices and Governance under climate change and urbanization: an analysis of Bangkok, Hanoi and Tokyo. Environ Sci Policy 64:101–117

Saraswat C, Mishra BK, Kumar P (2017) Integrated urban water management scenario modeling for sustainable water governance in Kathmandu Valley, Nepal. Sustain Sci, 1–17

Sharma D, Das Gupta A, Babel MS (2007) Spatial disaggregation of bias-corrected GCM precipitation for improved hydrologic simulation: ping river basin, Thailand. Hydrol Earth Syst Sci 11(4):1373–1390

Sluiter R (2009) Interpolation methods for climate data: literature review, KNMI intern rapport:IR 2009-04, The Netherlands

Srivastav RK, Schardong A, Simonovic SP (2014) Equidistance quantile matching method for updating IDF curves under climate change. Water Resour Manag 28:2539–2562

Takeuchi K, Brown RD, Washitani I, Tsunekawa A, Yokohari M (eds) (2003) Satoyama: the traditional rural landscape of Japan. Springer, New York

Tremblay H (2010) A clash of paradigms in the water sector? Tensions and synergies between integrated water resources management and the human rights-based approach to development. Tensions and Synergies Between Integrated Water Resources Management and the Human Rights-Based Approach to Development (August 1, 2010)

UNDESA-United Nations Development of Economic and Social Affairs (2016) International decade for action 'water for life' 2005–2015. http://www.un.org/waterforlifedecade/scarcity.shtml

UNEP (2012) The UN-Water Status Report on the Application of Integrated Approaches to Water Resources Management. Available from: www.unwater.org/rio2012/report

US Environmental Protection Agency – EPA (2015) Stormwater Best Management Practices (BMP) Performance Analysis. Boston, US: EPA. http://www.epa.gov/climatechange/basics. Accessed on 11th of August, 2015

Wang X, Huang G, Liu J (2014) Projected increases in intensity and frequency of rainfall extremes through a regional climate modeling approach. J Geophys Res Atmos 119:13,271–13,286. https://doi.org/10.1002/2014JD022564

WaSim (2012) Water balance Simulation Model (WaSim), Hydrology Software Consulting, J. Schulla Regensdorferstrasse 162 CH 8049 Zürich

Westra S, Fowler HJ, Evans JP, Alexander LV, Berg P, Johnson F, Kendon EJ, Lenderink G, Roberts NM (2014) Future changes to the intensity and frequency of short duration extreme rainfall. Rev Geophys 52:522–555

Willems P, Vrac M (2011) Statistical precipitation downscaling for small-scale hydrological impact investigations of climate change. J Hydrol 402:193–205. https://doi.org/10.1016/j.jhydrol.2011.02.030

Yan T, Wang J, Huang J (2015) Urbanization, agricultural water use, and regional and national crop production in China. Ecol Model 318:226–235

Yilmaz AG, Hossain I, Perera BJC (2014) Effect of climate change and variability on extreme rainfall intensity–frequency–duration relationships: a case study of Melbourne. Hydrol Earth Syst Sci 18:4065–4076

Yuan F, Ma M, Ren L, Shen H, Li Y, Jiang S, Yang X, Zhao C, Kong H (2016) Possible future climate change impacts on the hydrological drought events in the Weihe River Basin, China. Advances in Meteorology. https://doi.org/10.1155/2016/2905198

Part III
Integrating Urban Planning with Water-Related Disaster Management

Chapter 7
Improvement Practice and Planning Assessment of Tsunami Evacuation Plan at Community Level-Case Studies of Municipalities with Coastline in Chubu Region

Yuya Yamato, Zhenjiang Shen, and Ade Candra Masrul

Abstract This study investigated the practice of plan formulation for Tsunami evacuation. This planning assessment is carried out based on questionnaire while collecting necessary planning materials from municipalities with coastline in Chubu region. From the planning materials including planning documents and drawings, we classify methods of plan-making in the municipalities. As a result, there are differences in crisis recognition between the municipalities located in the coastal zone of the Sea of Japan and those in the coastal zone of Pacific Ocean, which have great impacts on plan formulation. According to the questionnaire, there are more public participation activities where crisis recognition is high. From the view of methods of plan-making, the planning can be classified into three types as Planner type, Public Hearing type, and Public Participation type.

Keywords Tsunami evacuation · Community participation planning · Planning contents · Determination awareness

7.1 Introduction

As one of Tsunami disaster countermeasures, a Tsunami evacuation plan was developed in all municipalities in coastal regions of Japan (from now on, municipality evacuation plan). It was based on the Act on the Promotion of Tsunami Mitigations (June 24, 1948, Law no. 77) under Article 9, paragraph 2, for the preparation of the Tsunami that may affect the municipality. It was planned to establish essential

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activities of municipalities such as evacuation recommended area, evacuation instructions, and emergency evacuation place. Also, there are Tsunami Evacuation Plans at the community level (hereafter, community level evacuation plan) that were decided according to actual situations in the community so that residents can evacuate quickly and safely. Neighborhood association units, voluntary disaster prevention organization units, elementary school units, evacuation spot units, and assumed Tsunami-inundation units are separated as the community unit. When Tsunami occurs, residents must seek shelters for evacuation and for this situation the community level evacuation plan is essential and necessary.

The necessity for deciding community evacuation plan is described in the basic plan for disaster prevention (Central Disaster Management Council (2015)). Moreover, to support the making of the community-level evacuation plan, the national government has summarized manual reports on Tsunami Evacuation countermeasure from Examination Committee (hereafter, manual reports) (Fire and Disaster Management Agency (2013)). Furthermore, several prefectures also published guidelines for Tsunami evacuation plan to support developing a community-level evacuation plan and municipality evacuation plan. Also, from the manual report, a method for making community level evacuation plan was recommended by workshops with the participation of organizations, such as municipalities, volunteer disaster prevention organizations, neighborhood associations and so on (hereafter, local residents). Organization of the local residents was described in paragraph 2 of article 5 of The Basic Law for Disaster Mitigation (Act No. 223, November 15, 1967).

Until now, there are several existing types of research on community-level evacuation plan in literature. Abe et al. (2005) proposed a flowchart for describing a community-level evacuation plan based on discussion from the workshop. Ota et al. (2006) suggested a management system for making policy on a community-level evacuation plan based on cooperation between municipalities and residents. Yashiro et al. (2004) conducted a survey on examining whether or not community-level evacuation plan was determined in all municipalities in Japan and proposed a flowchart of a community level evacuation plan for a chosen case study. Moreover, Nomura et al. (2013) determined community-level evacuation plan by workshops, organized survey data on residents' low recognition about their community and proposed a method for disaster prevention planning and disaster prevention education. Terumoto (2012) clarified the problems of Tsunami evacuation at the community-level by conducting a Tsunami evacuation drill. However, the above researchers only considered few municipalities as case studies or examined whether or not community-level evacuation plan was determined in all municipalities. Different from previous studies, this study clarifies what should be stated in the evacuation plan. Moreover, this study also clarifies factors affecting high enrichment of determination methods by evaluating enrichment of community-level evacuation plan's content based on determination methods and items for consideration derived from workshops.

To ask residents to take appropriate evacuation action during Tsunami, the contents which affect evacuation behaviors from start of evacuation to shelters should be described in the community level evacuation plan. Then, establishing a method for evacuation through evacuation drills is essential. Also, the contents which described in community-level evacuation plan could be confirmed by national guideline and guidelines for Tsunami evacuation plan published by prefectures and local disaster management plan (hereafter, guidelines). However, because now the enrichment of plan contents is delegated by determined objects, it is a matter that various factors affect the enrichment of plan contents. For each factor, there is a determination method and residents' participation situation is also considered influencing the enrichment of planning contents. Determination method is also delegated by determined objects. The determination method which is different according to residents' participation situation could be expected in three ways as follows. A determination method based on meetings held in municipalities (hereafter, Planner type). A determination method for confirming draft of planning contents determined by Planner via field work, public comments, and hearing from residents (hereafter, Public Hearing type). A determination method based on the residents' participation in workshops (hereafter, Public Participation type). Moreover, determination method is characterized by determination unit such as neighborhood association, primary school district and so on.

In the case of determination method based on Public Participation type, consideration items will be related to the conference for confirming evacuation method and so on, and related to the field in case of confirming dangerous spots by field works. These consideration items affect enrichment of the plan contents. Determination method and consideration items in Public Participation type have influents on determination awareness of community-level evacuation plan (hereafter, determination awareness) for residents and Tsunami damage estimation. As a future Tsunami disaster countermeasure, the necessity of community-level evacuation plan's determination is higher. Moreover, there is also a problem in the determination of community-level evacuation plan from previous studies.

This study firstly aims at clarifying the actual situation of the community level evacuation plan. Then, to obtain knowledge for improving enrichment of the plan contents, the study also clarifies the way for developing determination method, evaluates enrichment of the plan contents from determination method, and confirms the contents which should be described in the community level evacuation plan. In this study, we can show one factor which has high enrichment of community level evacuation plan when municipalities determine or revise community-level evacuation plan.

7.2 Method

First, we clarify the actual situation of community-level evacuation plan by knowing determination situation and problems in determination. In this study, we conduct questionnaire to know actual situation and method of determination on municipalities of the prefectures (Fukui, Ishikawa, Toyama, Niigata, Shizuoka, Aichi, Mie) with coastline in Chubu region.

Next, we obtain knowledge improvement of the plan contents' enrichment. Specifically, we confirm contents to be described in community-level evacuation plan from guidelines which have a strong association with community level evacuation plan in the prefectures of Chubu region. We did type classification from determination method in the questionnaire survey. The actual situation of the determination method of community-level evacuation plan is clarified by the types. Later, we evaluated enrichment of plan contents by the types to clarify determination method. Next, to clarify a factor as determination method of high enrichment, we analyze the relationship between assumption damage of Tsunami and determination method or determination awareness. Moreover, to clarify contents items, we focus on Public Participation type. We classify groups as to contents items "field" and "meeting". We evaluate enrichment of community-level evacuation plan by the types. Later, to clarify the factor of high enrichment type, we analyze the relationship between the groups and damage assumption of Tsunami or determination awareness of the local residents.

7.3 Outline of Research Area and Questionnaire Survey

The area of interest in this study is shown in Fig. 7.1. Many municipalities on the Pacific Ocean side are in and around the assumed epicenter of the Nankai Trough huge earthquake. In the Earthquake Research and Promotion Headquarters, it was calculated 60–70% that chance of an earthquake of M8-9 in Nankai Trough would occur within 30 years from 2013. However, as shown in Fig. 7.1, the frequency of the maximum class earthquakes of Nankai Trough is considered to be lower than one digit rate compared to a massive earthquake that occurs over a period of 100–200 years (Earthquake Research and Promotion Headquarters (2013)).

A questionnaire survey was conducted in May 2015 for determination situation and determination method of community-level evacuation, consideration items, and organizations involved in Public Participation type. The outline of questionnaire survey is shown in Table 7.1.

The reason why questionnaire survey was conducted in May 2015 is following. The Great East Japan Earthquake occurred in March 2011. The manual report related to it developed 2 years later in March 2013. It was considered to influence the determination of community-level evacuation plan, enrichment of the plan contents and publication of the guidelines. The questionnaire survey is conducted for official recognition of community-level evacuation plan as a municipality. The survey method was based on a questionnaire to the disaster prevention division of target municipality. For results of the questionnaire survey, 105 copies were mailed and 95 copies were collected by mailed or email (Table 7.2). The questionnaire collection rate was 90.5%. As community level evacuation plan differs in consciousness depending on the community, we consider that the plan contents differ by the

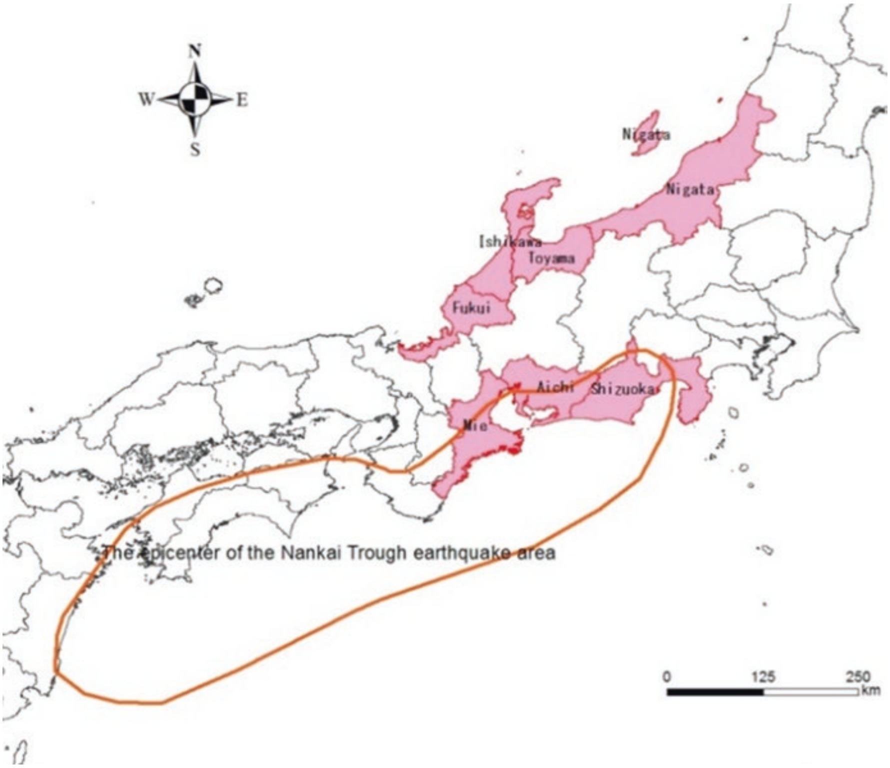

Fig. 7.1 Relationship between the prefectures in Chubu region and epicenter of the Nankai Trough earthquake area

Table 7.1 Outline of questionnaire survey

Method of survey	Mailing answer, E-mail answer
Distribution regions	Fukui, Ishikawa, Toyama, Niigata, Shizuoka, Aichi, Mie
Term of survey	2015.5.11–2015.6.3
Content of survey	1. Determination situation of evacuation plan at community level
	2. Reason for not determining evacuation plan at community level (free answer)
	3. Determination method and determination subject of evacuation plan at community level
	4. Community unit to determine evacuation plan at community level
	5. Considerations items and participating subject in Participation type
	6. Evacuation drill situation based on evacuation plan at community level
	7. Provision request for evacuation plan at community level

Table 7.2 Results of questionnaire survey

Prefecture	Number of responses/distribution number	Collection rate (%)	Uncollected	Rejection
Fukui	9/11	81.8	2	0
Ishikawa	15/16	93.8	1	0
Toyama	9/9	100	0	0
Niigata	13/13	100	0	0
Shizuoka	17/21	81.0	3	1
Aichi	15/17	88.2	0	2
Mie	17/18	94.4	1	0
Total	95/105	90.5	7	3

Table 7.3 Determination situation of community-level evacuation plan

	Number of responses (%)
Determined in all or specific communities	38 (41.8)
Being determined in all or specific communities	10 (11.0)
Planned to be determined in all or specific areas	21 (23.1)
Not determined and no plans	22 (24.2)
Total	91 (100.0)

community. Therefore, in the questionnaire survey, we requested community level evacuation plan for one community with the highest enrichment of plan contents and evaluated it.

7.4 Actual Situation and Problems in Community Level Evacuation Plan

In this chapter, actual situation and problems in community-level evacuation plan are clarified. From the results of a questionnaire survey, the actual situation of determination is summarized in Table 7.3. Four replies do not fall within the scope of a community-level evacuation plan for this study, so they were excluded. The ratio of "determined in all or specific communities" and "being determined in all or specific communities" are 52.8%. More than half of municipalities have determined. However, the ratio of determination is still low. We consider it is necessary to increase the ratio of determination in preparation for future Tsunami.

Next, we clarify problems of determination. Table 7.4 is summarized the reason why community level evacuation plan is not determined. The questionnaire survey was a free response, and similar answers are aggregated into groups. Regarding

Table 7.4 Reason for not determining community level evacuation plan

	Number of responses (%)
Not in a tsunami-inundation area	5 (12.5)
Respond to another plan	6 (15.0)
Earthquake assumptions in countries and prefectures differ	2 (5.0)
Low awareness of local people	3 (7.5)
Unification of municipal evacuation plans due to geographical factors	2 (5.0)
Municipal evacuation plan recently determined	3 (7.5)
Plan to determine it in the future	
Planned to determine it in the future	9 (22.5)
Other	10 (25.0)
Total	40 (100.0)

Tsunami-inundation area, it was described in Act on the Development of Tsunami Disaster Mitigation Area (December 14, 2011, Act no. 123), the provisions of article 8, paragraph 1.

There were answers “planned to be determined in a current fiscal year”, “planned to be determined in municipal evacuation plan recently”, and “budget, due to a shortage of department personnel but planned for the current fiscal year”. These answers were grouped into “plan to determine it in the future”. Examples of “other” were “shortage of employees”, “having priority jobs”, and “do not need to determine Tsunami evacuation plan because it has been discussed at the regular meeting of the neighborhood association”. There were three municipalities on the Sea of Japan side that did not respond. The highest ratio except “other” was “planned to be determined it in the future”. The result shows that municipalities were highly motivated to determine community-level evacuation plan.

7.5 Contents from Guideline to Be Described in Evacuation Plan

7.5.1 Targeted Guidelines

In this section, the guidelines are extracted to confirm the contents that should be described in the community level evacuation plan. The guideline of the prefecture is still not established sufficiently. We consider that some prefectures do not establish the guideline to support the determination of community-level evacuation plan. Therefore, to confirm the guidelines, we extract the guidelines which are closely related as shown in the flowchart of Fig. 7.2. As some prefectures do not publish guidelines of community-level evacuation plan yet, we consider that this method is the most appropriate for extracting the guidelines to confirm the contents to be described in the community level evacuation plan.

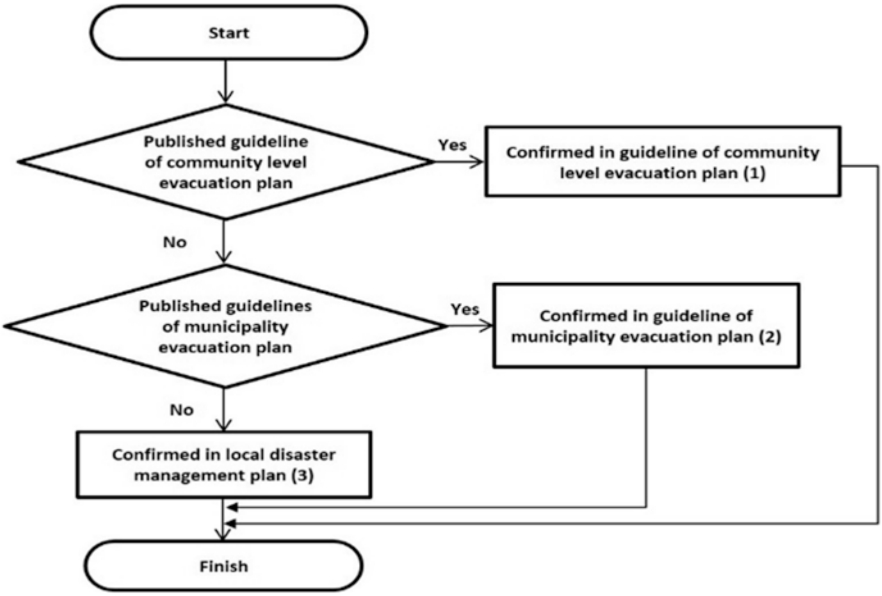

Fig. 7.2 Extraction of targeted guideline

From Table 7.5, the following guidelines are applicable in seven prefectures with coastlines in the Chubu region. The contents to be described in community level evacuation plan are confirmed from the guidelines in Table 7.5. The guidelines are published on the homepage. If it is not published yet, it is obtained by inquiring to prefecture employee.

1. Guidelines for determination of community-level evacuation plan: applicable in Mie prefecture. This guideline is characterized that residents determine an evacuation plan at the community level by themselves. The process is to lead determination of Tsunami evacuation plan at community level based on Participation type. In Mie prefecture, municipalities showed hazard map and evacuation spot to residents and conducted Tsunami evacuation drills. Mie Prefecture considered that this method is insufficient in understanding each person. Based on characteristics of the area where the arrival time of Tsunami varies from place to place, each resident is considered as a method for evacuating Tsunami. It is the guideline that its contents are summarized.
2. Guidelines for determination of municipality evacuation plan: applicable in Niigata prefecture, Shizuoka prefecture, and Aichi prefecture. Aichi prefecture included some guideline for a community level evacuation plan, but the purpose of the guideline is to support the determination of municipality evacuation plan.
3. Disaster management plan: applicable in Fukui prefecture, Ishikawa prefecture, and Toyama prefecture. Ishikawa prefecture has determined the guidelines for damage from the nuclear power plant, and it is not covered in this research.

Table 7.5 Guidelines to be covered, contents to be stated and reasons for selection

Region		Sea of Japan side				Pacific ocean side		
Prefecture		Fukui	Ishikawa	Toyama	Niigata	Shizuoka	Aichi	Mie
Guidelines for determining CEP	□1	×	×	×	×	×	×	○
Guidelines for determining MEP		×	×	×	○	○	○	–
Guidelines to be covered		LDMP			Guidelines for determining MEP			Guidelines for determining CEP
Title of guideline		LDMP –Earth-quake disaster countermeasures	LDMP – Tsunami disaster countermeasures	LDMP – earthquake and tsunami disaster counter measures	Guidelines for Determining MEP in Niigata	Large-scale Earthquake Counter-measure (Guidelines of Evacuation plan determination)	Guidelines for determi-ning MEP in Aichi	Guidelines for Tsunami Evacuation Planning at community

(continued)

Table 7.5 (continued)

Determination or revised date (final)		2015.3	2015.5	2015.6	2014.7	2013.9	2015.2	2013.9	Reason of selection
Determination with public participation type	□2	△	△	×	×	×	○	○	
Evacuation route		○	○	○	○	○	○	○	Necessary for knowing the route that can be used to evacuate safely in a short time to the evacuation spot
Dangerous zone		○	○	○	○	○	○	×	Necessary for knowing landslides and soil liquidation area at the time of the earthquake
Dangerous spot		×	×	×	×	×	×	○	Necessary for knowing facilities that may be overturned or collapsed when an earthquake occurs

Evacuation recommended area		△	△	×	○	○	○	×	It is one standard for evacuation of residents
Evacuation method		○	○	○	○	△	○	○	Evacuation ratio improves by checking evacuation method
Evacuation bag		△	○	△	×	×	×	○	It is preparation for evacuees, prepare for disasters
Information acquisition method		○	○	○	○	×	○	×	Necessary for obtaining accurate information
Evacuation drill method		○	○	○	○	×	○	○	Evacuation behavior is established for residents

(□1) "○" if it is maintained as a guideline; "×" if it is not
(□2) "○" if there is description of the flow, specific method and so on;
"△" if there is only the term listed; "×" if there is no description.
CEP: Community-level Evacuation Plan
MEP: Municipality Evacuation Plan
LDMP: Local Disaster Management Plan

Mie is the only prefecture that is published a guideline of the community-level evacuation plan, and its improvement is a future issue.

7.5.2 Contents to Be Described in the Community Level Evacuation Plan and Situation of Each Prefecture

Based on guidelines extracted in the previous section, contents to be described in evacuation plan at the community level are confirmed by a questionnaire survey, manual reports and guidelines. Contents described in the manual report are extracted first as the contents which should be described in the community level evacuation plan. After that, one or more descriptions are extracted from the guidelines of seven prefectures. It is related to the content mentioned above, and those with 10 or more applicable in community-level evacuation plan by questionnaire survey are extracted. As a result, the contents to be described in community-level evacuation plan are evacuation route, evacuation bag, dangerous zone, dangerous spot, evacuation recommended area, evacuation method, and information acquisition method. Table 7.5 shows the situation of each prefecture. Also, as the evacuation plan at the community level is not finalized upon the determination, the evacuation drill method is necessary as well. Confirmation of the contents to be described in community-level evacuation plan is conducted only by the guideline of the target. The Tsunami-inundation area, evacuation shelter, and evacuation spots are not included in this study because it is an clear description in the community level evacuation plan.

From the following, situation of each prefecture from the guideline in Table 7.5 will be described. For evacuation route, explanation of designation evacuation route is seen in all prefectures. In the case of a Tsunami evacuation, designation of evacuation routes is important and become the most essential content on evacuation. Therefore, it is considered that the description of designation route is important as indicated in each prefecture. Dangerous zone is described as evacuation spot and evacuation route which is avoided. It is seen in all prefectures except Mie. It is considered that dangerous zone is described in some prefectures because it has a significant influence on evacuation action of residents at Tsunami disaster. The dangerous spot is explained only in Mie prefecture. It is considered that dangerous spot is described based on Participation type because it may include resident owned facilities and need to obtain the consent of the local resident. Evacuation recommended area is described in Niigata Prefecture, Shizuoka Prefecture, and Aichi Prefecture. Evacuation recommended area is considered to be a standard for the municipality under evacuation advisory and an evacuation order for the evacuation of residents. So, the designation in the prefecture where guideline of municipality evacuation plan published is considered important. Evacuation method is described in all prefectures except Shizuoka. It is considered important for each prefecture because in Great East Japan Earthquake the evacuation of evacuees by automobile was obstructed evacuees on foot. Evacuation bag is described in Mie Prefecture and Ishikawa Prefecture. Since detail of evacuation bag differs from the community, it is considered that a few prefectures are described from the viewpoint of local residents in Public Participation type. Information acquisition method is described in all prefectures except Shizuoka and Mie. From the viewpoint of the importance of obtaining information in Tsunami evacuation, it is considered that the description is seen in some prefectures. Evacuation drill method is described in all prefectures except Shizuoka.

7.5.3 Detail of Contents to Be Described in the Community-Level Evacuation Plan

In the previous section, contents to be described in evacuation plan at community level from the guidelines is confirmed. This section confirms detail of contents to be described in the community-level evacuation plan. Detail of contents to be described in community level evacuation plan is shown in Figs. 7.3, 7.4, and 7.5. Although Nagaoka city and Joetsu city do not describe all the contents of prefecture guidelines, all the contents except executability in evacuation drills can be confirmed in these two cities and detail of contents are satisfied.

The evacuation route indicates cases of "evacuation route" and "evacuation direction only" considering that residents will evacuate as shown in Fig. 7.3. The

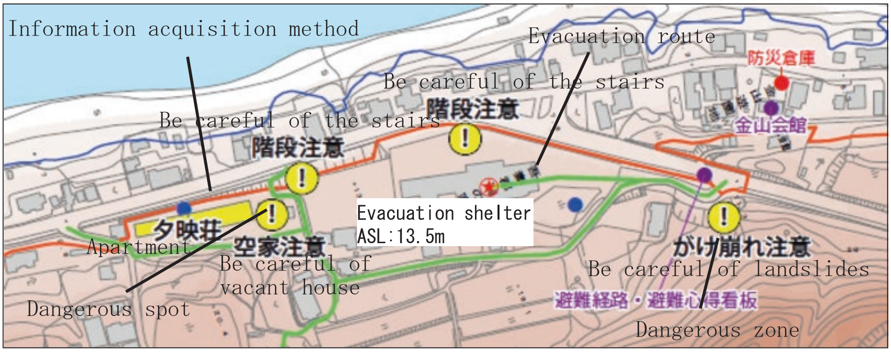

Fig. 7.3 Description of evacuation routes, dangerous zones, dangerous spot, and evacuation recommended areas. (Nagaoka City Tsunami Hazard Map)

(4) 避難の方法・避難先
1 原則として徒歩で避難します。 2 原則として個々で避難しますが、可能な限り近隣に声を掛けて避難します。 3 原則として、町内または地域ごとにあらかじめ定められた指定緊急避難場所・指定避難所に向かいます。

(4) Evacuation method, contact address
1 In general, evacuate on foot
2 In general, to evacuate individually, evacuate to inform as possible as the neighborhood
3 In general, evacuate to emergency evacuation spot, evacuation center in community

Fig. 7.4 Description of evacuation method and contact address. (Community level evacuation plan in Joetsu City)

more detailed evacuation route describes the contents detail. For dangerous zone, an earthquake occurs first in Tsunami disaster. Due to the earthquake, landslide could occur, and the possibility of broken down the evacuation route is considered. Therefore, detail of contents is a description of the area where there is a risk of sudden slope collapse or landslide as shown in Fig. 7.3. The dangerous spot is public facilities such as bridges, tunnels, underpasses, privately-owned facilities such as utility poles and block walls which are the possibility of collapse, vacant houses and so on. When an earthquake occurs, there is the possibility of collapse utility poles and block walls. Therefore, detail of the contents is described including privately-owned facilities as shown in Fig. 7.3.

The contents of evacuation recommended area are those indicated by height above sea level as shown in Fig. 7.3. Evacuation method is considered for healthy individuals and people in need of assistance during Tsunami disaster. Since the evacuation method of person who needs support is thought to be different depending on the type of support, it is necessary to consider in each. The evacuation method of majority healthy individuals is shown in Fig. 7.4. Contents of evacuation bag are a description of specific goods to respond the emergency as shown in Fig. 7.5. As for information acquisition method, detail of contents is considered to differ depending on the community. Specific information such as television, disaster prevention administrative radio, and public relations car are described in the method as shown in Fig. 7.6. As the effectiveness of the plan in evacuation drill needs the participation of many residents,

(3) 避難時に持ち出すものや装備・服装
1 動きやすく、安全な装備・服装 軍手、スニーカー、雨具、ヘルメット上着・セーター 等
2 非常用持ち出し袋の中身 非常食、懐中電灯、携帯ラジオ、ライター、持病の薬 等
3 貴重品や日用品 財布、携帯電話 等

(3) Items to bring out when disaster occurs, equipment, clothing
1 Easy to move, safe equipment, clothes Gloves, sneakers, rain gear, helmet, sweater, etc
2 Contents of evacuation bag Emergency food, flashlight, portable radio, lighter, medicine for chronic illness, etc
3 Valuables and daily necessities Wallet, mobile phone, etc

Fig. 7.5 Description of evacuation bag. (Community level evacuation plan in Joetsu City)

(2) 津波に関する情報の入手方法
1 防災行政無線 地震・津波の情報のほか、市から避難の情報をお伝えします。
2 携帯電話・スマートフォン 市域内にいる方には緊急速報「エリアメール」・緊急速報メールで地震・津波の情報や避難の情報をお伝えします。また、上越市安全メール登録者には、上越市からメールで津波の情報などをお伝えします。
3 新井町町内会からお知らせ 町内会で、拡声器を使用して、災害の状況を周知します。

(2) Information acquisition method on Tsunami
1 Disaster management radio communication system Earthquake and Tsunami warning are informed, and there is evacuation information from municipality
2 Mobile phone, smartphone People in the city is informed about Tsunami and evacuation by earthquake early warning e-mail. Joetsu city also informs about the Tsunami by email for safety mail registrant
3 Information from neighborhood association Neighborhood association informs the situation of disaster by loudspeaker

Fig. 7.6 Description of information acquisition method. (Community level evacuation plan in Joetsu City)

detail of contents for participation in evacuation drill is to drill all residents who participated in evacuation drill based on a community level evacuation plan.

7.6 Actual Situation and Evaluation of the Plan Contents Enrichment

In Sect. 7.5 we confirmed the contents to be described in community-level evacuation plan (hereafter, plan). From the results of a questionnaire survey, it is possible to categorize the determination method presumed in Sect. 7.1 like Planner type, Public Hearing type, and Public Participation type. In this chapter, we evaluate the actual condition of determination method, the enrichment of plan contents by type, and clarify the determination method. Then, to clarify the factors that have high enrichment to the plan contents, we analyzed the relationship between assumption damage of Tsunami, determination method and consciousness of local residents.

7.6.1 Actual Situation of the Plan Determination Method by Types

Based on questionnaire survey's results, Table 7.6 shows a summary of the plan determination method by type. From Table 7.6, Public Participation type is the highest result of 54.2%, and it shows that the consciousness of local residents was high. It is considered that the consciousness of local residents in the Tsunami has been grown due to the Great East Japan Earthquake. The ratio of Planner type is tended to be higher than Public Hearing type. In next section, we evaluate enrichment of plan contents by types and clarify the determination method of the plan.

7.6.2 Contents to Be Described and Evaluation of Plan Contents Enrichment by Types

In this section, we analyze each content to be described in the plan and then evaluate enrichment of the plan contents by types. An evaluation index is the contents to be described in the plan, and the contents detail ratio confirmed in Sect. 7.5.

Table 7.6 How to determine the plan by type

Type	Number of responses (%)
Planner	12 (25.0)
Public hearing	10 (20.8)
Public participation	26 (54.2)
Total	48 (100.0)

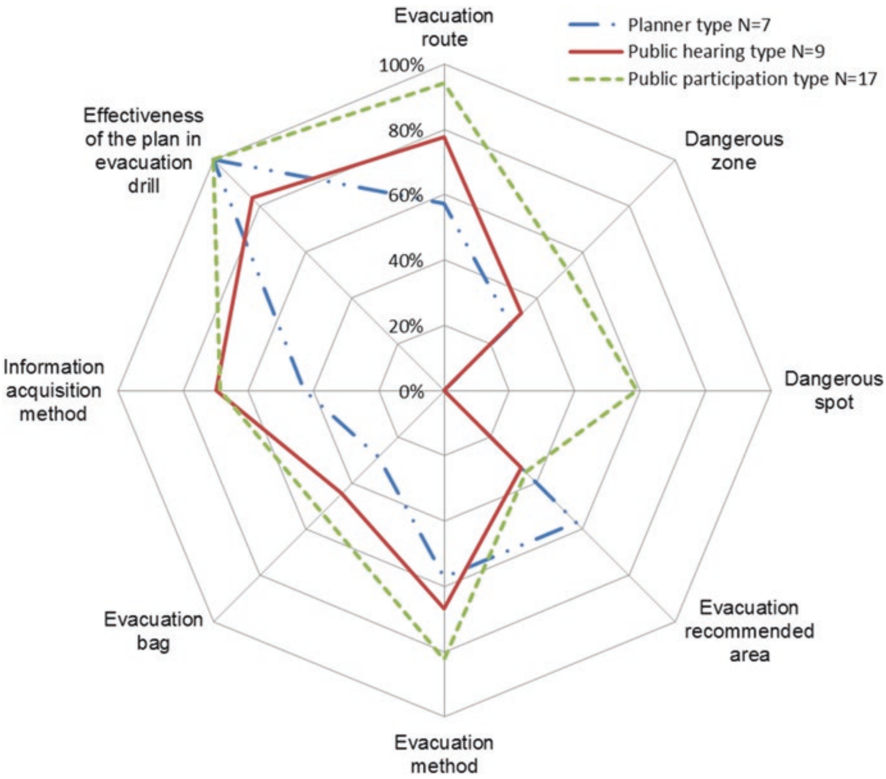

Fig. 7.7 Ratio of planned content by type

The enrichment evaluation was done only on the content described in the plan, which was provided in the questionnaire survey. We received the plan to be determined in the questionnaire survey. As it was being determined, there was no evacuation drill based on the plan yet, and effectiveness of the plan in evacuation drill cannot be evaluated. The description of evacuation bag and evacuation method were not described at the time of receiving the questionnaire. Since there were cases planned in the future, it is necessary to pay attention to the point.

We classified the plan from the questionnaire survey. Planner type has been used in seven municipalities, Public Hearing type in nine municipalities, and Public Participation type in 17 municipalities. Figure 7.7 shows the ratio of each plan content. Enrichment of the plan is the size and overall balance properties of radar chart area. The calculating method of description ratio is the proportion of what was described in the plan for each population type.

1. Analysis of the contents ratio to be described in the plan

- Evacuation routes

The ratio of description was higher in the order of Public Participation type, Public Hearing type, and Planner type. When evacuation routes were designated,

Table 7.7 Group name of participant in public participation type (N = 17)

Group name	Municipality employee	Prefecture employee	Learning experienced person	Disaster preven-tion expert	Disaster prevention leader	Neighbor-hood association	Voluntary disaster prevention organization
Ratio	100%	11.8%	11.8%	17.6%	17.6%	94.1%	100%
Group name	Voluntary fire employee	Elementary and high school	Elderly association	Social worker	Social welfare corporation	Other residents	
Ratio	17.6%	5.9%	11.8%	23.5%	11.8%	17.6%	

designation other than the main road such as roads managed by neighborhood association was necessary, especially when considering evacuation from houses. It is considered that evacuation routes are not able to know the road managed by neighborhood association only. Indeed, many of evacuation routes described in Planner were only main roads. Therefore, it is necessary to designate evacuation route based on opinions of local residents who most understand the community.

- Dangerous zones and dangerous spot

Description of the dangerous spot is only in Public Participation type. Contents that needs the most adjustment when determining the plan as the dangerous spot was related to privately owned facilities. As shown in Table 7.7, when the dangerous spot is described in community-level evacuation plan by Public Participation type, it can get the consent of local residents like neighborhood association and voluntary disaster prevention organization. Dangerous zone is the same as a dangerous spot for the participation of local residents. Landslide area related to private land is considered to have the consent of the community.

- Evacuation recommended area

The ratio of Planner type is the highest while Public Participation type and Public Hearing type is almost the same. Evacuation recommended area was determined only by the municipality and considered that it was emphasized in Planner type. Also, Public Hearing type and Public Participation type were not emphasized. As a factor of this, Public Participation type and Public Hearing type have a high proportion of determination by neighborhood association as shown in Table 7.8. Since Planner type was determined in a wide area such as multiple neighborhood associations, Public Participation type, and Public Hearing type were considered for the entire area rather than a specific evacuation by the community.

- Evacuation method

The ratio of description was higher in the order of Public Participation type, Public Hearing type, and Planner type. As a factor, the evacuation method on foot was the main principle. However, the content that needs to be decided on a community basis, such as a method of calling to the neighborhood, was decided by local residents in the discussion of the neighborhood association. Therefore, as shown in Table 7.8, it was considered that proportion of the plan was high in Public

Table 7.8 The plan determination unit

Determination unit	Neighborhood association	Elementary school	Multiple neighborhood association	Evacuation spot	Inundation area	Response number (%)
planner type	0 (0.0)	2 (28.8)	4 (57.1)	1 (14.3)	0 (0.0)	7 (100)
Public hearing type	5 (55.6)	0 (0.0)	3 (33.3)	0 (0.0)	1 (11.1)	9 (100)
Public participation type	15 (88.2)	0 (0.0)	1 (5.9)	0 (0.0)	1 (5.9)	17 (100)
Total	20 (60.6)	2 (6.1)	8 (24.2)	1 (3.0)	2 (6.1)	33 (100)

Participation type and Public Hearing type with a high ratio of determination by neighborhood association unit.

- Evacuation bag

Description ratio was higher in the order of Public Participation type, Public Hearing type, Planner type, and description ratio of the plan content was lower overall. As shown in Table 7.8, Public Participation type and Public Hearing type have high determination ratio of neighborhood association unit. Planner type is considered to describe general contents indicated in hazard map or the like which was not the plan.

- Information acquisition method

Public Hearing type and Public Participation type had a high description ratio. As a factor, in some cases municipality requests the local residents to inform public relations car to communicate with a loudspeaker or the like in the community when a disaster occurs. Therefore as shown in Table 7.8, Public Participation type and Public Hearing type had a high determination ratio in neighborhood association unit. Information acquisition method was considered to be described by obtaining the consent of neighborhood association.

- Effectiveness of the plan in an evacuation drill

Planner type and Public Participation type description ratio were 100%. It was an opinion that Public Hearing type was only conducted in some communities as the test. It was found that the effectiveness of the plan in evacuation drill was high in all types.

2. Evaluation of the enrichment of plan contents by types

   - Planner type

Evacuation routes, evacuation recommended areas, evacuation methods, and effectiveness of the plan in evacuation drill tended to a high description ratio. On the other hand, description ratio of dangerous zones, dangerous spot, evacuation bag, and information acquisition methods were low. Enrichment of the plan contents tended to be different depending on the contents. Municipalities determined the Planner type. Therefore, the plan contents only specified by municipalities and contents related to the establishment of evacuation behavior had high description ratio. However, the plan contents that needs to be confirmed and considered at the meeting were low in the description ratio. Enrichment of the plan contents was low and unbalanced overall.

- Public Hearing type

Description ratio of evacuation route, evacuation method, information acquisition method and effectiveness of the plan in evacuation drill were high. Evacuation route and information acquisition method tended to be high when compared with Planner type. On the other hand, description ratio of evacuation bag was about half and description ratio dangerous zone, dangerous point and evacuation recommended area tended to be low. As for Planner type, the plan contents which need to be confirmed by field work and considered at the meeting tended to be low. Enrichment of the plan content was higher than Planner type, and the overall balance was slightly better.

- Public Participation type

The overall balance was a good trend with high description ratio of all contents except for evacuation recommended area. It is considered in Public Participation type that the high enrichment of the plan contents has been determined because participation of local residents and description ratio of considering many items was confirmed in the field walk and meetings. In the evaluation of plan contents enrichment by type of determination method, the most enrichment and a good overall balance were by Public Participation type. Public Hearing type and Planner type were in the next turn. As the tendency, if participation of local residents increased, the enrichment of the plan contents will be better.

In this study, we received the plan determined by the municipality and the plan determined only by local residents such as voluntary disaster prevention organization. Enrichment of the plan contents determined only by local residents was low. In general, it was considered that municipalities know the contents to be described in the plan. However, since the local residents have the most knowledge in the community and there were many contents that cannot only be understood by municipalities, it is important that municipalities and local resident cooperate in the determination of the plan.

7.6.3 Factors for Public Participation Type

In the previous section, we analyzed the contents to be described in the plan and enrichment of the plan contents. We found that the one with the highest level of enrichment was Public Participation type. In this section, we analyzed the relationship between the Tsunami damage estimation with determination method and the consciousness of local residents with Tsunami damage estimation. It was done to understand one of the factors to be the Public Participation type.

Table 7.9 Relation between determination method and Tsunami height

Number of responses (%)				
Tsunami height (×)	1 m ≤ × < 5 m	5 m ≤ × < 10 m	× ≥ 10 m	Total
Planner type	3 (42.9%)	2 (28.6%)	2 (28.6%)	7 (100%)
Public hearing type	3 (33.3%)	5 (55.6%)	1 (11.1%)	9 (100%)
Public participation type	2 (11.8%)	10 (58.8%)	5 (29.4%)	17 (100%)
Total	8 (24.2%)	17 (51.5%)	8 (24.2%)	33 (100%)

The damage caused by Tsunami was considered the highest Tsunami height (from now on Tsunami height) reaching the municipalities, the reach time of Tsunami, and Tsunami-inundation area. Tsunami height was most widely known and has the most significant influence on determination consciousness of the plan of municipalities and local residents. So in this study, we focus on the Tsunami height and analyze it. Classification of the Tsunami height was divided into three groups which were described by national guidelines related to disaster prevention. The first group is 1 m or more and less than 5 m, the second group is 5 m or more and less than 10 m, and the third group is 10 m or more. Table 7.9 shows the relationship between the determination method and Tsunami height. For Planner type, each Tsunami height was average, but the ratio tended to be relatively higher at 1 m or more and less than 5 m. The ratio of Public Hearing type and Public Participation type tended to be higher than 5 m or more and less than 10 m.

Regarding the relationship between determination method and Tsunami height, it was tended to be Public Participation type when the Tsunami height estimation was high. However, there was no notable difference from the relationship between determination method and Tsunami height.

Next, the consciousness of local residents was considered to be high in Public Participation type. In the questionnaire survey, we investigated the determination method and found that local residents were the determination subject for Public Participation type by about 70.6% and the consciousness of local residents tended to be high. The Awareness of local residents was considered to be related to damage estimation (Tsunami height) which affected the disaster awareness in Tsunami damage of local residents.

From the following, we analyzed the relationship between determination awareness of the local residents and the damage aspect (Tsunami height). Since determination subject in Planner type and Public Hearing type were municipalities, the analysis was conducted only with Public Participation type involving municipalities and local residents. Definition of determination subject was proposed by local residents to municipalities when the plan was determined. After that when local residents mainly developed the determination of the plan, the determination subject was local residents. In other cases, the determination subject was a municipality. Table 7.10 shows the relationship between determination subject and Tsunami height by Public Participation type. In the case of Tsunami height was more than 10 m, it was found that determination subject was the local residents and determination awareness of the local residents was high. In the

Table 7.10 Relationship between determination subject and Tsunami height by public participation type

Number of responses (%)				
Tsunami height (×)	1 m ≤ × < 5 m	5 m ≤ × < 10 m	× ≥ 10 m	Total
Municipalities	1 (25.0)	4 (75.0)	0 (0.0)	5 (100.0)
Local residents	1 (8.3)	6 (50.0)	5 (41.7)	12 (100.0)
Total	2 (11.8)	10 (58.8)	5 (29.4)	17 (100.0)

relationship between determination method and Tsunami height, there was no notable difference from the Tsunami height.

Determination subject focused on Public Participation type was found to be a high ratio of the local residents. Also, in the case of Tsunami height was more than 10 m, the local residents were highly aware of Tsunami disaster, and determination subject tended to be a high ratio of the local residents.

In this chapter, we evaluated the enrichment of the plan contents and found that Public Participation type was the highest enrichment. It was found that the determination unit of the plan had a high ratio for the neighborhood association that emphasized the community. To know one of the factors to be Public Participation type, we analyzed the relationship between determination method with Tsunami height, and determination subject and Tsunami height. As a result, it was found that in Public Participation type the determination ratio of the local residents was high and in the case of Tsunami height was more than 10 m, determination subject tended to be the local residents.

Public Participation type was greatly differenced from other types of the enrichment of plan contents where the local residents need to be considered for field survey and meeting. Therefore, in the next chapter, we focus on Public Participation type and conduct group classification from consideration items of field and meeting. We also evaluate enrichment of the plan contents by the group and clarify one of the factors that are a high enrichment in the groups.

7.7 Evaluation of Enrichment of the Plan Contents by the Groups

In this chapter, we focus on Public Participation type and conduct group classification from consideration items of field and meeting. We also evaluate enrichment of the plan contents by the groups and clarify one of the factors that are a high enrichment in the groups.

Table 7.11 shows consideration items for field and meeting. The group classification was conducted in the following process. In the case of consideration items for the field are 1 or more and consideration items for the meeting are 1 or more and less than 4, it is field group. In the case of consideration items for the field are 0 or more and consideration items for the meeting are more than 1, it is meeting group.

Table 7.11 Consideration items for field and meeting

	Considerations items
Field	Confirm evacuation route in field work
	Confirm evacuation place in field work
	Confirmation of evacuation zone and evacuation spot in field work
Meeting	Task extraction
	Conduct before the evacuation starts
	Evacuation bag
	Information acquisition method
	Evacuation method of healthy person
	Evacuation method of supported person
	Plan determination and consensus

Table 7.12 Group classification by municipality

Municipality	Field	Meeting	Group classification result
A	0	3	Meeting group
B	3	2	Field group
C	0	5	Meeting group
D	0	7	Meeting group
E	3	3	Field group
F	3	7	Integrated group
G	1	2	Field group
H	0	4	Meeting group
I	3	5	Integrated group
J	0	3	Meeting group
K	3	1	Field group
L	3	4	Integrated group
M	3	3	Field group
N	3	7	Integrated group

In the case of consideration items for the field are 2 or more and consideration items for the meeting are 4 or more, it is an integrated group.

Evaluation of enrichment of the plan contents from group classification was conducted on contents that were considered to affect enrichment of the plan contents from consideration items. The evacuation routes, dangerous zones, the dangerous spot were considered as the consideration items related to the field. Evacuation bag, evacuation method, and information acquisition method were considered as the consideration items related to the meeting.

The enrichment of the plan contents was evaluated with six contents. Classification result by the municipality is shown in Table 7.12. We classified field group was six municipalities, meeting group was five municipalities, and integrated group was six municipalities. The indicator was in the same way for evaluation method of enrichment of the plan contents. It was the description ratio to be described in the plan and

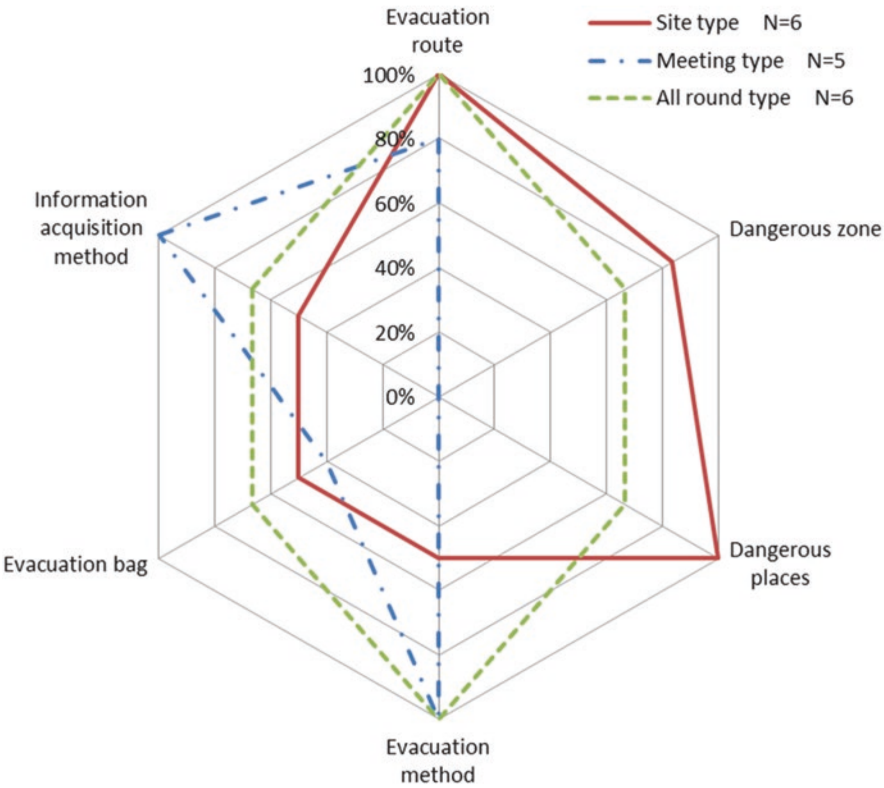

Fig. 7.8 Description ratio of planned content by type

detail of the contents. Figure 7.8 shows description ratio of planned content by type. In the same way of the previous chapter, calculating method of description ratio is description ratio of each population group.

7.7.1 Evaluation of the Enrichment of Plan Contents by the Groups

- Field group

The ratio of evacuation route, dangerous zone, and dangerous spot was high. On the other hand, evacuation method, evacuation bag, and information acquisition method were about half, and these were lower than the other groups. In other words, field group was considered to be understandable to describe in the plan to confirm the evacuation route, dangerous zone, and dangerous spot in field walk. However, as it was attached important to consider items of the field for evacuation route, dangerous zone, and dangerous spot in the field work, items to be considered in evacuation method, evacuation bag, and information acquisition method at the meetings were lower than the other groups. The overall balance was better

- Meeting group

The ratio of evacuation routes, evacuation methods, and information acquisition methods was high. On the other hand, there was no description of dangerous zone and dangerous spot. As evacuation routes were important contents, these were considered at the meeting. Evacuation bag was at a low ratio of 40%, and as for meeting group, it was found that evacuation bag was not considered important as considerations items. In other words, meeting group was not confirmed items of the field by field work, but information acquisition method and evacuation method of healthy volunteers and supported persons were considered at the meeting. Therefore, the content items were plain to describe in the plan. The overall balance was bad.

- Integrated group

The overall ratio was high, and the balance was good. In comparison with field group, the plan contents for field items were low. In the case of compared with meeting group, enrichment for plan contents of the meeting was almost the same. Therefore, in the case of a number of consideration items increased, it was found that enrichment of the plan contents was high. It was because disaster awareness of the local residents was high and became one of the factors that considered many items.

As a result of evaluating enrichment of the plan contents by the groups, it was found that enrichment of the plan content was the highest in integrated group. Overall balance was good, and it was higher as the number of considerations items increases. Also, in the case of considering many items relating to the field, it was found that the enrichment of the plan contents was higher than the case of considering many items relating the meeting and the overall balance was improved. Therefore, we consider it is possible to improve enrichment of the plan contents by many consideration items or by confirmation of field work.

7.7.2 Factors of Field Group and Integrated Group

In the previous section, enrichment of the plan contents was evaluated by the groups. As a result, in the case of field group or integrated group, it was found that enrichment of the plan contents was higher. In this section, we analyze the relationship between Tsunami height and determination subject by the groups and clarify the factors that make field group and integrated group. Definition of Tsunami height and determination subject is the same as those described in Sect. 7.6.3.

First, we analyze the relationship between Tsunami height and the groups. Table 7.13 shows the relationship between Tsunami height and the groups. In the case of Tsunami height is 10 m or more, it was in many cases of field group and integrated group. As a factor, the awareness of the local residents was high in the

Table 7.13 Relationship between Tsunami height and the groups

Number of responses (%)				
Tsunami height (×)	1 m ≤ × < 5 m	5 m ≤ × < 10 m	× ≥ 10 m	Total
Field group	0 (0.0)	4 (66.7)	2 (33.3)	6 (100)
Meeting group	1 (25.0)	4 (75.0)	0 (0.0)	5 (100)
Integrated group	1 (16.7)	2 (33.3)	3 (50.0)	6 (100)
Total	2 (11.8)	10 (58.8)	5 (29.4)	17 (100)

Table 7.14 Relationship with the determination subject and the groups

Number of responses (%)			
Determination subject	Municipality	Local residents	Total
Field group	1 (16.7)	5 (83.3)	6 (100)
Meeting group	4 (75.0)	1 (25.0)	5 (100)
Integrated group	0 (0.0)	6 (100)	6 (100)
Total	5 (29.4)	12 (70.6)	17 (100)

case of Tsunami height was high, and we consider it was because of considered many items in the field work and meeting. There was no difference in other Tsunami height.

Next, we analyze the relationship between determination subjects by the groups as shown in Table 7.14. The ratio of municipalities that determined the meeting group was high. Field group and integrated group were high ratios of the local residents. In the case of determination subject was the local residents, they were actively engaged in activity such as fieldwork and evaluating items to be considered at the meeting.

In this chapter, we focused on Public Participation type and evaluated the enrichment by classifying the groups from consideration items. As a result, in the case of field group and integrated group, we found enrichment of the plan contents was high. Later, to know the factors that make field group and integrated group, we analyzed the relationship between Tsunami height and determination subject by the groups. As a result, field group and integrated group are found to be many in the case of Tsunami height was more than 10 m and the local residents are the determination subject.

7.8 Conclusion

The main findings obtained by this study are as follows. For municipalities in the Chubu region, we clarified the actual situation of the plan formulation and problems in determination. We confirmed contents to be described in the plan from description ratio of the plan and the guidelines developed by the country and the prefecture. Contents to be described in the plan from the guidelines were evacuation route, dangerous zone, dangerous spot, evacuation recommended area, evacuation method and evacuation bag. Also, we extracted the method of evacuation drill for the effectiveness of the plan in evacuation drills after the plan determination and summarized the situation of each the plan contents by the prefectures. Also, we confirmed detail of the contents to be described in the plan from the guidelines.

From the questionnaire survey results, we categorized the determination method in Planner type, Public Hearing type, Public Participation type, and clarified the actual situation of the determination method. To clarify the method of determination, we evaluated the enrichment of the plan contents by the types. As a result, in the case of determining in Public Participation type, the enrichment was highest and overall balance was good. Then followed by Public Hearing type and Planner type.

We clarified that enrichment of the plan contents was high in case of participation of the local residents increased. Notably, it was only Public Participation type that contains a description of dangerous spot and determination of Public Participation type was effective. Also, Public Participation type was found to be understandable to coordinate with the local residents because the plan determination unit was neighborhood association and the planning area was not wide. Also, to know the factors to be Public Participation type, we analyzed the relationship between determination method and Tsunami height. In the case of determination subject was the local residents, it tends to be Public Participation type. Later, we focused on Public Participation type. To know determination subject was the local residents, we analyzed the relationship between determination subject and Tsunami height. Although there was no noticeable difference between the determination method and the Tsunami height, the relationship between the determination subject and the Tsunami height tend to be determined by the local residents in the case of more than 10 m of Tsunami height.

After that, we focused on Public Participation type and evaluated enrichment of the plan contents by the types to field group, meeting group, and integrated group from consideration items of field and meeting. As a result, the integrated group was the most enrichment of the plan contents, and the overall balance was good. Also, enrichment of the plan contents tended to be higher as the number of consideration items increase. It clarified that confirmation by field work was effective. To know the factors to be field group and integrated group, we analyzed the relationship between Tsunami height and determination method by the types. Relationship with Tsunami height tended to be field group and integrated group in the case of more than 10 m, and disaster awareness of the local residents tended to be high in the case of the Tsunami damage estimation was large. The relationship with determination subject tended to be field group and integrated group in the case of determined by the local residents.

Therefore, when the plan was determined, it is concluded that consideration of many items and confirmation by field work is effective in Public Participation type. It is important that determination of the plan be carried out by neighborhood association on community and one of the factors for high enrichment of the plan contents is Tsunami height above 10 m. Also, it is crucial that determination subject is the local residents.

As for the future issues, it is not yet clear how the consideration items for field and meeting are affected by the community. It is necessary to analyze the awareness of local residents and what groups are participated in the determination. It is also necessary to analyze from the survey of the actual community situation and the guideline.

References

Abe Y, Kamio H et al (2005) Proposal and development of tsunami evacuation plan in coastal area by workshop method. Proc Coast Eng 52:1271–1275

Central Disaster Management Council (2015) Basic plan for disaster prevention, P111

Earthquake Research and Promotion Headquarters (2013) Long term evaluation of the Nankai Trough's earthquake activity, 2nd edn. Overview Material, P24

Fire and Disaster Management Agency (2013) Manual reports on Tsunami Evacuation countermeasure from Examination Committee

Nomura N, Miyazima M, et al (2013) A study on disaster risk communication using the workshop technique -Case study of Wajima district in Wajima city. J Assoc Earthq Eng Pap 69(4): 528–538

Ota K, Nishida H et al (2006) Action program for comprehensive Tsunami countermeasures of Kushimoto Town, Wakayama. J Soc Saf Sci 8

Terumoto K (2012) The design and implementation of a practical tsunami evacuation drill. J Jpn Soc Civ Eng, Eng Plan 68(5):I_63–I_74

Yashiro H, Nishikawa S et al (2004) A case study on drawing up a plan for evacuation in Tsunami at community level. AIJ J Technol 19:359–364

Chapter 8
Integrated Criteria for Flood Disaster Mitigation in Indonesian Urban Masterplan; Housing and Settlement Suitability Case in Palu Urban Masterplan

Rifai Mardin and Zhenjiang Shen

Abstract The growing number of urban residents in the world urges some governments including Indonesia to provide an ideal housing and settlement by considering climate change factors that impact the occurrence of floods in their urban areas. This study aims to integrate housing and settlement planning within the Indonesian Urban Masterplan (RTRW-Kota) with flood mitigation system by identifying spatial planning criteria related to housing and settlement planning and disaster mitigation within the Indonesian regulations. The criteria are then incorporated to integrated criteria in the modelling suitability area for housing and settlement planning. The method is using content analysis to identify these criteria and then model them in GIS environment. This study found 10 standard criteria for housing and settlement planning with disaster management, 7 related to spatial planning and other 3 related to disaster mitigation respectively.

Keywords Integrated criteria · Flood disaster · Housing and settlement · Urban planning

8.1 Introduction

Integrating of disaster risk reduction within all sectors including urban planning is very important (UNISDR 2015). As one of the most significant type of disaster, flood hazard is a thoughtful devastating, challenging economic damage, and threats human lives especially in urban area (Ran and Nedovic-Budic 2016;

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Tingsanchali 2012). Housing and settlement planning as a part of the urban planning hold an important key to reduce the disaster risk. The integration of disaster mitigation and spatial (urban) planning could lead to disaster resilient communities (Francesch-Huidobro et al. 2015; Kornakova and March 2013). Moreover, learning from Rotterdam, Guangzhou and Hongkong, integrating flood disaster mitigation with urban development and economic growth still remains a challenge (Francesch-Huidobro et al. 2015). This research is to answer the challenge by promoting integrated criteria of flood disaster mitigation and housing-settlement suitability in urban planning.

Land-use suitability analysis is an important step in an urban/regional environmental planning process (Liu et al. 2014; Malczewski 2004). The land-use suitability can be construed as a guidance value of urban land-use function to be accepted. The suitability process gives a value for each land feature, when the value is high, then the land is more likely to attract human activities. The result of the land-use suitability analysis will define which area of the land is valuable to be developed (Kii and Nakamura 2017; Malczewski 2004).

In the 1950s, the single-objective decision tools lost their advantage in a decision-making process. This was a result of the complexity in the real world which cannot be adopted only by using a simple decision-making process. Slowly, the simple decision tools are replaced by multiple criteria analysis (MCA), combine with the decision making process (MCDA) (Rebecca Barnes and Ashbolt 2006). Started in the 1950s, as development invitations in scientific fields, GIS-modelling has developed into varied fields including suitability analysis. Now, GIS and MCDA have evolved to become a handful tool for decision analysis in evaluating alternatives for spatial planning and suitability land-use planning (Kain and Söderberg 2008; Malczewski 2004, 2006; Mardin 2009). The MCDA is a method which evaluates alternatives based on a set of criteria. These criteria are closely linked to the policy objectives and are developed to provide a functional appraisal of selecting the best alternatives related to all the potential cost and benefit effects (Liu et al. 2014; Mardin 2009).

Worldwide urban inhabitants by 2050 in projected 70% of the world's populations, are estimated that 1.5 million people migrate to the cities every week (Wilson Center 2017). With an average growth rate of 4.2% between 1993 and 2007, this rapid population growth also occurred in Indonesia. The urbanization process makes Indonesia as one of the most urbanized countries in Asia, with 51% urban populations in 2011, and by 2025, the projection of urbanization will increase to 68% (World Bank 2013). Population growth in urban area is also highly related to the increasing of disaster risk (Caparros-Midwood et al. 2015; Kita 2017).

For the case study in Indonesia, the flood is not something extraordinary as a routine flooding occurs throughout Indonesia. According to National Board for Disaster Management (*BNPB-Badan Nasional Penanggulangan Bencana*) from September 2011 to May 2016, there were more than 1.211 flood disasters appeared throughout Indonesia and these impacted millions of people and thousands of houses (BNPB 2016). This problem pushes Indonesia to realize the importance of disaster mitigation in the spatial planning process. Therefore, Indonesia Government has authorized and enacted Act Number 24/2007 on *Disaster Management*. The law is intended to provide a strong legal basis for disaster management at the district or city, provincial and national levels. The Indonesian government also revised the spatial law draft of 1992 by a new law, Indonesian Act No 26/2007 on *Spatial Planning*. The Act No 26/2007 stated that, all the spatial planning process through Indonesia cities should incorporate risk reduction in their spatial plan document (RTRW). As an operational document of spatial planning, Indonesian urban masterplan (RTRW-Kota) regulates three important aspects in the urban area; land-use, urban infrastructure, and strategic area. To regulate these aspects, every municipality should determine their goals, policies and strategies in advance. Later, all the three aspects will be regulated by using guidance and control provisions for urban land-use.

As part of the cultivated area (*kawasan budidaya*), housing and settlements are important factors for a holistic city planning. In Indonesia, the policy of housing and settlements development are directed to meet the needs of decent and affordable housing in a healthy and safe environment. According to Act 1/2011 about *Housing and Settlement Area*, the good housing and settlements have to be supported by public infrastructures, public utilities and other facilities on a sustainable basis. The planning should also accordance with the spatial land-use arrangement.

The housing and settlements as a part of the Indonesian urban masterplan and Disaster Mitigations look completing each other, including the regulatory and operational explanation guidelines, but these spatial regulations on the level of implementation seem very far from the reality (Birkmann et al. 2014). It means that although the regulations are available, it has not provided a clear method that can link disaster mitigation and settlements in spatial planning. The aim of this study is to integrate the criteria of flood disaster mitigation and housing settlements in urban masterplan by answering these 2 objectives. The first objective is to define the related criteria in both disaster mitigations and housing-settlement planning regulations, and the second is to build a suitability model in the study area using the identified criteria.

8.2 Method

To answer the objective of the study, two different methods are constructed in 2 stages. First is finding criteria for the guidelines of housing and settlements planning. The found criteria are used to reconstruct housing and settlements planning in municipality masterplan that is adaptive to flood disaster in the second stage.

8.2.1 Finding Criteria for Settlement in Indonesian Urban Masterplan and Flood Disaster Management – A Content Analysis

Content analysis of spatial regulation documents and disaster mitigation regulation documents is used to find the criteria for housing and settlements planning and flood disaster mitigation. To identify the relevant documents, Abedinnia et al. (2017) defined 5 steps including: a. Initial search, b. First refinement, c. Second refinement,

d. Snowball search and, e. Final assessment. Because the material in this research is not as complicated as the research which carried out by Abedinnia et al., this research modifies the process only into 4 steps where the refinement process is done at one step. The steps can be stated as follows:

1. *Initial search*; As mentioned, the regulations on disaster mitigation and spatial planning come from 2 different roots which are Act No 26/2007 and Act No. 24/2007. By using this two Act group, the research process found 11 regulations highly related to spatial planning and 3 regulations related to disaster mitigation.
2. *Refinement*; The process comes to the next step where the refinement process is carried out. This process is to limit the content of regulations which are discussed; "housing and settlement" and "disaster mitigation". The process found 5 regulations on spatial planning and 2 regulations from disaster mitigations.
3. *Snowball search*; this is the backward and forward process to check the relevant references that could complete the required criteria. This step adds 2 more regulations.
4. *Final assessment*; all documents which are selected from previous steps are completely read to access their relevance and to conclude the criteria.

8.2.2 Modeling the Integrated Criteria of Flood Disaster Mitigation with Housing-Settlement in Indonesian Urban Masterplan

8.2.2.1 Criteria

As to answer the second question, this research moves to the second phase, which is measuring housing and settlements suitability area using Multi-criteria Decision Analysis (MCDA) in GIS environment. The criteria that had already been found in the first phase are extracted into spatial data in the form of map layers and then it is analyzed by ArcGIS platform (ArcGIS 10.0).

There are two categories of criteria where all criteria/factors for evaluation/analysis of land-use suitability fall within these two categories. The categories are the opportunities (benefit) criteria and constraint criteria. Opportunities criteria which some scholars also defined as benefit (from cost and benefit analysis term) is the favourable condition where the criteria are most likely to be chosen as desirable conditions, while constraint criteria are where the allocated land cannot be chosen because the location is prohibited to be developed such as water body, protected forest, etc.

8.2.2.2 Analytical Hierarchy Process (AHP) Weighting

AHP is chosen as criteria weighting tools because it can help determine the best choice that involves many criteria based on intuition and perception while keeping consistency (Saaty 1990). AHP provides the possibility for decision makers to represent the interaction of sustainable factors in complex and unstructured situations. This analytical tool helps decision makers to identify and simultaneously prioritize based on their intended goals, existing knowledge, and experience for each of the problems faced (Saaty 1990). The weight factors only applied for opportunity criteria and not applied for constraint criteria, since the constraint criteria are strict requirements.

8.2.2.3 Suitability Mapping

The suitability map is an outcome from calculating every criteria map score. A composite map developed by overlaying the opportunity map and the constraint map. The result reflects the degree of opportunity (or suitability) with ranked values allocated to all mapping units. The mathematic equation for the opportunity criteria can be found in the following formula

$$T_{opp} = \sum_{n}^{i=1} a_i j_i = a_i j_i + a_2 j_2 + \ldots + a_n j_n \tag{8.1}$$

Where T_{opp} is the total opportunity value, a_i is the score of opportunity of i-th criteria, j_i is the weight of opportunity i-th criteria, and n is the number of the criteria

The mathematic equation for the constraint criteria is described as;

$$T_{cons} = \sum_{n}^{i=1} c_i \tag{8.2}$$

Where T_{cons} is the total constraint value, c_i is the value of constraint of i-th criteria, and n is the number of the criteria.

The suitability equation is symbolized as;

$$S = T_{opp} - T_{cons} \tag{8.3}$$

8.2.2.4 Material for Mapping the Suitability Models

In reconstructing of residential area planning in accordance with RTRW directives, it needs some indicator maps which have become the standard in settlement planning according to the direction of spatial regulation in Indonesia. Criteria are converted into thematic maps that will be spatially analyzed with GIS software. In addition to the above theme data, basic maps and supporting maps in the spatial analysis process are also needed to determine the settlement areas that are suitable for the purpose of this study. The data preparations for the analysis in this research are rectification of map and digitization of the raster data. The process are as follows

(a) Standardize the coordinate system of the existing map into a uniform system. A common problem obtained in the spatial mapping system in Indonesia is the unavailability of the same basic map. All maps will use Transverse-Mercator projection system, WGS 1984, and UTM Zone 50S.

(b) Digitizing Raster Maps. All raster maps data should be converted to vector maps and this process is manually carried out by digitizing process. The process itself uses a scale of 1: 20,000 to produce detailed 1: 50,000 scale maps in accordance with RTRW standard maps.

As much as possible, all maps used are the same maps with 2009 RTRW-Kota document. Some of maps that are available in the RTRW-Kota document in particular and disaster maps related to disaster mitigation regulation can be taken from other accountable source.

8.2.3 Study Area

8.2.3.1 Palu

According to the *President Regulations No 88/2011,* Palu is the capital city of Central Sulawesi Province, Indonesia, which is defined as one of the national local centers to serve the international, national and regional scale activities. The region consists of five dimensions of mountains, valleys, rivers, bays and oceans. Astronomically, Palu is located between 0°, 36' to 0°, 56' south latitude and 119°, 45' to 121°, 1" East longitude. It lies almost on the Equator line and altitude of Palu is between 0–700 m above sea level. The area of Palu reaches 395.06 km^2 and it is divided into eight districts (kecamatan) and 44 Village (kelurahan) (Palu Statistic Bureau 2016) (Fig. 8.1).

Since the 70s, in general, the development of the settlement in Palu has shown a concentrated form on the core of the city, part of river banks and very close to Palu estuary. However, there is a distinct physical development on the periphery urban of the city (Mardin 2011).

In 2015, the estimated population of Palu was 368.086 inhabitants, consisting of 185.105 males and 182,981 females. The estimation of the population density was 932 people/km^2. Based on the village's administration, the population density in the city center was higher when compared to the fringe area (Palu Statistic Bureau 2016).

8.2.3.2 Flood in Palu

The development of Palu city started with agriculture process in the fertile area, especially on the floodplain area around the main rivers. Over time, these areas began to grow into a city center. The new function of city center directly makes this area the most densely populated area (Mardin 2011) and the floodplain landform brings the consequences of flood disaster. In reality, Palu had bad history of the flood disaster and this is also worsened by the position of the tidal surge along the northern part of the city.

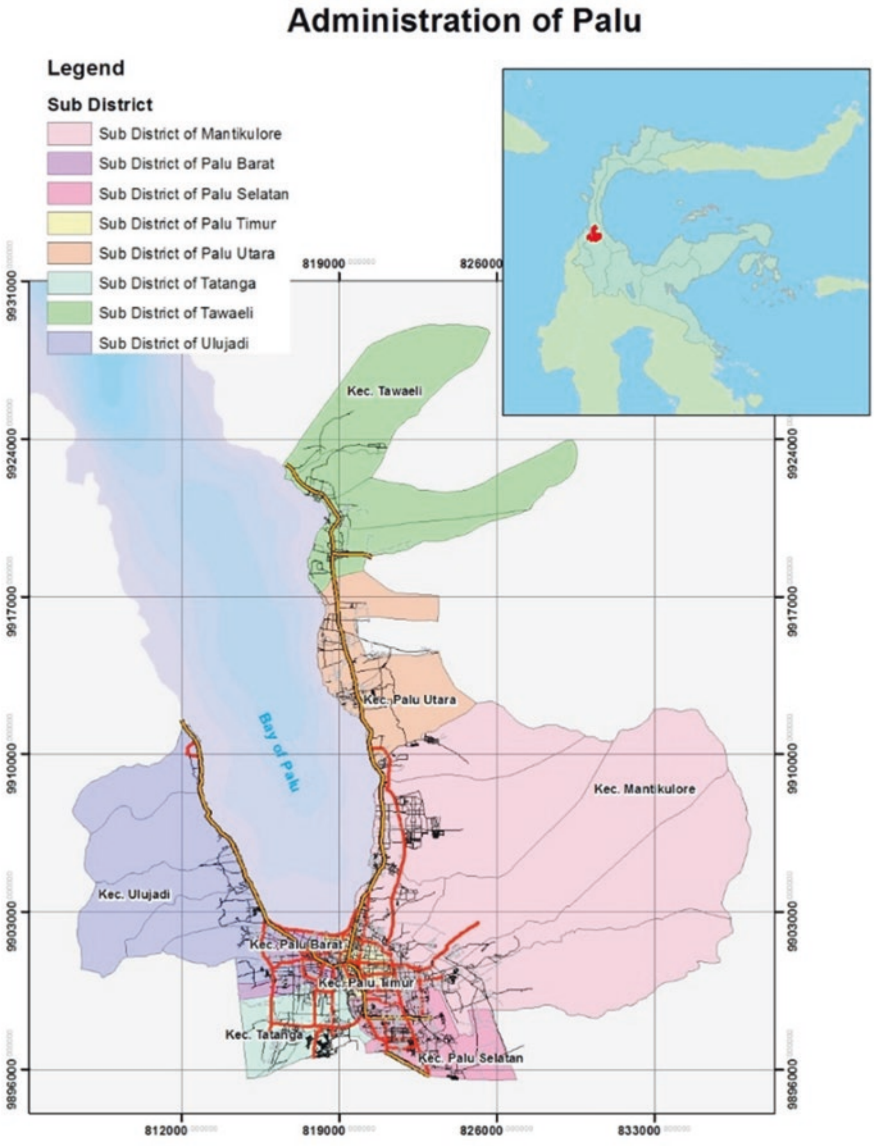


Fig. 8.1 Administration map of Palu

All rivers in Palu area, including the main river (Palu River), have a longitudinal profile and large slope gradient. When a flood occurs, the current is strong and very destructive. However, the flooded area is relatively narrow and the flood time is relatively short. Since the type of flood is a flash flood, it makes difficult for the people to be displaced into safety area (Municipality of Palu 2014). Flooding in Palu is a routine recurring event between 1–3 years during the heavy rain. It has a devastating impact on society, especially for people who live in city center area (Palu Barat District). As an example, in 2011, the total area impacted by the flood was 756 Ha (submerged) with 300 people displaced. There were no casualties, but the loss was estimated to be more than 560 Million Rupiah. The flood occurred in two districts: Palu Selatan District and Palu Barat District. Although the submerged area in Palu Barat District is only 50Ha, due to the dense population, the loss in this area is very high, with around 500 Million Rupiah estimated (Municipality of Palu 2011).

8.2.3.3 Housing and Settlement in Palu Urban Masterplan

Other than floods and other natural disasters, the Municipality of Palu also has various problems in their spatial planning including complying the demands of sustainable urban development, and being enforced by the spatial regulation especially Act 26/2007. Palu Municipality developed their urban masterplan in 2009 and this plan is one of the first urban planning regionally created by using the latest rules. As a pioneer in municipality masterplan, this urban planning product is very important to be reviewed to gain valuable lessons about the housing and settlements planning process.

Like most municipality masterplan in Indonesia, Palu urban masterplan is made to follow the standard of planning which has been established by law. This masterplan was made in 2009, 2 years after Act No 26/2007 launched, then officially this masterplan was designated as a Palu spatial guideline in 2011 with a validity period of 20 years until 2021.

The existing Palu urban masterplan consists of several sections. However, in this study, the main concern is directed to the housing and settlement planning of land-use. Based on the existing urban plan data and map, the total area of settlement is 9104.08 Ha where it is divided into 3 categories which are; (a) low-density settlement areas (271.40 Ha); (b) medium-density settlement areas (517.40 Ha); and (c) high-density settlement areas (8314.82 Ha). Figure 8.2 shows the distribution of the settlement and area of each district.

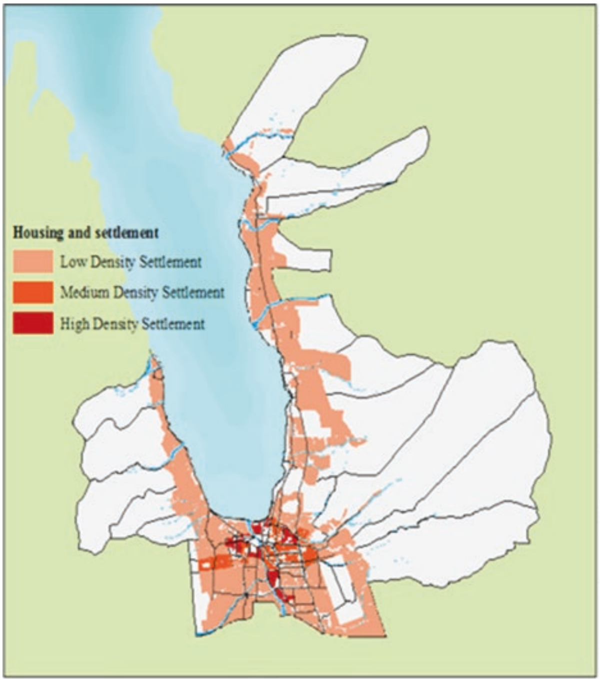
The map (Fig. 8.2) is clearly shown the distribution of high-density settlement in the core of the city along the Palu River through the estuary, while the low density is distributed to other part designated as a cultivated area outward from the core of the city.

8.3 Results

8.3.1 The Criteria

8.3.1.1 Criteria for Housing and Settlement in Spatial Planning

Based on the Content Analysis process (see Sect. 8.2.1), several criteria and indicators could be defined related to housing and settlement planning. The operational level criteria could be found in five Regulations, which are;



District	Density	Ha
Mantikulore	Low Density	2,308.52
	Medium Density	125.70
	High Density	-
Palu Barat	Low Density	194.61
	Medium Density	179.69
	High Density	96.02
Palu Selatan	Low Density	1,270.18
	Medium Density	-
	High Density	85.38
Palu Timur	Low Density	-
	Medium Density	212.46
	High Density	90.00
Palu Utara	Low Density	1,465.46
	Medium Density	-
	High Density	-
Tatanga	Low Density	1,129.92
	Medium Density	0.01
	High Density	-
Tawaeli	Low Density	732.96
	Medium Density	-
	High Density	-
Ulujadi	Low Density	1,213.17
	Medium Density	-
	High Density	-
Total	Low Density	8,314.82
	Medium Density	517.86
	High Density	271.40
All		9,104.08

Fig. 8.2 Map of housing and settlement area. (Source: Municipality of Palu 2009)

(a) Minister of PW Regulations Reg. No 20/2007 about Technical Guidance on Physical & Environmental, Economic and Socio-Cultural Aspects in RTRW Preparation
(b) Minister of PW Regulations Reg. No 41/2007, about Guidelines for Spatial Planning in Cultivated Area
(c) Minister of PW Regulations Reg. No 15, 16, and 17/2009, about RTRW Masterplan
(d) Minister of Public Housing Regulations Reg. No 10/2014, about, Natural Disaster Mitigation Guidelines for Housing and Settlement Areas
(e) SNI 03-1733-2004 – Indonesian Standard for Housing planning procedures in urban areas

From these documents, the research found at least there are 8 very important criteria discussed including: slope condition, availability of fresh water sources, avoiding disaster prone, surface drainage, not in protected area, not in agricultural area, not in irrigated rice field, and distance from other reserve area. The source regulations and the criteria can be seen in Table 8.1 below.

1. Slope (Topography);

Settlement area developed best on a flat terrain as the flat landform can reduce the cost of construction of the housing and for the settlement infrastructures.

Table 8.1 Criteria for housing and settlement area

No	Suitability Criteria from Spatial Planning Guidelines	Sources				
		a*	b*	c*	d*	e*
1	Slope conditions	□	■	□	□	■
2	Available sources of fresh water	□	■	■	□	■
3	Not in prone disaster areas (landslide, flood, erosion, abrasion);	□	■	□	■	■
4	Good soil drainage	□	■	□	□	■
5	Not in a Protected area;	■	■	■	■	■
6	Not located in agricultural area	■	■	■	□	□
7	Not located in Irrigated Rice Field	□	■	□	■	□
8	Not in the dangerous distant from other reserve area (*sempadan*)	□	■	□	■	□

■ Indicated □ Not indicated

Sources:
a*Minister of PW Reg. No 20/2007
b*Minister of PW Reg. No 41/2007
c*Minister of PW Reg. No 15, 16, and 17/2009
d*Minister of Public Housing Reg. No 10/2014
e*SNI 03-1733-2004 – Indonesian Standard for Housing planning procedures in urban areas

The important for topography is highly discussed on Minister of PW Reg. No 20/2007 and SNI 03-1733-2004 – Indonesian Standard for Housing planning procedures in urban areas, and indicated in other 3 regulations. In Regulation No 20/2007, the housing and settlements should be fitted in landform slope between 0–25%, while it is mentioned in SNI that the best slope for housing and settlement is in between 1–8%, then followed by slope of 8–15%.

Based on the above consideration, the slope criteria will be classified into 5 score class that can be seen in the following Table 8.2.

2. Fresh Water/Groundwater Source

Availability of fresh water is an important indicator on finding housing and settlement locations. That is why Reg. No 20/2007 and SNI 03-1733-2004 indicate the importance of this aspect as indicator to be considered. Similar to the slope indicator, other regulations do not significantly mention about this indicator.

Water is one of basic human need and the ability to access water will greatly facilitate the development of residential areas. Locations with abundant raw water sources will get the best value, while the less likely to have water, become less favor for housing and settlement area. The classification of groundwater source for housing and settlement can be found in the following Table 8.3.

3. Not in Disaster Prone Area

The prone disaster area is discussed within the 4 out of 5 regulations including: Reg. No 41/2007, Reg. No 10/2014, Reg. No 15, 16, and 17/2009 and SNI

Table 8.2 Criteria for slope indicator

Criteria	Slope (%)	Score
Flat	0–8	5
Considerably flat	8–15	4
Moderately sloping	15–25	3
Steep	25 – <45	2
Very steep	>45	1

Table 8.3 Criteria for groundwater source

Criteria	Class	Score
Very high productivity	High suitability	5
High productivity	Suitable	4
Medium productivity	Medium suitability	3
Low productivity	Low suitability	2
Very low productivity	Not suitable	1

Table 8.4 Criteria for disaster prone area

Criteria	Class
Disaster prone area	Not suitable
Not disaster-prone area	Very suitable

03-1733-2004. The indicator about prone disaster area for housing and Settlement are not detailed, and it refers to "other related regulations".

In Reg. No 41/2007, Reg. No 10/2014, Reg. No 15, 16, and 17/2009 and SNI 03-1733-2004, the classification of disasters prone area is not explained in detail. In general, disaster-prone disaster class only divided into 2 classes: Disaster Prone Area and not Disaster-Prone Area. The following table shows the criteria and the score of each criterion (Table 8.4).

4. Soil Drainage

Soil drainage appears only in regulations. No 10/2014, and SNI 03-1733-2004 while other 3 regulations do not indicate this as a very important indicator.

Soil drainage indicates the speed of water to be absorbed into the soil. Surface soil drainage reflects a land in conditions always damp or inundated by water. For most housing and settlement, the best (very suitable) class are in 1 and 2 grades. Grade 2, 3 and 4 are suitable, while 5,6 and 7 are not suitable for the purpose. Identification of surface soil drainage levels can be done through field surveys by conducting observations in each terrain unit. The soil drainage class is presented in the following Table 8.5.

Table 8.5 Criteria for soil drainage

Criteria	Grade	Class	Score
Excessively drained	1	High suitability	5
Somewhat excessively drained	2	Suitable	4
Well drained	3	Medium suitability	3
Moderately well drained	4	Low suitability	2
Somewhat poorly drained – very poorly drained	5	Not suitable	1

Table 8.6 Criteria for not in protected area

Criteria	Class	Score
Not in protected area	Very suitable	5
In protected area	Not acceptable	0

Table 8.7 Criteria for not in agricultural area

Criteria	Class	Score
In agricultural area	Suitable	5
Not in agricultural area	Not suitable	0

5. Not in Protected Area

The Protected Area is a designated area with the primary function of protecting the environment which includes natural resources and artificial resources. Because of the importance of this factor, all the regulations mention this indicator as one of the basic rules for housing and settlement planning in Indonesia.

Same as disaster prone area indicator, indicator for Protected Area only has two class: suitable and not acceptable. All the protected area should be free from housing and settlement functions, following table explains the class and value (Table 8.6).

6. Not located in agricultural area

The idea of this indicator is to assure the Sustainable Agriculture Land in Indonesia. Population growth, economic and industrial development resulted to degradation of agricultural land. This has threatened the national carrying capacity in maintaining food self-sufficiency, resilience and sovereignty.

From 5 regulations, 3 regulations mention this indicator, while other two regulations (Minister of Public Housing Reg. No 10/2014 and SNI 03-1733-2004) do not mention about it. Thus, the classification of this indicator is only divided into 2 classes: Suitable and Not Suitable and it can be described as the table above (Table 8.7).

7. Not located in Irrigated Rice Field

Similar to the agricultural issue, rice field faces enormous problems and challenges, especially the high transfer of rice field to non-agricultural functions as a result of population growth. The classification can be expressed in Table 8.8 below.

8. Not in the dangerous distant from other reserve areas (Buffer distance-*sempadan*)

Table 8.8 Criteria for not in agricultural area

Criteria	Class	Score
Not in irrigated rice field	Suitable	5
In irrigated rice field	Not suitable	0

Table 8.9 Criteria for buffer distance

Criteria	Class
Not in buffer distance	Very suitable
In buffer distance	Not acceptable

In Indonesia, buffer distance of spring water, river and beach is a protected area for maintaining the preservation of ecosystem functions and all of its resources as well as used to avoid the threat of natural disasters. The buffer distance area is allocated for public space and public access including open space, tourist area and other settlement support areas. Depending on their characteristic, buffer distance for river inside urban area is set from 3 to 30 m. In case of spring water, buffer distance is 200 m. Meanwhile, it reaches 100 m from the highest tide in case of beach. Buffer distance also applies for Flight Operational Safety Area (*KKOP*). This indicator is highly mentioned in the Reg. No 15, 16, and 17/2009 as well as SNI 03-1733-2004, while other 3 regulations do not indicate it (Table 8.9).

8.3.1.2 Flood Disaster Mitigation Criteria for Spatial Planning

As mentioned in Sect. 8.1, there are two regulations on disaster management that meet the criteria of spatial planning, which are BNPB regulation No 21/2008 and BNPB Regulation no 2/2012. After the content analysis brought into the two documents, it is clear that BNPB Regulation No 21/2008 discussed mainly about *Implementation of Disaster Management* which means flood disaster is not specifically discussed. The discussion of flood disaster only is mentioned as part of multi-disasters that should be counted in Indonesian spatial planning.

Later, in the Head of National Board for Disaster Management (BNPB) Regulation No 2/2012 about *General Guidelines of Disaster Risk Assessment,* flood disaster criteria are discussed. According to flood disaster management, the disaster risk is based on multi factors ranging not only physical but also social, economic and ecological (BNPB 2012; Cutter et al. 2000; Evers et al. 2016). To measure the disaster risk, Wisner et al. (2003) proposed a pseudo-equation as follows:

$$R = H\,x\,V$$

Where:

R: Disaster Risk

H: Hazard Threat – The frequency (possibility) of a particular disaster tends to occur in a certain intensity at a particular location

V: Vulnerability – The expected loss (impact) in an area in a particular disaster case occurs with a certain intensity. The calculation of these variables is usually defined as exposure (population, assets, etc.) multiplied by the sensitivity for the specific intensity of the disaster.

Considering community and government capacity factors in reducing disaster risk, BNPB Indonesia has adopted the disaster risk pseudo-equations and then added capacity factors on measuring disaster risk reductions (BNPB 2012).

$$R = H\,x\,\frac{V}{C}$$

Where:

C: Adaptive Capacity – capacity available in the area to recover from a specific disaster.

Based on this understanding and the content analysis process, the Criteria for mitigation planning consist of **Hazard Threat**, **Vulnerability** and **Capacity**. The schematic relations between the criteria of disaster risk can be drawn as shown in the following diagram (Fig. 8.3);

1. Hazard Threat

Hazard threat is the composite value of physical/geomorphologic of flood prone area which has been already validated with flood history. The data were collected by fieldwork and the model simulation using SRTM data, the results then were validated with flood hazard history. The Criteria can be seen in the following table (Table 8.10).

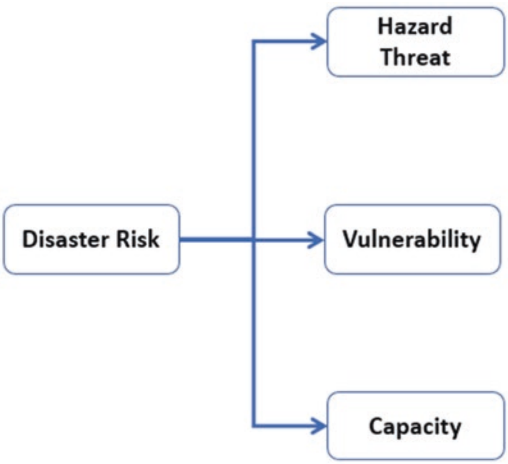


Fig. 8.3 Disaster risk indicator diagram. (Source: BNPB Regulation no 2/2012)

Table 8.10 Hazard thread criteria

Hazard index	Class index			Weight
	Low	Medium	High	
Disaster prone map from flood model using (SRTM) validated with history	<0.76 m	0.76–1.5	>1.5	100%

2. Vulnerability

The vulnerability criteria are highly related to social factors and social economic factors. The studies about social vulnerability are related to the number of populations, gender, age, education level, social status and economic. It also discussed the access to public health and employment (Kita 2017).

Vulnerability criteria consist of 4 composite factors which are; (a) social vulnerability (based on criteria of Population and Vulnerable groups), (b) Economic Vulnerability (based on GRDP and Land-use) (c) Physics vulnerability (buildings and infrastructures) and (d) Environmental Vulnerability (ecology).

Similar to the previous criteria, each indicator gives class index which is Low, Medium and High. It depends on the precondition in the location. The value of the class index and the weight can be found in the following Table 8.11.

3. Capacity

The third important factor that contributes to hazard risk is the capacity, where capacity itself consists of 5 criteria (a) regulation on disaster management, (b) early warning and disaster risk assessment, (c) People Knowledge on Disaster preventions, (d) Reduction of Risk Factors and (e) Development of Preparedness in every sector. The capacity is divided by 3 different class indexes which are Low, Medium and High. It depends on the availability of each criterion. The detail can be found in the following Table 8.12.

8.3.1.3 Integrated Indicator for Housing and Settlement Planning and Disaster Mitigation Planning

The integrated indicator should consider the previous two groups criteria. In the first housing and settlement group, the (flood) disaster is already incorporated into the criteria but it is not detailed enough. While in the group of disaster mitigation, the criteria of disaster management are elaborated in more detail and clearer.

This research proposed indicator for "disaster prone area" that is replaced by three criteria from disaster management, which are Hazard Threat, Vulnerability, and Capacity as described in Fig. 8.4 below.

From all of the housing and settlement criteria, we can see that there are 3 groups. First is the group with full scale score listed from 1–5, these criteria will be easily adapted to the MCDA model and the second group are criteria with a very limited choice like criteria of disaster prone area and criteria of rice field, the given option

Table 8.11 Vulnerability criteria

Vulnerability Index	Class Index			Weight (%)
	Low	Medium	High	
Social vulnerability				**40**
Population density	<500 pop/km^2	500–1000 pop/km^2	>1000 pop/km^2	60
Venerable groups (disable person/children/older groups)	<20%	20–40%	>40%	40
Economic vulnerability				**25**
Gross regional domestic product (GRDP)	<Rp 100 million	Rp 100–300 million	>Rp 300 million	40
Productive land area	<Rp 50 million	Rp 50–200 million	>Rp 200 million	60
Physic vulnerability				**25**
Building vulnerability (number of house)	<Rp 400 million	Rp 400–800 million	>Rp 800 million	40
Public facility	<Rp 500 million	Rp 0.5–1 billion	>Rp 1 billion	30
Critical facility	<Rp 500 million	Rp 0.5–1 billion	>Rp 1 billion	30
Environmental vulnerability				**10**
Protected forest	<20 Ha	20–50 Ha	<50 Ha	30
Natural Forest	<25 Ha	25–75 Ha	<75 Ha	30
Mangrove/mangrove forests	<10 Ha	10–30 Ha	<30 Ha	10
Shrubs	<10 Ha	10–30 Ha	<30 Ha	10
Swamp	<5 Ha	5–20 Ha	<20 Ha	20

Table 8.12 Capacity criteria

Capacity index	Class index			Weight
	Low	Medium	High	
Local regulation on disaster management,	Capacity index level 1–2	Capacity index level 3	Capacity index level 5	100%
Early warning and disaster risk assessment,				
People knowledge on disaster preventions,				
Reduction of risk factors				
Development of preparedness in every sector				

is only limited by two scores, which are value (score) 0 for not suitable class and value 5 (the highest score) for the suitable class.

The third group is criteria with very strict regulation. The settlement area should never fall into Buffer distance or protected area. The model will automatically remove all the possibility of the land on this area to be selected. The third group is clearly considered as constraint criteria. The following table shows all criteria and their score (Table 8.13).

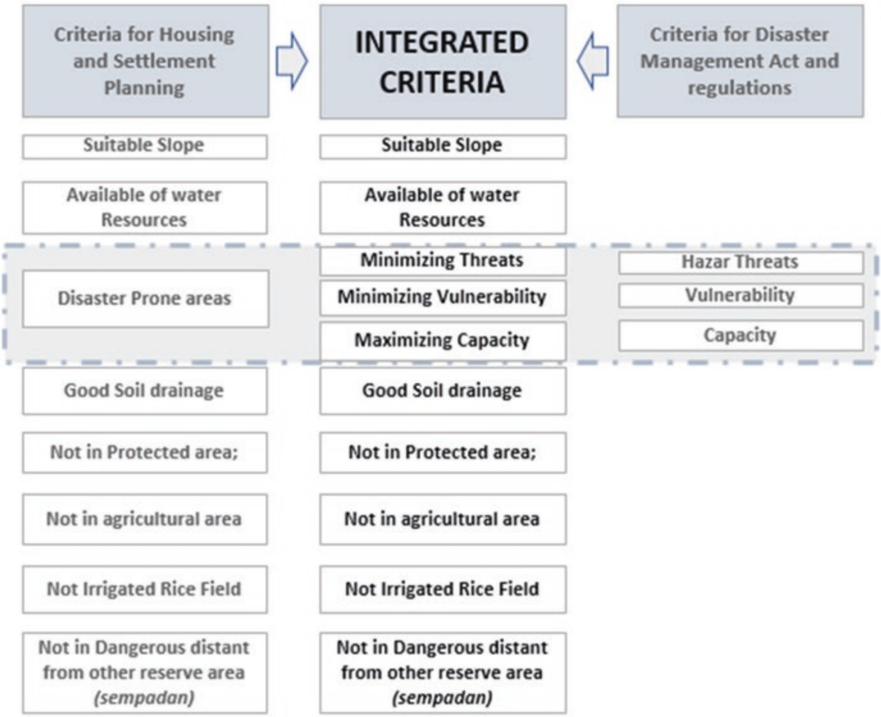


Fig. 8.4 The indicator and criteria scheme

Table 8.13 Integrated criteria and the score class

No	Integrated criteria	Score class				
		5	4	3	2	1
1	Suitable slope	0–8%	8–15%	15–25%	25 – <45%	>45%
2	Availability of water resources	High suitability	Suitable	Medium suitability	Low suitability	Not suitable
3	Minimizing threats	High suitability	Suitable	Medium suitability	Low suitability	Not suitable
4	Minimizing vulnerability	High suitability	Suitable	Medium suitability	Low suitability	Not suitable
5	Maximizing capacity	High suitability	Suitable	Medium suitability	Low suitability	Not suitable
6	Good soil drainage	High suitability	Suitable	Medium suitability	Low suitability	Not suitable
7	Not in a protected area;	Constrain criteria				
8	Not located in agricultural area	Not in agricultural area		Not applicable		
9	Not located in irrigated Rice field	Not in irrigated Rice field area		Not applicable		
10	Not in the dangerous distant from other reserve area (*sempadan*)			Constrain criteria		

The 8 opportunity criteria are weighted using AHP, the process using the AHPcalc version 04.05.2016. As the result of this process, the integrated criteria showing "Minimize Hazard Threat Area" are the strongest criteria (with a weight of 42.7%) followed by the "Maximizing Capacity" criteria with 23.9%, and the indicator "Minimize Vulnerability"(16.0%) in the third place. The weakest criteria are "Good Soil drainage" (1.2%) in the lower place followed by "Available of water source" (1.6%) in the 7th place. Table 8.14 and Fig. 8.5 about AHP Matrix for housing and settlement Criteria below show the full results of the weight according to the Analytical Hierarchy Process.

Table 8.14 AHP result for housing and settlement criteria

Criterion		Comment	Weights (%)	Rank
1	Slope	Relatively flat slope	2.8	6
2	Source of water	Available sources of fresh water	2.0	7
3	Soil drainage	Good soil drainage	1.2	8
4	Agriculture area	Not located in agricultural area	4.7	5
5	Irrigated Rice field	Not located in irrigated Rice field	9.0	4
6	Hazard threats	Minimize hazard threat area	42.7	1
7	Capacity	Maximizing capacity	23.9	2
8	Vulnerability	Minimize vulnerability	13.7	3

Matrix		Slope 1	Source of Water 2	Soil Drainage 3	Agriculture area 4	Irrigated Rice field 5	Hazard 6	Capacity 7	Vulnerability 8	**normalized principal Eigenvector**
Slope	*1*	1	5	7	1/6	1/7	1/9	1/8	1/7	2.8%
Source of Water	*2*	1/5	1	5	1/7	1/8	1/8	1/5	1/5	2.0%
Soil Drainage	*3*	1/7	1/5	1	1/7	1/8	1/8	1/7	1/7	1.2%
Agriculture area	*4*	6	7	7	1	1/9	1/8	1/6	1/5	4.7%
Irrigated Rice field	*5*	7	8	8	9	1	1/7	1/7	1/9	9.0%
Hazard	*6*	9	8	8	8	7	1	8	9	42.7%
Capacity	*7*	8	5	7	6	7	1/8	1	9	23.9%
Vulnerability	*8*	7	5	7	5	9	1/9	1/9	1	13.7%

Fig. 8.5 AHP Matrix for housing and settlement criteria

8.3.2 Urban Housing and Settlement Suitability Model in Palu Municipality Masterplan (RTRW Kota Palu) Using Integrated Criteria

The reconstruction process of suitability location for housing and settlement in this research is to find the best location for housing and settlement planning using newly proposed integrated criteria and indicators from spatial planning regulations and disaster mitigation regulation as mentioned in Sect. 8.3.1.1. The result is then used for reviewing the Housing and Settlement Planning in RTRW-Kota Palu.

8.3.2.1 Source of the Data

1. Spatial Planning maps

The data for this model were taken from the existing theme maps in the RTRW-Palu 2009 document. The map sources can be seen as follows

(a) Map for Protected Area theme, collected from Land-use Map RTRW-Kota Palu 2009
(b) Map for Dangerous Distance – Buffer (*Sempadan*), developed from river map and coastline map of RTRW-Kota Palu 2009
(c) Thematic map for Slope, derived from 3-dimension TIN map of RTRW-Kota Palu 2009
(d) Thematic map for Source of Water, taken from Water Aquifer Map RTRW-Kota Palu 2009
(e) Map for Not Irrigated rice field, collected from Land-use Map RTRW-Kota Palu 2009 (which has no Irrigated rice field found in it)
(f) Soil drainage map RTRW-Kota Palu 2009
(g) Map for Not Agricultural Land, collected from Land-use Map RTRW-Kota Palu 2009 (which has no Agricultural-land found in it)

Other than the above thematic maps, this research also uses the map from Palu BAPPEDA (Development Planning Agencies of Palu) office and housing and settlement map from RTRW-Kota 2009. The maps are:

(a) Administration Boundary from Management Information System (SIM) Kota Palu, BAPPEDA Palu 2013
(b) Existing Road from Management Information System (SIM) Kota Palu, BAPPEDA Palu 2013
(c) Housing and settlement map for Palu (Municipality of Palu 2009)

2. Disaster Map

Palu had already built their flood hazard map in 2009, the vulnerability map and the capacity map had already been included in these flood hazard maps. These maps were already verified by the flood history in this area. Produced in a cooperation between Palu Municipality, UNDP and SC-DRR Program, these maps had been prepared based on the rules set by the Indonesian regulations. These maps are shown in the following Figs. 8.6, 8.7, 8.8, and 8.9.

8.3.2.2 Suitable Location for Housing and Settlement

Getting all the desired criteria and indicators, this research overlays all the criteria maps using the MCDA process to produce the suitability map for housing and settlement. All criteria scores are divided into 5 classes except for 4 criteria (Protected Area, Not in Agricultural, Irrigated Rice Field, buffer distance Indicator) which only have 2 classes. For protected area and buffer distance (sempadan), criterion will be used as the constraint factors which will delete all the value within its area.

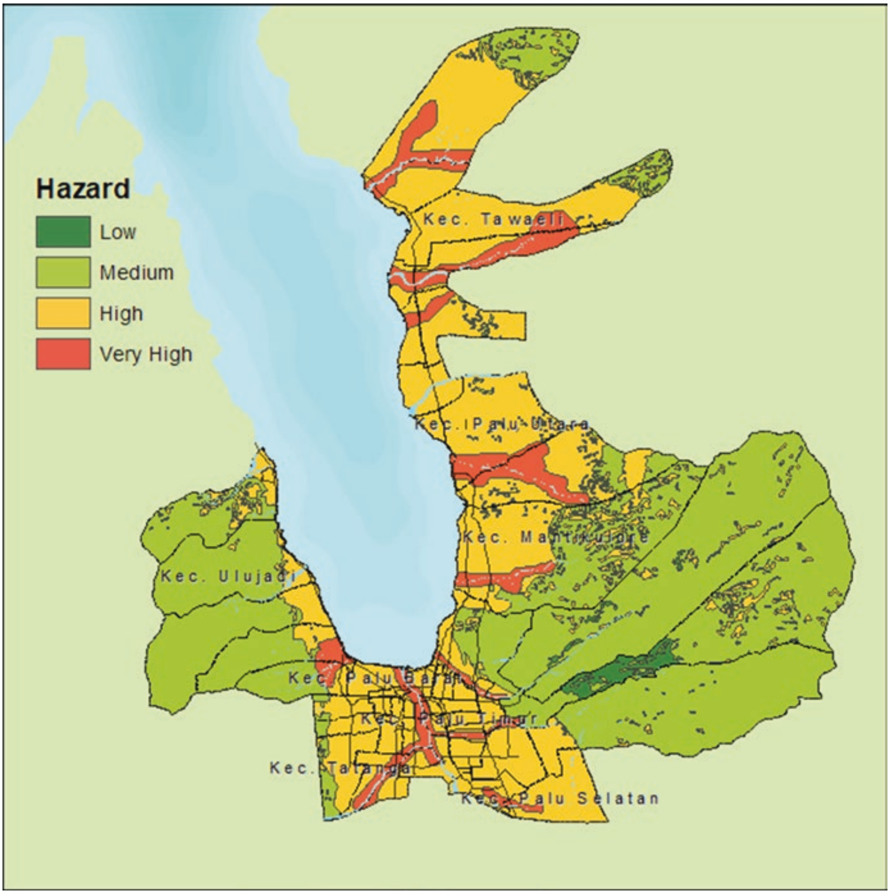


Fig. 8.6 Hazard threat map. (Source: SC-DRR 2009)

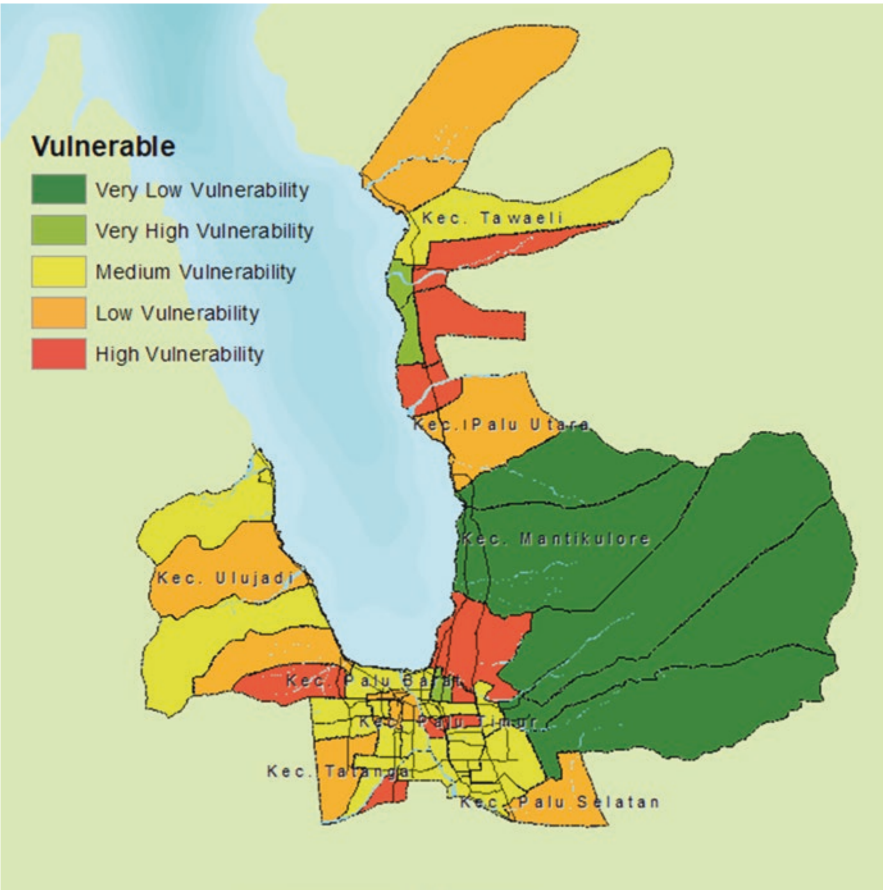


Fig. 8.7 Vulnerability map. (Source: SC-DRR 2009)

Not in Agricultural and Irrigated Rice Field criteria are not available in Palu. There is no policy that supports Rice Field and Agriculture in the RTRW Map. Therefore, this research will remove these two criteria.

For Hazard threat, Vulnerability, and Capacity maps, this research will use the given SC-DRR map to complete the analysis. The class for these maps will use 5 grades. The lowest grade (1) is an undesirable condition whereas the highest-grade (5) in the criteria is a favorable condition. The example for the hazard threat class is that the higher the hazard threat value, the farther from the flood prone.

Specifically, for Hazard threat criteria, the highest score gets a value of 4 based on existing data (SC-DRR map), the entire city of Palu is an area potential to get a flood disaster (with a class range of 1–4).

To gain the most suitable locations for housing and settlement, each criteria class and its weight in this research are then multiplied as in the Eq. 8.1 (see Sect. 8.2.2.3). The results find 5 suitability classes (using Jenks Natural Break in ArcGIS) and after

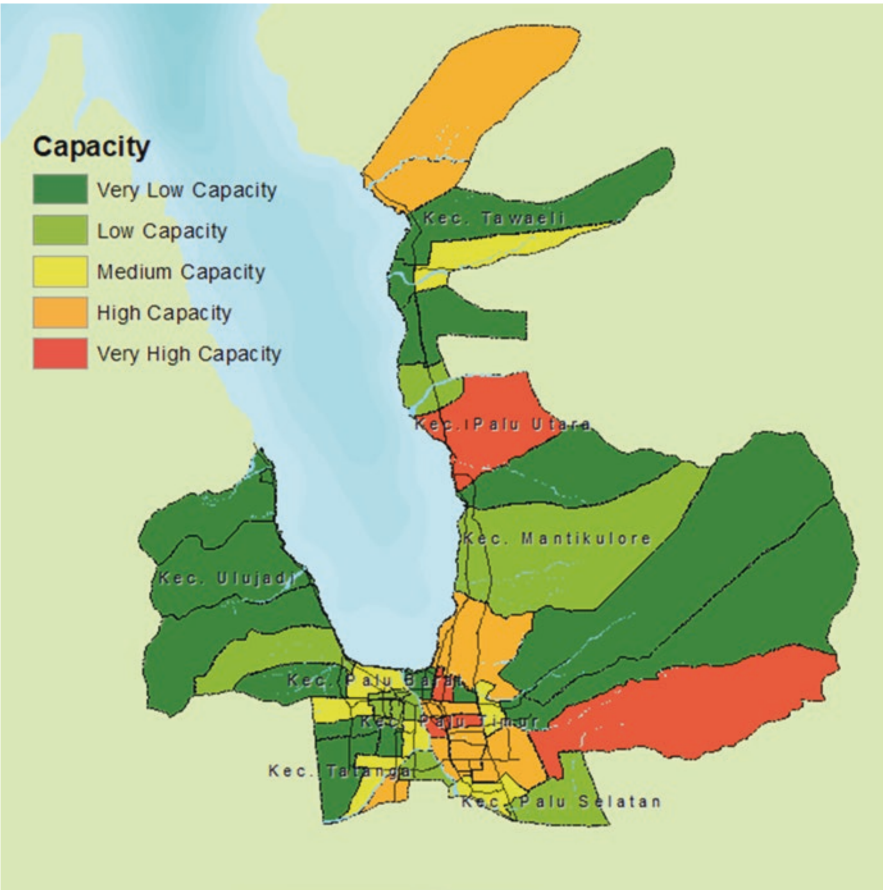


Fig. 8.8 Capacity map. (Source: SC-DRR 2009)

reducing protected area and buffer distance area (Eqs. 8.1, 8.2, and 8.3), the outcome shows that 2955.13 Ha is in very suitable class, 3592.52 Ha is in suitable class, and 2126.12 Ha is highly unsuitable. The result is shown in the following tables and map (Tables 8.15 and 8.16).

Base on Table 8.16 and Table 8.15 and Suitability map (Fig. 8.10. Suitability map for Housing and Settlement), it can be seen that most of the region with very suitable class are on flat slope areas and the very suitable class is within *Mantikulore, Palu Timur* and *Palu Selatan* District, and some parts in *Palu Utara* and *Tatanga*. The medium and suitable classes of this model still show the same performs. Majority of these types of suitability class are in the relatively flat terrain, and away from the river/coastline. In other words, the majority of these suitability classes are within *Palu Selatan, Palu Barat,* and *Palu Utara* administration.

The highly unsuitable areas are majority in the hilly area with a fair slope. In the city center, the highly unsuitable area also appears along the river and the coastline, and some of this highly unsuitable area falls inside the "buffer distance (sempadan)" area.

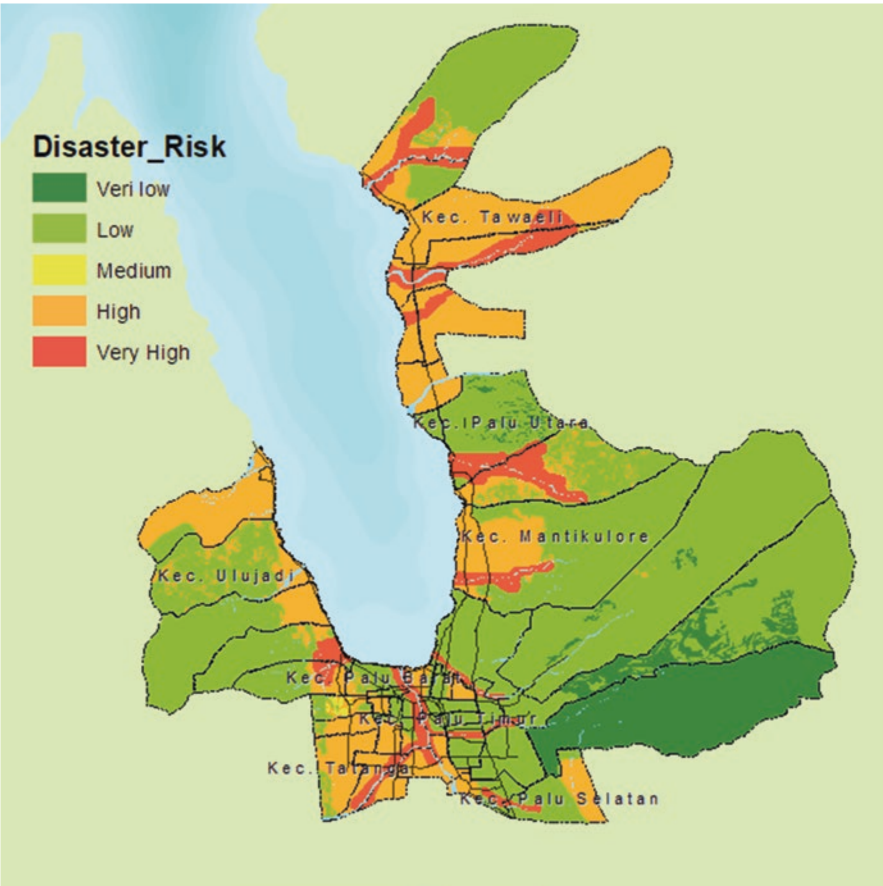


Fig. 8.9 Disaster risk map. (Source: SC-DRR 2009)

The result shows that the suitability class on the model are mostly driven by 3 criteria which are; the impact of **flood disaster threat**, the **capacity** of the local government and the community to counter his threat, and the **vulnerability** of the community in this area. The **buffer distance (Sempadan)** and **Protected Area** criteria are also important to reduce the risk of flood disaster in the populated area.

8.4 Conclusion

Several important regulations have been issued by Indonesian Government regarding the issue of spatial planning and disaster mitigation. From these regulations, we can draw some key criteria and indicators that can be integrated into the spatial planning especially housing and settlement planning with disaster mitigations.

Table 8.15 Suitability area on each district

District	Suitability class	Area (Ha)	District	Suitability class	Area (Ha)
Mantikulore	5	1189.69	Palu Timur	5	342.31
	4	340.38		4	41.01
	3	548.15		3	70.42
	2	1349.63		2	91.73
	1	1358.41		1	17.98
Palu Barat	4	220.92	Palu Selatan	5	823.47
	3	234.68		4	304.82
	2	147.78		3	727.07
	1	49.18		1	38.87
Palu Utara	5	484.86	Tatanga	5	114.8
	4	921.63		4	246.79
	3	971.16		3	321.27
	2	217.63		2	513.22
	1	152.82		1	73
Tawaeli	4	1382.98	Ulujadi	4	133.99
	3	931.21		3	228.84
	2	1054.01		2	642.52
	1	245.17		1	190.69

Table 8.16 Suitability area

Suitability (Jenks Natural Break)	Class		Area (Ha)
3.62–4.22	***5***	*Very suitable*	2955.13
3.22–3.61	***4***	*Suitable*	3592.52
2.95–3.21	***3***	*Medium*	4032.80
2.63–2.94	***2***	*Unsuitable*	4016.52
1.67–2.62	***1***	*Highly unsuitable*	2126.12
Total			16,723.09

This research listed 10 criteria and indicators that have been mentioned in the regulations where 7 criteria come from Spatial Planning and 3 criteria come from Disaster Mitigation regulations. The criteria are; 1. Suitable Slope, 2. Availability of Water Resources, 3. Minimizing Threats, 4. Minimizing Vulnerability of hazard, 5. Maximizing Capacity from hazards, 6. Good Soil drainage, 7. Not in a Protected area, 8. Not located in the agricultural area, 9. Not located in Irrigated Rice Field, and 10. Not in the dangerous distant from other reserve area (sempadan).

Using these criteria and weighted in AHP, the model that had been carried out in the second phase, shows that the group of disaster mitigations held the most important factor to be reconsidered on housing and settlement planning. The models of the full criteria weight can be seen as follows (Table 8.17):

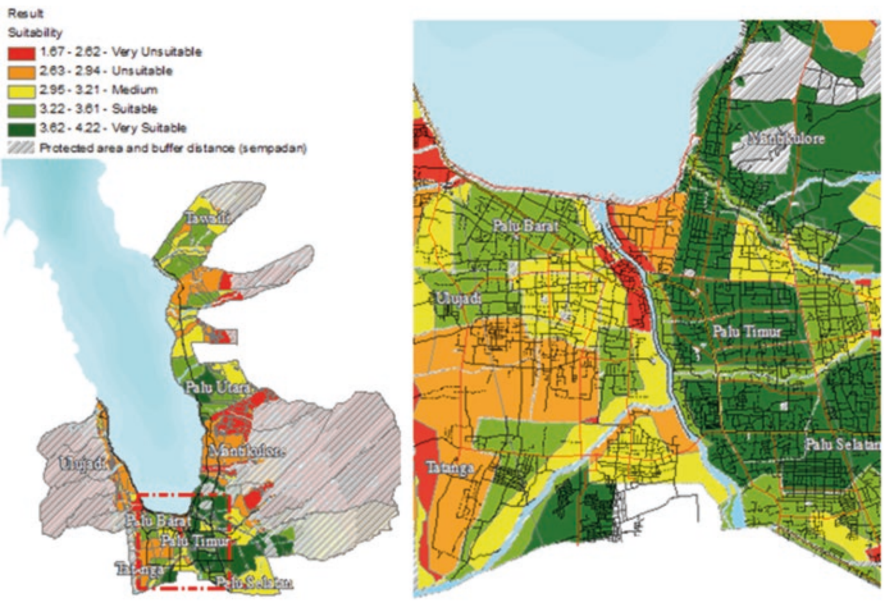


Fig. 8.10 Suitability map for housing and settlement

Table 8.17 The result of the integrated criteria

No	Integrated criteria	Regulation Source	Categories	AHP weights %
1	Suitable slope	Spatial planning	Opportunity criteria	2.8
2	Availability of water resources	Spatial planning	Opportunity criteria	2.0
3	Minimizing threats	Disaster mitigation	Opportunity criteria	42.7
4	Minimizing vulnerability	Disaster mitigation	Opportunity criteria	13.7
5	Maximizing capacity	Disaster mitigation	Opportunity criteria	23.9
6	Good soil drainage	Spatial planning	Opportunity criteria	1.2
7	Not in a protected area	Spatial planning	Constrain criteria	
8	Not located in agricultural area	Spatial planning	Opportunity criteria	4.7
9	Not located in irrigated Rice field	Spatial planning	Opportunity criteria	9.0
10	Not in the dangerous distant from other reserve area (*sempadan*)	Spatial planning	Constrain criteria	

8.4.1 Limitation of the Research

The development of spatial planning document (RTRW-Kota 2009) in Palu does not merely use only flood disaster analysis, but also consider more complex factors including multi-hazard criteria, existing settlement condition, community perception (during Focus Group Discussion), and city government strategy in achieving its development objectives. Based on these reasons, the result of this research does not carried out any further analysis which complements the above-mentioned limitations.

Another limitation is on the preparation of weighting process. The AHP phase only used the subjective opinion of the researcher, the more relevant stakeholder is strongly needed to be included in the weighting process.

8.4.2 Further Research

This research only puts the initial stages of further research. Based on the findings, it is very interesting if the operational research process undertaken by the municipal of Palu can be reviewed to gain the advantages and disadvantages of their process in the development of their RTRW-Kota document. It will also be interesting if the further research has considered overall disaster factors including evacuation systems in disaster prone areas as mentioned in the regulations.

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References

Abedinnia H, Glock CH, Schneider MD (2017) Machine scheduling in production: a content analysis. Appl Math Model 50:279–299. Retrieved http://www.sciencedirect.com.ezproxy.utp.edu.co/science/article/pii/S0307904X17303335

Barnes R, Ashbolt N (2006) Review of decision tools and trends for water and sanitation development projects. In: 32nd WEDC international conference, Colombo, Sri Lanka: Sustainable development of water resources, water supply and environmental sanitation

Birkmann J, Garschagen M, Setiadi N (2014) New challenges for adaptive urban governance in highly dynamic environments: revisiting planning systems and tools for adaptive and strategic planning. Urban Clim 7:115–133. Retrieved https://doi.org/10.1016/j.uclim.2014.01.006

BNPB (2016) Portal data Indonesia – Data.go.id. Retrieved 26 April 2017. http://data.go.id/dataset/data-bencana-banjir-2

BNPB, National Disaster Management Agency of the Republic of Indonesia (2012) Regulation of the head of national disaster management agency of the republic of Indonesia number 2 year 2012 on general guidance on study of disaster risk

Caparros-Midwood D, Barr S, Dawson R (2015) Optimised spatial planning to meet long term urban sustainability objectives. Comput Environ Urban Syst 54:154–164. Retrieved https://doi.org/10.1016/j.compenvurbsys.2015.08.003

Cutter SL, Mitchell JT, Scott MS (2000) Revealing the vulnerability of people and places: a case study of Georgetown county, South. Source Ann Assoc Am Geogr 90(4):713–737. Retrieved http://www.jstor.org/stable/1515440%5Cnhttp://www.jstor.org/page/

EM-DAT (2016) 2015 Disasters in numbers (1):2. Retrieved http://www.emdat.be

Evers M, Jonoski A, Almoradie A, Lange L (2016) Collaborative decision making in sustainable flood risk management: a socio-technical approach and tools for participatory governance. Environ Sci Policy 55:335–344. Retrieved https://doi.org/10.1016/j.envsci.2015.09.009

Francesch-Huidobro M, Dabrowski M, Tai Y, Chan C, Stead D (2015) Governance challenges of flood-Prone Delta cities: integrating flood risk management and climate change in spatial planning. Prog Plan. Retrieved https://doi.org/10.1016/j.progress.2015.11.001

Kain JH, Söderberg H (2008) Management of Complex Knowledge in planning for sustainable development: the use of multi-criteria decision aids. Environ Impact Assess Rev 28(1):7–21

Kii M, Nakamura K (2017) ScienceDirect ScienceDirect ScienceDirect Development of a Suitability Model Development of a Suitability Model for Estimation of Global Urban Land Cover for Estimation of Global Urban Land Cover. Transport Res Procedia 25:3165–3177. Retrieved https://doi.org/10.1016/j.trpro.2017.05.358

Kita SM (2017) Urban vulnerability, disaster risk reduction and resettlement in Mzuzu. Int J Disaster Risk Reduct 22:158–166. Retrieved http://ac.els-cdn.com/S2212420916306719/1-s2.0-S2212420916306719-main.pdf?_tid=1d3d85de-1944-11e7-a99f-00000aab0f27&acdnat=1491316779_caee83e49a634cedf7a102afb2dd9f34

Kornakova M, March A (2013). Finding appropriate participation in Urban planning for reduction of disaster risks. 1–12. Retrieved http://www.soacconference.com.au/2013-conference/wp-content/uploads/2013/12/Kornakova-Environment.pdf

Liu R, Zhang K, Zhang Z, Borthwick AGL (2014) Land-use suitability analysis for Urban development in Beijing. J Environ Manag 145:170–179. Retrieved https://doi.org/10.1016/j.jenvman.2014.06.020

Malczewski J (2004) GIS-based land-use suitability analysis: a critical overview. Prog Plan 62(1):3–65

Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. Int J Geogr Inf Sci 20(7):703–726. Retrieved http://www.tandfonline.com/doi/abs/10.1080/13658810600661508

Mardin R (2009) Collaborative decision making in railway planning, a multi criteria evaluation of JOGLOSEMAR project, central java – Indinesia. Enschede, ITC (1)

Mardin R (2011) Analisis Perkembangan Fisik Kota Palu Dengan Citra Landsat. Ruang 3:45–54

Municipality of Palu (2009) RTRW Kota Palu 2009

Municipality of Palu (2011) Laporan SLHD Kota Palu Tahun 2011

Municipality of Palu (2014) Laporan SLHD Kota Palu Tahun 2014

Palu Statistic Bureau (2016) Statistik Daerah Kota Palu 2016

Ran J, Nedovic-Budic Z (2016) Integrating spatial planning and flood risk management: a new conceptual framework for the spatially integrated policy infrastructure. Comput Environ Urban Syst 57:68–79. Retrieved https://doi.org/10.1016/j.compenvurbsys.2016.01.008

Saaty TL (1990) How to make a decision: the analytic hierarchy process. Eur J Oper Res 48(1):9–26

Tingsanchali T (2012) Urban flood disaster management. Procedia Eng 32:25–37. Retrieved https://doi.org/10.1016/j.proeng.2012.01.1233

UNISDR (2015) Sendai framework for disaster risk reduction 2015–2030. In: Third world conference on disaster risk reduction, Sendai, Japan, 14–18 March 2015. (March):1–25

Wilson Center (2017) URBAN PERSPECTIVES: climate change, migration, planning and financing A NEW GENERATION OF IDEAS 2017. Retrieved https://www.wilsoncenter.org/publication/urban-perspectives-climate-change-migration-planning-and-finance-new-generation-ideas

Wisner B, Blaikie P, Cannon T, Davis I (2003) At risk: natural hazards, people's vulnerability, and disasters 2. J Homel Secur Emerg Manag 2(2). Retrieved (http://www.degruyter.com/view/j/jhsem.2005.2.2/jhsem.2005.2.2.1131/jhsem.2005.2.2.1131.xml).

World Bank (2013) City planning labs a concept for strengthening city planning capacity in Indonesia

Chapter 9
Design Parameters of Residential Building for Improving Performance of RHS: Evidence from Fuzhou, Fujian Province, China

Xinyi Lin, Zhenjiang Shen, and Senchen Huang

Abstract Rain water harvest system (RHS) has been widely adopted in residential buildings and was proved to be an effective approach for reusing rainwater as the replaceable resource of domestic water. However, due to the complicated design procedures and confusing design codes, the insufficient cooperation between architects and RHS engineers leads to poor performance of RHS and also restrictions on the extensive utilization of RHS. The majority of previous studies take little consideration from the view of the architect while the later shows much concern on the operational parameters of building design. For more effective cooperation, the implementation of RHS in residential building should be integrated in the stage of primary design. Therefore, we are intended to propose a series of Cooperative Design Parameters (CDP), which are integrated with Residential Building Design (RBD) and RHS Design (RHSD), for the purpose of improving the performance of RHS in residential buildings.

Keywords Water management · Rainwater harvesting system (RHS) · High-rise residential building · Water saving efficiency · Building design · Urban planning

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9.1 Introduction

9.1.1 Contribution

The Rainwater Harvesting System (RHS) is developed to improve the usage of rainwater, however, the conventional design procedures along with the separated and complicated design parameters of both RHS and residential buildings lead to a restricted cooperation between architects and RHS engineers and a poor performance of RHS in residential buildings.

To ensure a better performance of RHS in residential buildings, it is necessary to introduce a cooperative design method at the beginning of building design.

In this research, we first worked out a unified design index system by co-considering the codes and criteria of both Residential Building Design (RBD) and RHS Design (RHSD), and termed related parameters as Cooperated Design Parameters (CDP). Architects and RHS engineers can assess the influence of CDP on the performance of RHS by estimating two widely used indicators: Waste Saving Efficiency (WSE) and Rainwater Use Efficiency (RUE).

These recommended values of CDP are obtained based on a hypothesized implementation of RHS in Fuzhou. By referring this CDP, designers can revise the predetermined parameters in both RBD and RHSD so as to achieve higher performance of RHS.

The result, detailing these parameters for the purpose of an easy and positive application of RHS (Fig. 9.1), is intended to fill up the gap of simultaneous design between residential building and RHS, and will also improve the cooperation between architects and RHS designers, as well as the independent implementation of RHS.

9.1.2 Background

9.1.2.1 Description of RHS in RBD

Typical RHS components usually include a catchment area, a filter to remove the initial portion of roof runoff, a cistern (also known as storage tank), and a pump to supply system demand. The building roof is the most commonly used catchment for rain-water harvesting, since it occupies a large proportion of total impervious area in urban areas and generally contributes to quality rainwater that may apply to some non-potable uses in the household.

Residential buildings are generally designed with diversified schemes for number of floors, household number in each floor and dwelling unit size. It is obvious that the variables in RBD and RHS are different, proving that it is worthwhile to adopt a simultaneously cooperative design with unified parameters in both RBD and RHSD for a better cooperation between RHS engineers and architects.

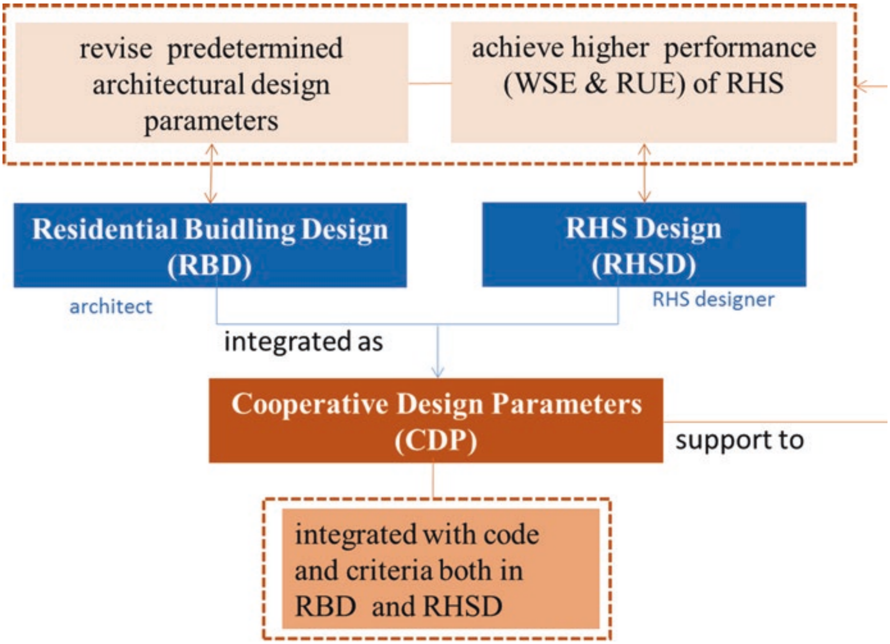


Fig. 9.1 Scheme of the contribution of this research

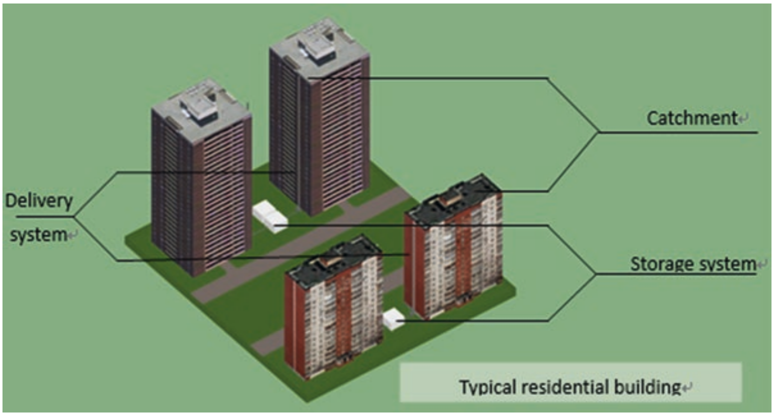


Fig. 9.2 Composition of RHS in typical residential building

Therefore, in this research, RHS is assumed to be applied in a typical single spot residential building. Rainwater is harvested by roof, collected in cistern, and supplied as the non-potable domestic water. The schematic diagram of RHS in residential building is shown in Fig. 9.2.

9.1.2.2 Previous Study of Applying RHS in Residential Building

Water availability has been a matter of concern all over the world. It has been reported that RHS can contribute to significant water saving in residences across countries.

The integration of RHS in residential building is an ongoing process that develops over time. Present literatures show that harvesting rain water with appropriate storage capacity can be used to control storm water runoff (Aad et al. 2010; Damodaram et al. 2010) and meet the demand of non-potable water for human uses such as toilet flushing, garden irrigating and machines washing (Fayez A. Abdulla* and A.W. Al-Shareef 2009), especially in the residential areas subject to serious water crisis and enormous pressure on the domestic water supply system in peak hours.

However, RHS is widely adopted in residential buildings due to specific location conditions. For instance, in Brazil, a study performed by Ghisi et al. (2007) showed that the potential of water saving in 62 cities based on water harvesting ranged from 34% to 92%, with an average potential for potable saving as 69%. In Australia, Coombes and Barry (2007) analyzed 27 houses in Newcastle and concluded that rainwater usage would increase potable water saving by 60%. In Germany, a study performed by Herrmann and Schmida (2000) showed that the potential of potable water saving in a house, using roof runoff harvested in a 46 m^3 tank for toilet flushing, might vary from 30% to 60%, which depended on the demand and roof area. In Beijing, Zhang et al. (2009) observed that harvesting all roof runoff for use in toilet flushing can reduce potable water consumption in residential buildings by about 25%.

Nonetheless, most of such researches are specific to a certain residential community, that is why, until now, there is no easily adopted codes which can be used independently by architects or RHS engineers, thus not only resulting in excessively conservative and costly designs, but also poor performance of water saving and rain water use.

What's more, the previous works have mostly overlooked details of RBD from the perspectives of RHS, and are rarely involved with discussion on the impacts of roof area (A) and occupants' water demand (D) that matter much to the performance of RHS. Few efforts have been made to explore the simultaneous design between RHS and residential buildings.

Therefore, how to fill in the gap of cooperation between urban planners and engineers and how to inspire them to promote the implementation of RHS in residential buildings by simplifying design procedures and parameters remain the core problems of this research.

This work is designed to observe the impacts of detailed design factors on RHS performance from the view of both RBD and RHSD (Fig. 9.3). The integration is expressed in the mathematical relationship between roof area (A) and occupants' water demand (D) among these design factors.

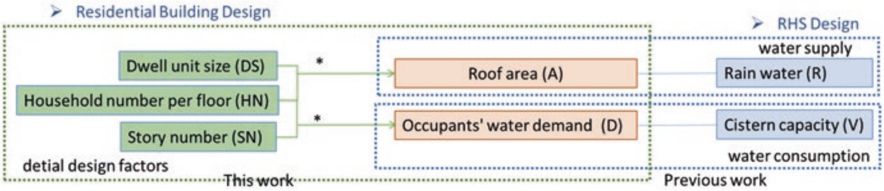


Fig. 9.3 Difference between current work and previous work

9.1.2.3 Assessment Indicators of RHS Performance

For the performance assessment of RHS in residential buildings, two indicators are widely used in previous works, one of which is Water Saving Efficiency (WSE) and the other is Rainwater Use Efficiency (RUE). Both indicators are given in percentage and expressed as Eqs. (9.1) and (9.2) (Mun and Han 2011). WSE indicates the ratio of toilet flushing water conserved by cisterns to overall demand of water. A higher WSE value means that the rainwater has the potential to become a major source of water supply. RUE indicates the proportion of total rainwater supply to amount of collected rainwater in a given catchment area and period. A higher RUE value means that the rainwater is collected and used efficiently in the RHS (Mun and Han 2011)

$$WSE = \frac{\sum Y_t}{\sum D_t} \tag{9.1}$$

$$RUE = \frac{\sum Y_t}{\sum R \times \sum A} \tag{9.2}$$

where,

Y = Yield (recovery) volume from the cistern (m^3)
D = Demand volume of toilet flushing water (m^3)
R = Rainwater (mm)
A = Roof area (m^2)

9.1.2.4 Sizing Method of Cistern Capacity

Since the capacity of cistern is one of the most significant design parameters, the water demand of household and the water yield from storage system play a conclusive role in calculating WSE and RUE. The capacity of cistern is associated with total volume of available collected rainwater and impacts the performance of RHS, so we choose to start our research with cistern sizing.

Based on previous studies, there were several approaches to determine cistern volume, including "less than 0.5% relative increment of WSE", "minimum net

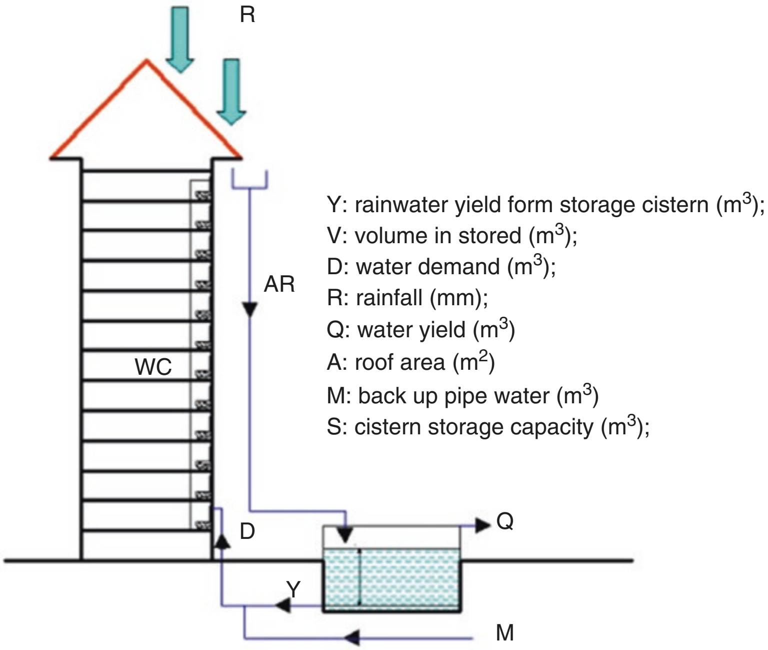


Fig. 9.4 Schematic diagram of RHS behavioral model in residential building

present value" and "maximum rainwater used". We have tried three methods to select the min result as the optimal volume of cistern.

9.1.2.5 Behavioral Model of RHS in Residential Building

To calculate values of WSE and RUE, it is required to use the calculation method for the value of Yield. We hereby introduce a widely used behavioral model, the Yield-After-Spillage (YAS) algorithm (Fig. 9.4), which can be used to describe the supply-spillage behavior of cistern (Fewkes 1999; Morales-Pinzón et al. 2012; Devkota et al. 2015). This algorithm is evaluated by adopting a rule of supply-spillage, which generally means that rainwater collected in cistern would be used up without any spillover, nonetheless, when the inflow volume exceeds the remaining storage capacity of cistern, the rainwater for domestic use is triggered after spillage (Olaoye and Akinwale 2013; Fewkes and Wam 2000).

YAS operation rules assume the current yield as the lesser of the volume of stored rainwater in the previous time interval and the demand in the current time interval. The current stored rainwater is then obtained by adding the current rooftop rainwater runoff to and subtracting the current yield from the rainwater volume stored in the previous time interval, except for overflows (with respect to cistern storage capacity) discharged to the sewer system (Jenkins et al. 1978).

Researches show that YAS operation algorithm has made a conservative estimation on RHS performance irrespective of the model time scale (Fewkes and Wam 2000), and conclude that its sensitivity to changes of storage capacity and water demand remains low (Olaoye and Akinwale 2013; Fewkes and Wam 2000). Researches also suggest that YAS would be used as the standard of comparison and calibration instead of other algorithms. The equation is expressed as Eqs. (9.3) and (9.4).

$$Yt = \min \begin{cases} Dt \\ Vt - 1 \end{cases} \tag{9.3}$$

$$Vt = \min \begin{cases} Vt - 1 + Qt - Vt \\ S - Yt \end{cases} \tag{9.4}$$

Where, subscript ‘t’ indicates the current time step. In this research, the data of daily rainwater and water demand are used because that Olaoye Rebecca A and Coker Akinwale (2013) and Campisano and Modica (2014) have proved that daily legend is reliable. In our assumption, all variables are always calculated at the end of each day.

9.2 Methodology

9.2.1 Extraction of Cooperative Design Parameters (CDP)

A cooperative design, a method integrating main design parameters of both building design and RHS design simultaneously, is standardized at the beginning of residential community site planning. The proposal of cooperative design aims at supporting urban planners to apply RHS in the process of primary design of residential community.

According to the previous RHS applications, RHS has always been designed after the primary design of buildings, which proves to be less efficient due to the fact that performance of RHS will be restrained by conditions of existing buildings. Based on our assumption, in the cooperative design, RHS should be designed along with the primary design of buildings involving selection of suitable devices and sizing of collection system. All these parameters are subject to the control of urban planners (Fig. 9.5).

According to the Design Code for Residential Building (GB50096-2011) and the Guide Manual for Sponge City Construction (China 2014), the executor and contents of each design step, and the relationship between each other are shown in Fig. 9.6. In the step of cooperative design, details of main design objects in both RBD and RHSD should be included, such as building type, capacity, occupants,

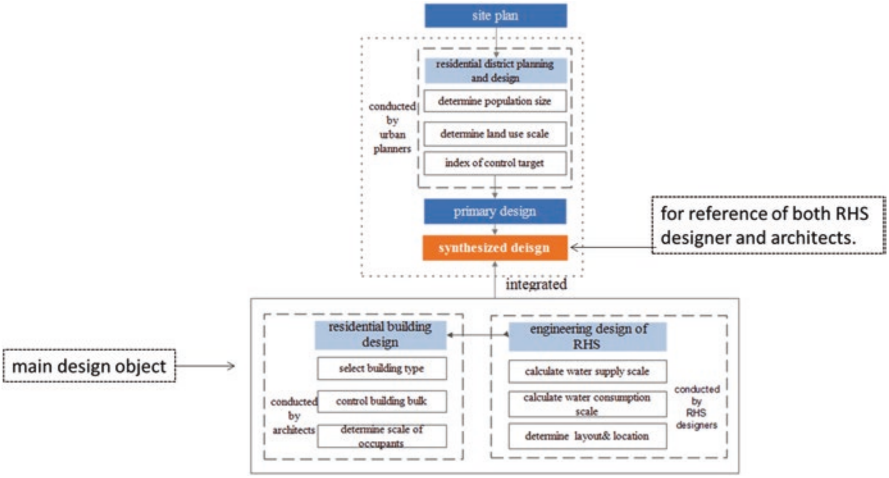


Fig. 9.5 Scheme of RHS in residential building

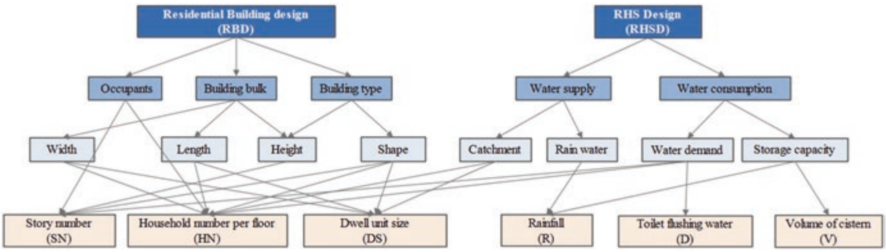


Fig. 9.6 Extraction of CDP from RBD and RHSD

balance of water supply and water consumption, which will exert significant impacts on performance of RHS.

According to the design code, during the design process of RBD and RHSD, main design objects can be classified by several factors including width (W), length (L), height (H), shape (S), roof area (A), rainwater (R), volume of cistern (V) and water demand of household (D) and these factors can also be further divided based on their mathematical relationships. As a consequence, principal cooperative design parameters affecting the performance of RHS can be summed up as stories number (SN), household number of each floor (HN), dwelling unit size (DS), cistern volume (V), amount of rainfall (R) and water demand (D). It should be highlighted that D and R only vary with local conditions. So the performance assessment will focus on the combination of SN, HN and DS (Fig. 9.6).

Fig. 9.7 Location of case study

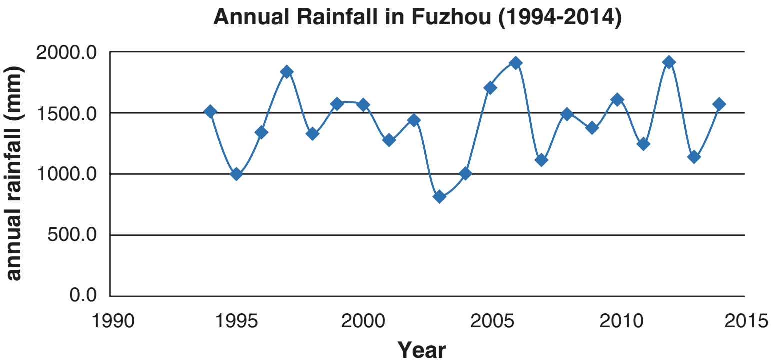


Fig. 9.8 Annual rainfall data of Fuzhou city (1994–2015)

9.2.2 Case Study

Fuzhou, a city located in the southeast of China with coordinates at 26°04′34″N, 119°18′23″E (Fig. 9.7), shows a typical subtropical oceanic monsoon climate and abundant mean annual rainfall of 1369.9 mm. According to the recommended minimum rainfall for the implementation of RHS, Fuzhou demonstrates a great potential. After examining the continuously recorded average yearly rainfall from 1954 to 2015, we choose the average daily rainfall during the latest 5 years (Fig. 9.8).

Within the last decade, although the tendency of Fuzhou's water supply capacity is flattened on average (Fig. 9.8), the water consumption per capital has been decreasing due to the increasingly growing population, that is, the water supply

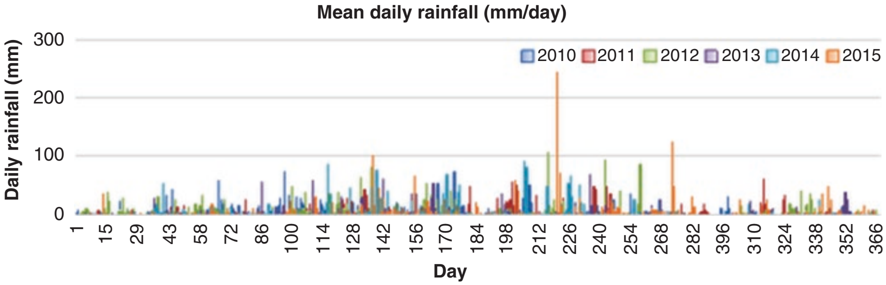


Fig. 9.9 Daily rainfall data of Fuzhou in 2010–2015

Table 9.1 Water demand of general household

Type of use	Reserve type	%	Economical type	%	General type	%
Toilet flushing	30	34.8	3.5	32.1	40	29.1

system remains under much pressure for domestic water supply. It is believed that the pressure of domestic water supply may be relieved by increasing the reuse effectiveness of rain water resources and applying RHS in residential buildings to promote the proportion of self-built water supply. Therefore, this research is conducted based on the assumption of applying RHS in a typical residential building of Fuzhou.

9.2.3 Data Collection

To estimate the influence of CDP on the performance of RHS in residential buildings, a case study for Fuzhou (a city in Fujian Province, China), is presented in this paper. The input data of CDP for simulation are prepared based on local circumstances, including precipitation, habit of water consumption and local building design codes.

9.2.3.1 Precipitation

In this study, the daily rainfall data from 2010 to 2015 (Fig. 9.9) were used because the hourly data were difficult to obtain.

9.2.3.2 Water Demand

In Fuzhou, according to the standard of water quantity for Chinese residential use, the volume of daily water demand per capita are shown in Table 9.1. For the simulation of RHS's performance assessment, 40 L/person/day in general type is used as daily toilet flushing demand.

Table 9.2 Type and proportion of residential buildings

Type	I. Low-rise (1–3)	II. Medium-story (4–6)	III. Multi-story (7–9)	IV. High-rise (10–23)	V. Super high-rise (23–33)
Number	40	243	266	316	311
Percentage	3.40%	20.63%	22.63%	26.91%	26.43%

9.2.3.3 Classification of Building Types

In this research, building types for study will cover all types of apartments with a limited number of households in each floor, with dwelling unit. We have collected 1179 samples of local residential buildings to decide the range of necessary variables of buildings.

According to the Code for Civil Buildings Design (GB5032-2005), the type of residential buildings in China could be classified by the stories number (SN) as low-story (1–3), medium-story (4–6), multi-story (7–9), high-rise (10–23) and super high-rise (over 23 stories but less than 100 m ≈ 33 stories).

9.2.3.4 Distribution of Residential Building Types

The number and percentage of each building type was based on the collected data from 1179 local residential building samples, which is shown in Table 9.2.

9.2.3.5 Dwelling Unit Size (DS)

Commonly in residential buildings, the area of roof top is associated with the number of households and dwelling unit size, in consideration of tax jurisdiction standards. As for the DS, dwelling units may be classified by 90 m^2 below, 90–140 m^2, and over 140 m^2.

9.2.3.6 Household Number (HN)

As for the household number (HN), according to the definition and the classification in design codes, and based on the 1179 building samples, a residential apartment should be designed with at least 2 households and maximum 8 households in each floor for the consideration of fire safety, well ventilation and views. As per the collected data, the classification and combination of SN are listed as below, '–' means no sample exists in this CDP combination. WSE and RUE will be calculated under various combination of CDP (Table 9.3).

Table 9.3 Main cooperative parameters and distribution of residential building type

			HN						
			2	3	4	5	6	7	8
Type	SN	DS	Distribution of building (%)						
Low-rise	1–3	≤90	–	–	–	–	–	–	–
		90–140	–	–	–	–	–	–	–
		≥140	3.40	–	–	–	–	–	–
Medium-story	4–6	≤90	1.50	–	–	–	–	–	–
		90–140	3.90	–	–	–	–	–	–
		≥140	15.23	–	–	–	–	–	–
Multi-story	7–9	≤90	–	3.90	2.45	–	1.47	–	–
		90–140	6.40	1.50	2.00	–	0.50	–	–
		≥140	4.41	–	–	–	–	–	–
High-rise	10–23	≤90	–	–	2.45	1.45	2.45	–	0.95
		90–140	0.50	1.45	3.92	0.50	3.92	–	0.50
		≥140	2.45	3.92	2.45	–	–	–	–
Super high-rise	23–33	≤90	–	–	3.43	–	1.47	0.50	2.45
		90–140	2.00	3.92	4.89	0.95	0.95	–	0.50
		≥140	1.47	1.90	2.00	–	–	–	–

9.2.3.7 Dimension of Cistern

According to the limitation of installation space, the dimension of cistern should be limited by the dimension of building. Considering that the average floor height is 3.5 m, the height of cistern is supposed to be 3.00 m or less (Fig. 9.10). As shown in the figure, the common range of width and length of building in both slab type and spot type is from 10 m to 30 m (Fig. 9.10), so the maximum dimension of cistern would be under 10*10*3 (300 m^3). For simulation, in order to remain adequate volume for rainwater, the maximum value of cistern capacity is set as 350 m^3 and the range of cistern volume is determined by the range of available rainwater volume harvested from roof top with 5 increments in each value (Fig. 9.10).

9.2.4 Simulation Approach for RHS Performance Assessment

To assess the performance of RHS under various combinations of CDP, the simulation is conducted through two major parts. The first step is cistern sizing. In this step, three methods are used to choose the minimum volume of cistern in consideration of lowest cost, including "less than 0.5% relative increment of WSE", "demand side estimation" and "maximum rainwater used". The second step is the simulation of RHS performance under different combinations of CDP with the determined optimum volume of cistern conducted in Metlab in July, 2013.The output of WSE and RUE under various CDP were calculated through the approach represented in Fig. 9.11.

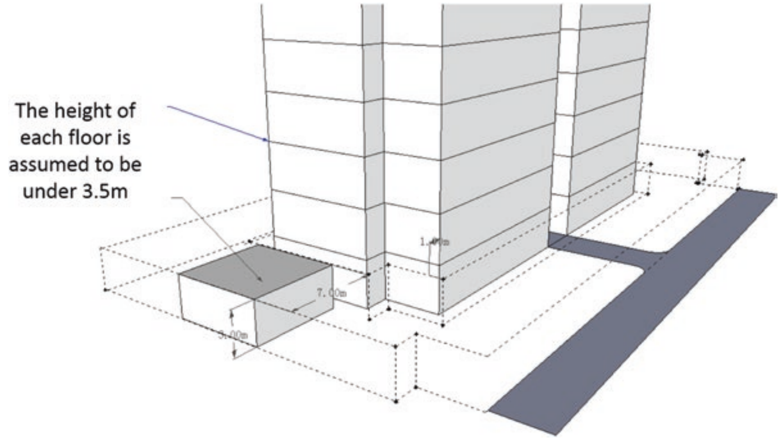


Fig. 9.10 Scheme of the limitation of the height of Cistern by the height of floor

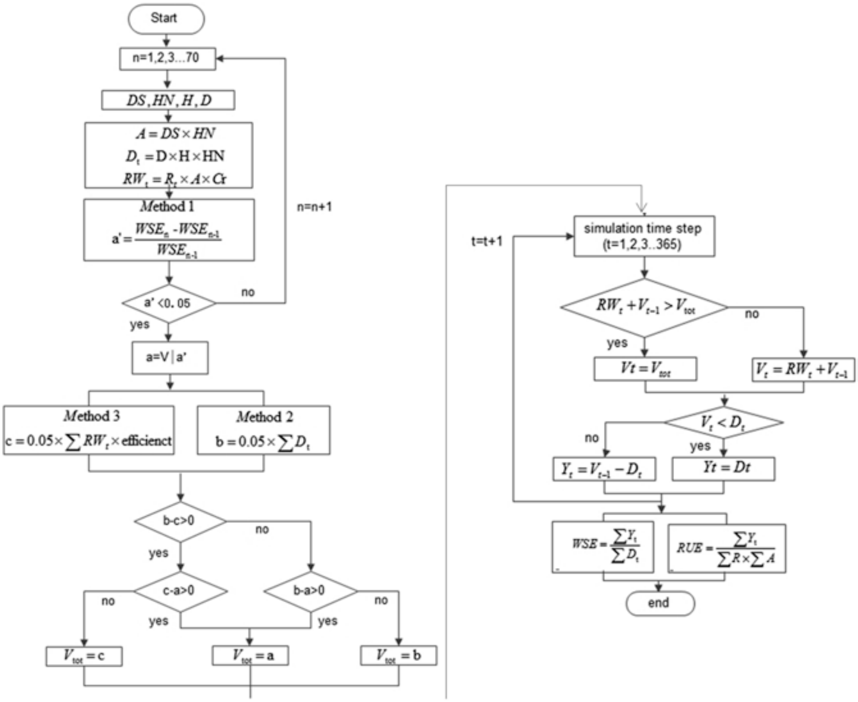


Fig. 9.11 Simulation approach of calculating WSE and RUE

Where:

'*A*': area of rooftop;

'*RW*': available rainwater for domestic water use;

'*Cr*': efficiency of rainwater collected by rooftop;

'*n*': step of calculation;

'a', 'b' and 'c': cistern's volume;

'*t*': simulation days of 1 year;

'*Vtot*': maximum capacity of cistern;

'*Vt*': current rainwater volume collected in cistern;

'*Y*': yield of rainwater for domestic use;

'D': volume of water demand.

Table 9.4 Input data for simulation

Notation	Name	Unit	Max	Min
DS	Dwelling unit size	m^2	350	40
HN	Household number per floor		2	8
SN	Stories of building		1	33
R	Rainfall	mm	370	0
V	Volume of rainwater in cistern	m^3	350	5
D	Water demand of each house	L	50	

The classification, features and ranges of aforementioned CDP for evaluation in each building type is represented in Table 9.4. The data input for evaluation on the implementation of RHS in apartment is also summarized in Table 9.4.

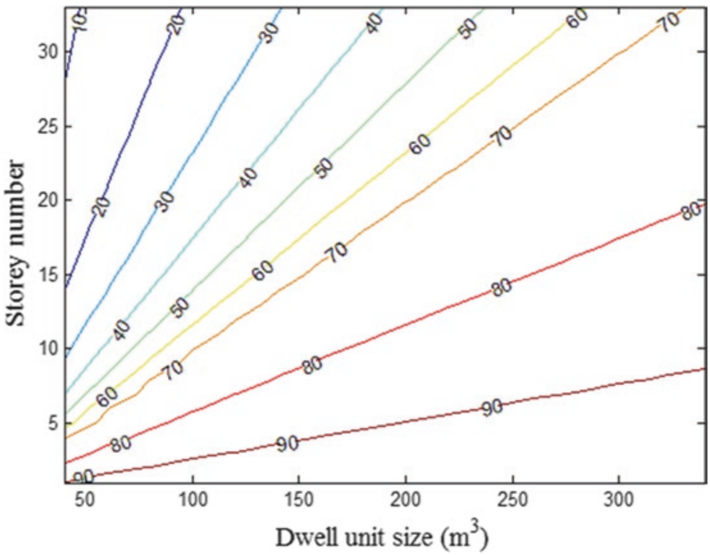
9.3 Results

9.3.1 WSE Under Various Combinations of CDP

Figure 9.12 shows the results of WSE against different combinations of CDP. The contour lines with different colors represent the variations of WSE for each household number (HN). The horizontal axis represents the value of dwelling unit size (DS), the vertical axis represents the value of stories number (SN), and each point in these contour plots represents a specific cistern volume calculated by the sizing regulation.

It is showed that with the increasing HN, WSE decreases slightly, and WSE decreases obviously along with the increase of SN. WSE shows a negative growth with the increase of SN while it shows a positive grow with DS, and the increasing speed will get slow if DS ≥140, meanwhile WSE has its limitation around 80%. This is because that with the growth of SN and HN, the total water demand will expand relatively. To the contrary, with the increase of DS, the rooftop for harvesting rainwater is considerably increased.

This figure also indicates that almost half of all combinations of CDP could achieve over 50% WSE. For the low-story apartments, the value of WSE remain at the level of 90%, irrespective of the value of DS and HN; in the case of medium-story apartment, WSE keeps around 80% only if the value of DS is larger than 90 m^2. Thereafter, with the increase of SN, we can obviously find that only up to 60% WSE is maintained (Table 9.5).



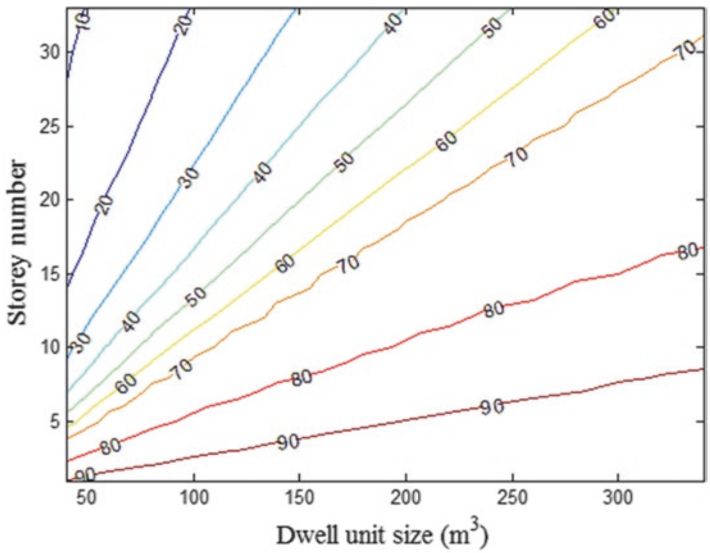


Fig. 9.12 (**a–g**) WSE contour under different combinations of stories number and dwelling unit size (**a**) 2 households per floor. (**b**) 3 households per floor. (**c**) 4 households per floor. (**d**) 5 households per floor. (**e**) 6 households per floor. (**f**) 7 households per floor. (**g**) 8 households per floor

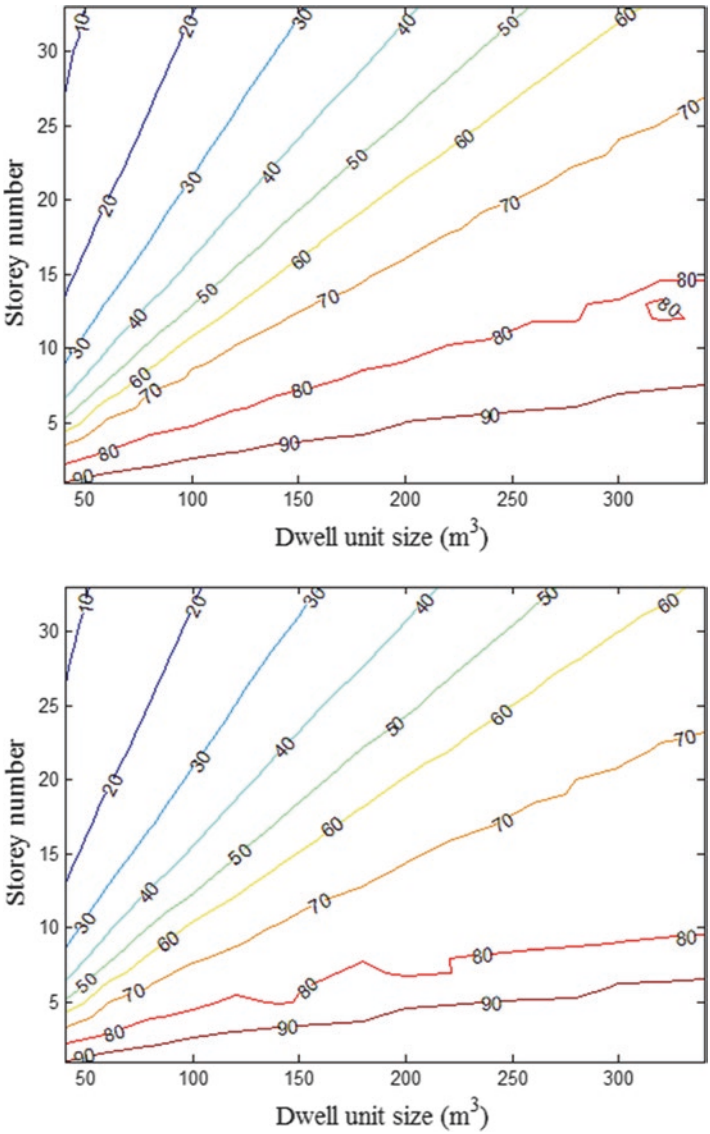
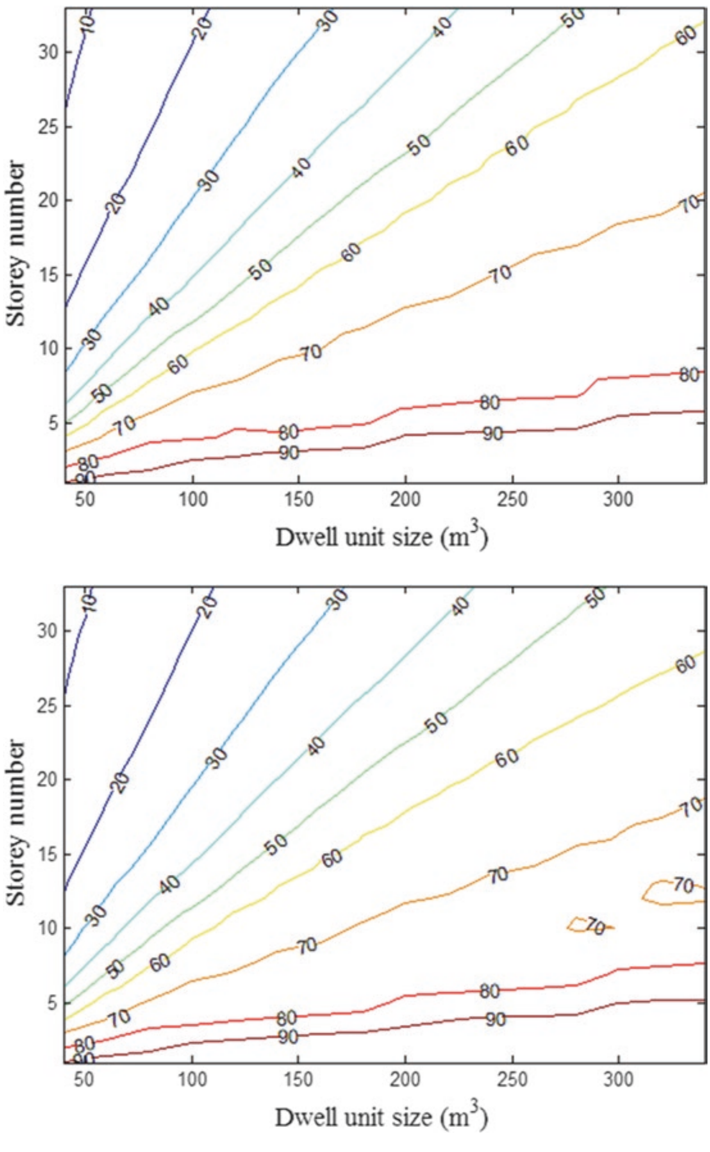


Fig. 9.12 (continued)



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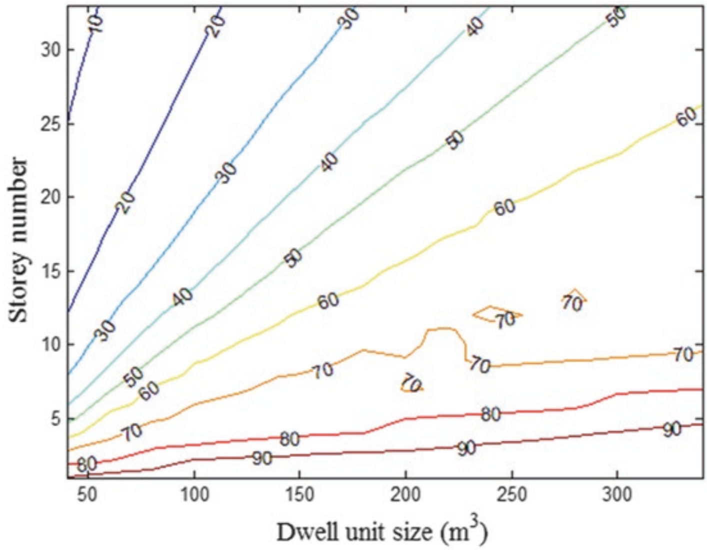


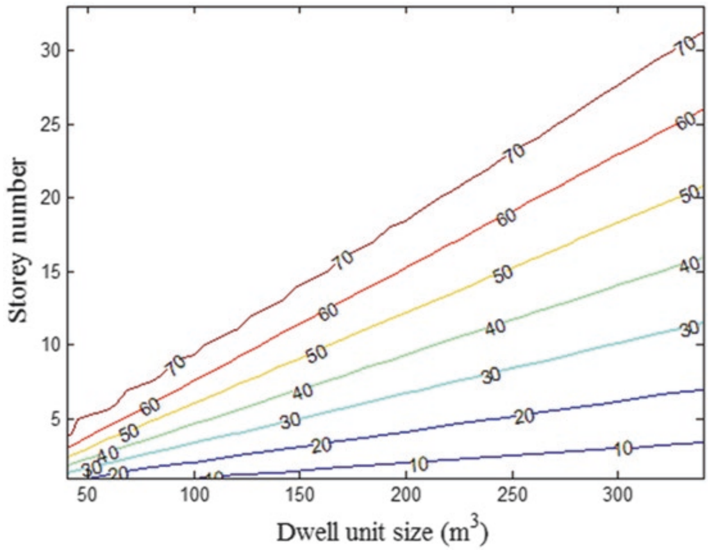
Fig. 9.12 (continued)

Table 9.5 Range of WSE under different combinations of CDP

			HN						
			2	3	4	5	6	7	8
Type	SN	DS	WSE (%)						
Low-rise	1–3	≤90	–	–	–	–	–	–	–
		90–140	–	–	–	–	–	–	–
		≥140	≥90	–	–	–	–	–	–
Medium-story	4–6	≤90	40–85	–	–	–	–	–	–
		90–140	75–90	–	–	–	–	–	–
		140≤	83–95	–	–	–	–	–	–
Multi-story	7–9	≤90	–	30–76	29–73	–	28–72	–	–
		90–140	67–83	62–82	60–81	–	59–70	–	–
		140≤	77–92	–	–	–	–	–	–
High-rise	10–23	≤90	–	–	15–60	14–59	13–59	–	12–50
		90–140	29–77	27–75	26–74	24–70	24–70	–	23–62
		140≤	45–88	42–88	40–87	–	–	–	–
Super high-rise	23–33	≤90	–	–	9–28	–	7–25	6–24	5–22
		90–140	20–45	20–50	18–40	17–39	17–38	–	17–34
		140≤	30–77	29–75	28–73	–	–	–	–

9.3.2 RUE Under Various Combinations of CDP

The value of RUE is defined as the proportion of total rainwater supply to the amount of collected rainwater in a given catchment area and period. In some extent, RUE can illustrate the potentiality of rainwater usage. Therefore, RUE shows a negative growth with the increase of HN while it shows a positive growth along with DS. The increase trend of RUE is more significant with the increase of SN than the increase of HN, which is displayed in Fig. 9.13.



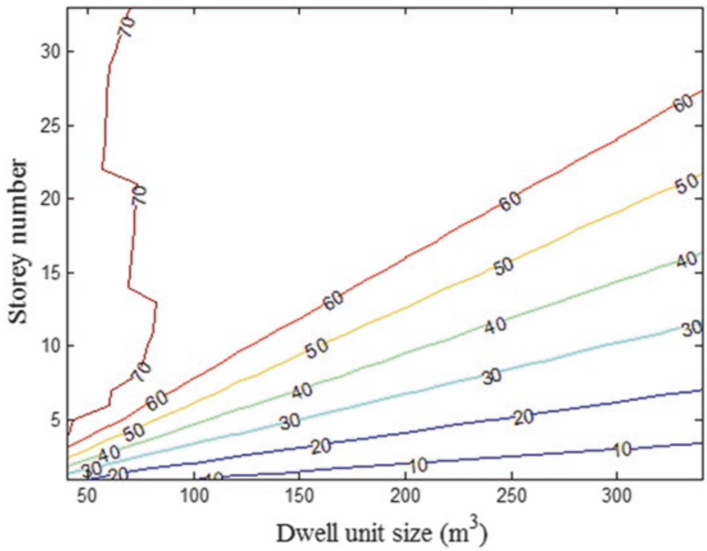


Fig. 9.13 (**a–g**) RUE contour with different combinations of stories number and dwelling unit size. (**a**) 2 households per floor. (**b**) 3 households per floor. (**c**) 4 households per floor. (**d**) 5 households per floor. (**e**) 6 households per floor. (**f**) 7 households per floor. (**g**) 8 households per floor

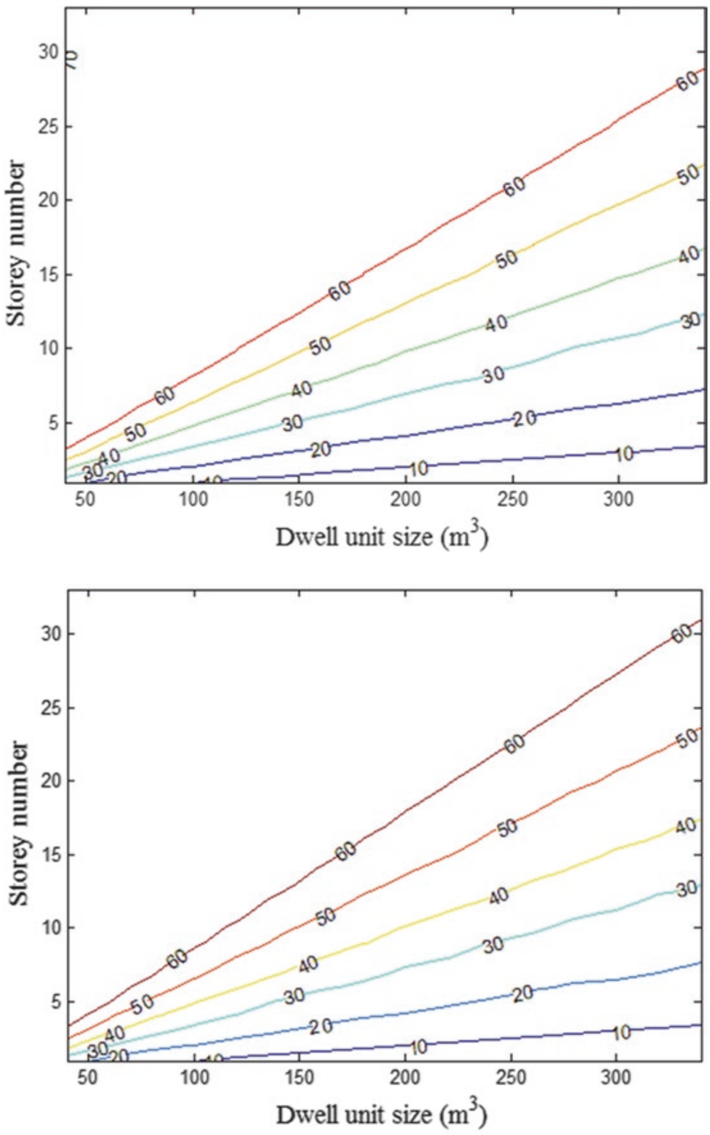


Fig. 9.13 (continued)

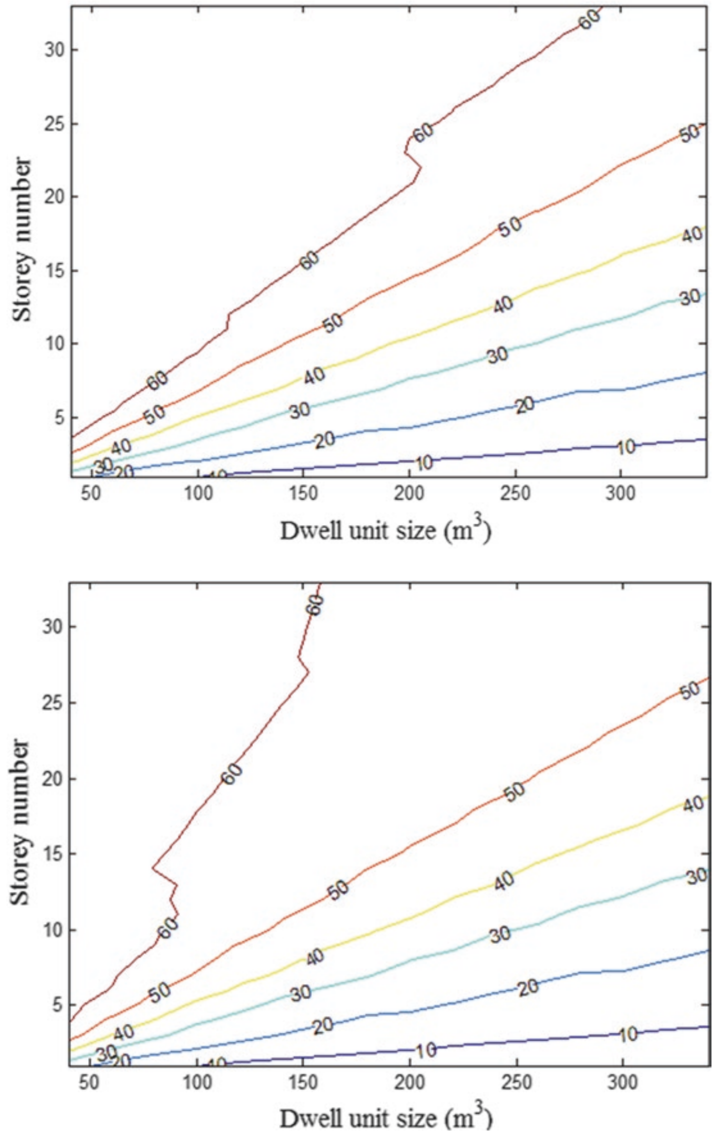


Fig. 9.13 (continued)

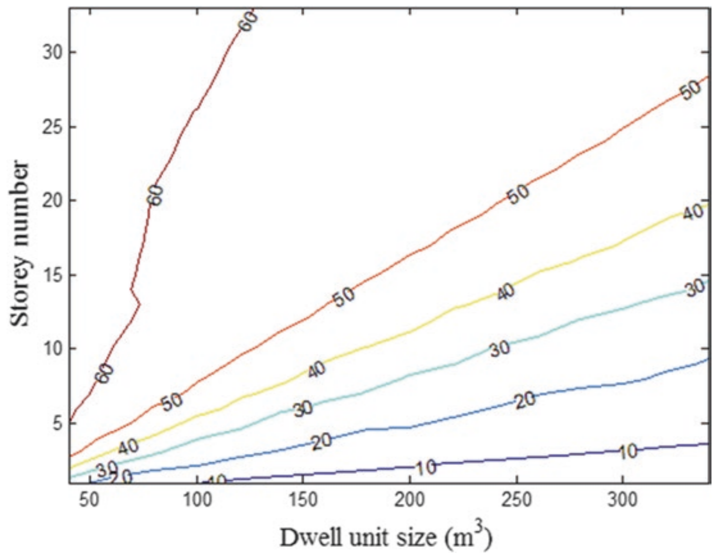


Fig. 9.13 (continued)

The results show that compared with SN, RUE changes slightly against HN and DS since the increase of HN and lower value of DS lead to little increase of total roof area. However, if the value of SN is at a high level (over 20 stories), the increase of stories number will not cause obvious development of RUE. That is because that the high level of SN generates a large number of households which consequently cause a dramatic expansion of water demand.

This figure indicates that over 60% rainwater could be collected and reused as toilet flushing water among different combinations of CDP. We can also conclude that if any building is higher than 9 stories, and the value of DS is under 140 m^2, then the value of RUE will achieve more than 50%. In a word, in any story of an apartment, when it is supposed to keep RUE around 60%, the value of DS is suggested to be larger than 100 m^2. The increase rate of RUE against SN is quicker than DS and HN.

Table 9.6 shows the results of RUE range under each type of residential building.

9.3.3 Optimal Combination of CDP for Better RHS Performance

Table 9.7 summarizes the results of WSE and RUE. The red block marks out the recommended combination of CDP which can achieve more than 50% WSE, while the green block marks out the recommended combination of CDP for achieving more than 50% RUE. We overlay these colors together and the gray part shows the optimal combination of CDP for better performance of RHS.

Table 9.6 Range of RUE under different combinations of CDP

			HN						
			2	3	4	5	6	7	8
Type	SN	DS	RUE (%)						
Low-rise	1–3	≤90	–	–	–	–	–	–	–
		90–140	–	–	–	–	–	–	–
		≥140	15–22	–	–	–	–	–	–
Medium-story	4–6	≤90	30–73	–	–	–	–	–	–
		90–140	21–58	–	–	–	–	–	–
		140≤	19–53	–	–	–	–	–	–
Multi-story	7–9	≤90	–	55–76	52–70	–	50–65	–	–
		90–140	39–70	40–65	39–62	–	35–61	–	–
		140≤	19–52	–	–	–	–	–	–
High-rise	10–23	≤90	–	–	62–70	61–70	61–70	–	55–63
		90–140	53–75	52–68	51–66	50–65	48–63	–	45–58
		140≤	28–73	27–66	25–64	–	–	–	–
Super high-rise	23–33	≤90	–	–	68–70	–	≥68	≥62	58–63
		90–140	≥75	65–68	66–68	≥65	≥65	–	57–63
		140≤	55–75	53–67	50–68	–	–	–	–

Table 9.7 Range of RUE under different combinations of CDP

			HN						
			2	3	4	5	6	7	8
type	SN	DS	WSE (%)						
I. low-rise	1~3	a. ≤90	–	–	–	–	–	–	–
		b. 90~140	–	–	–	–	–	–	–
		c. 140≤		–	–	–	–	–	–
II. multi-story	4~6	a. ≤90		–	–	–	–	–	–
		b. 90~140		–	–	–	–	–	–
		c. 140≤		–	–	–	–	–	–
III. medium-story	7~9	a. ≤90	–			–		–	–
		b. 90~140				–		–	–
		c. 140≤		–	–	–	–	–	–
IV. high-rise	10~23	a. ≤90	–	–				–	
		b. 90~140						–	
		c. 140≤				–	–	–	–
V. super-rise	24~33	a. ≤90	–	–		–			
		b. 90~140						–	
		c. 140≤				–	–	–	–

recommended combination for achieving more than 50% WSE

recommended combination for achieving more than 50% RUE

9.4 Conclusion and Discussions

This research proposed a cooperative design method to improve the cooperation of urban planners and RHS designers for a more efficient implementation of RHS.

For a better performance of RHS, urban planners along with water supply and sewage engineers can estimate the hypothetical WSE and RUE based on predetermined design or revise their design using the hypothetical WSE/RUE.

Results show that the multi- and medium-story apartments with 2–4 households and dwelling unit size between 90–140 m^2 are the most appropriate building type for higher WSE and RUE during the implementation of RHS.

This research is also subject to certain restraints. Before cooperative design, the implementation of RHS in residential buildings should consider carefully the economic feasibility and adjust these measures to a larger scale. So the further work would be focused on the potentiality of applying RHS in residential communities.

References

Aad MPA, Suidan MT, Shuster WD (2010) Modeling techniques of best man-agreed practices: rain barrels and rain gardens using EPA SWMM-5. J Hydrol Eng 15:434–443

Abdulla FA, Al-Shareef AW (2009) Roof rainwater harvesting system for household water supply in Jordan. Desalination 243(1):195–207

Campisano A, Modica C (2014) selecting time scale resolution to evaluate water saving and retention potential of rainwater harvesting tanks. Procedia Eng 70:218–227

Coombes PJ, Barry ME (2007) The effect of selection of time steps and average assumptions on the continuous simulation of rainwater harvesting strategies. Water Sci Technol 55(4):125–133

Damodaram C et al (2010) Simulation of combined best management practices and low impact development for sustainable stormwater management. Jawra J Am Water Res Assoc 46(5):907–918

Devkota KP et al (2015) Simulation the impact of water saving irrigation and conservation agriculture practices for rice-wheat systems in the irrigated semi-arid drylands of Central Asia. Agric For Meteorol 214–215:266–280

Fewkes A (1999) The use of rainwater for WC flushing: the field testing of a collection system. Build Environ 34:765–772

Fewkes A, Wam P (2000) A method of modelling the performance of rainwater collection systems in the United Kingdom. Build Serv Eng Res Technol Int J 21(4):257–265

Ghisi E, Bressan DL, Martini M (2007) Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil. Build Environ 42:1654–1666

Herrmann T, Schmida U (2000) Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. Urban Water 1(4):307–316. https://doi.org/10.1016/S1462-0758(00)00024-8

Jenkins SH et al (1978) Industrial water and wastes. Water Res 12(2):136–137

Morales-Pinzon T et al (2012) Financial feasibility and environmental analysis of potential rainwater harvesting system: a case study in Spain. Resour Conserv Recycl 69(12):130–140

Mun JS, Han MY (2011) Design and operational parameters of a rooftop rainwater harvesting system: definition, sensitivity and verification. J Environ Manag 93(2012):147–153

Olaoye Rebecca A, Akinwale C (2013) Examining the effectiveness of rainwater collection systems in a nigerian leper colony using the behavioural model. J Eng Appl Sci 8(1):1–8

Zhang D, Gersberg RM, Wilhelm C, Voigt M (2009) Decentralized water management: rainwater harvesting and greywater reuse in an urban area of Beijing, China. Urban Water 6(5):375e3