Enhancing Cities' Resilience to Floods through Urban Planning and Policy Measures: Case Studies of Zhengzhou and Mumbai

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Abstract. Flood is an important disaster harming populations around the world. With the rapid changes in the world today, climate change has aggravated the rigorousness of flooding in recent years. Urban floods also can cause large amounts of damage. Therefore, it has become an urgent issue to improve cities' resilience to floods, in which this study aims to address urban pluvial floods in particular. Through analyzing the problems and solutions in two case studies, the 2021 "7.20" Zhengzhou Flood in China and the 26 July 2005 Mumbai Flood in India, this study found that the failure to combat the floods fully in both cases were caused by similar causes and require similar solutions in terms of governance, infrastructure, environment, and education. Existing and potential solutions were suggested to improve mitigation efficiency, such as the structural Sponge city measure and pro-poor urban planning, and the smaller innovative rescue facilities and the use of Artificial Intelligence (AI). This study provides some reference towards the common flaws of cities in terms of flood mitigation and suggested some useful strategies. To improve the weakness of this study in terms of depth and scope, future scholarship could compare more cities around the world and analyse the issues in greater depth.

Keywords: Urban flood resilience; Urban planning; Extreme rainfall, Innovative flood

1   Introduction

Climate change is an important factor in the increased frequency and severity of floods in recent years [1]. Floods (including glacial lake outbursts floods) was the natural disaster with the highest annual average occurrence globally of 170 from 2003-2022 [2]. Urban flooding can result in drastic consequences for not only property damage, financial loss, and also the loss of lives [3]. Therefore, methods to increase resilience towards flooding has become an increasingly significant topic that cities need to address. Floods can be distinguished into different categories, including fluvial flooding, pluvial flooding, and coastal flooding [4]. This essay will discuss urban pluvial flooding in particular. As one might ask "How can cities enhance their resilience to flooding through urban planning and policy measures?" This essay will discuss the 2021 "7.20" Zhengzhou

Flood in China and the 26 July 2005 Mumbai Flood in India. By using these two cities as case studies, the essay aims to analyse the issues in these two incidents and what policies and measures cities can adopt in the future in order to become more resilient in the face of potential pluvial flooding.

2   Literature Review

The severity of the Zhengzhou 2021 "7.20" Flood attracted wide public attention in China. There are also many existing scholarships on Zhengzhou "7.20" Flood. Some scholarship included analyses of the disaster, some used mathematical models to indicate the risk levels of different areas of the city, and some analyzed government management issues and gave suggestions of the measures which can be taken. In addition, there is also an official governmental report on the incident in Chinese called "Henan Zhengzhou "7.20" Extreme Rainfall Investigation Report," which included a description of the incident, the weaknesses of the local governments in the issues, investigations into the major incidents in the disaster, and suggestion of solutions towards this type of disaster.

   There are also many existing scholarships on the Mumbai 2005 Flood. Some scholarship analysed the incident, some papers assessed for Mumbai's flood vulnerability, and some articles examined related health issues and environmental management issues stemming from the disaster.

2.1   Definitions

Pluvial is "rain-related" [5]. Pluvial flood is a flood caused by rain accumulation. It happens after rainfall within a short period of time but high in intensity, where the rainwater is unable to be infiltrated or transported using draining facilities quickly [5]. Urban pluvial flooding is called "the invisible hazard" due to its characteristic of often occurrences in locations not threatened by flooding with little forecasting [5].

   Resilience is the ability of endurance and bouncing back. Urban flood resilience is a city's ability to hold up to flood and the disasters which it brings, and the city's ability to maintain its current state and to change according to disasters [6].

3   Case study 1: Zhengzhou 2021

3.1   Background

Zhengzhou is the provincial capital city of Henan province in China. It has a metro area population of 12,742,000 in 2021 [7]. It is known for being one of the main high speed railway transportation centres in China and is also known for its manufacturing industry.

3.2   Causes

The causes of the flood include:

1) firstly, Henan experienced continued transfer of water vapor due to the irregular spreading of pressures of different latitudes and vortex systems [8].

2) In addition, the subtropical high pressure shifted north uncommonly, forming a channel which allowed the movement of water vapors, which travelled to Zhengzhou instead of traveling to the mountains [8].

3) The then caused extreme rainfall led to waterlogging in Zhengzhou, and also led to other natural disasters as well [9].

4) Zhengzhou's topography of being higher geographically and being lower in the northeast led to the occurrence of both waterlog and flooding [9].

From 17 to 23 July 2021, there were severe rainfall levels in Zhengzhou [10]. On 20 July, Zhengzhou recorded rainfall level of 624.1mm, which is similar to Zhengzhou's annual average rainfall level of 640.8mm, exceeding historical records [9].

The movement of the rainfall was from the northern parts of Henan province (17-18 July) to Zhengzhou (19-20 July) then to the north (21-22 July), and then it slowly stopped (23 July) [9].

A large number of areas was flooded, including 2067 underground spaces and infrastructure of neigbbourhoods, many regions lost access to water, electricity, and the internet. Road transportation was inaccessible [9].

There were serious incidents during the disaster, including flooding of a Zhengzhou subway train and hospitals. Rescue and evacuation were conducted by firefighters and armed police forces, including rescue teams deployed from other areas of China.

In the end, the disaster resulted in total 380 deaths and missing individuals, a financial loss of 40.9 billion RMB, 34.1% of the 120.6 billion RMB, the total direct economic loss of Henan province during the disaster [10].

3.3   Analysis of the Incident

Zhengzhou's failure to fully respond to the disaster was due to several reasons:

1) Disaster: The rainfall level was very rare, as meteorologists commenting that it happens only "once in a thousand years" [11].

2) Infrastructure: Zhengzhou's current drainage standards could not endure the extreme rainfall [9].

3) Management: The emergency response lacked efficiency and there was late report or covering up of numbers of deaths and missing individuals by the local government [9].

3.4   Suggestion of Solutions

Several solutions for improving Zhengzhou's resilience to extreme rainfall events have been advised [9]. Based on three main aspects, governance, infrastructure, and education, the suggestions are as follows:

In terms of governance, to train government personnel and enhance responsibilities by refining job duties, effective command, and thorough investigation. Organization is also recommended for improvement, by reforming the emergency system, creating an emergency commanding organization, and to refine risk assessment system and regulations [9].

For infrastructure, it was advised urban planning to need to integrate natural disaster management into planning, and public infrastructure and drainage standards need to be upgraded. The urban weather forecasting system is advised to be improved, and river encroachment to be controlled. It was also suggested to set up Urban Safety Risk Detection centers and allocate emergency devices such as satellite phones, communication drones, and power generating cars [9].

Education such as public training, integrating disaster management into education system, and practice through activities are suggested to be implemented to help the public to better understand flood disasters and be able to protect themselves [9].

Through assessing Zhengzhou's comprehensive emergency-response capacity to flood disaster (CERCF), it was concluded that as there are major differences in terms of emergency abilities of different regions in Zhengzhou, the government should implement different measures for each region to strengthen the weaknesses of each area [12]. Also, it is recommended that there should be effective communication between regions, and that the government should financially aid cities, improve urban planning, and train personnel's emergency knowledge to improve cities' CERCF [12].

4   Case Study 2: Mumbai 2005

4.1   Background

Mumbai is the capital city of Maharashtra state, India. It has a population of 12 million people in 2005 [13]. It is the trade and financial centre of India.

The Mumbai railways are called the "lifeline of the city" because they transport half the city's population to work every day from their homes in the northeastern suburbs.

In Mumbai, the monsoon rainfall last from June to October [13]. A monsoon is "a major wind system that seasonally reverses its direction" [14]. The Indian monsoon "blows from the northeast during cooler months and reverses direction to blow from the southwest during the warmest months of the year" [14]. The average annual rainfall levels in Mumbai are 2300mm, as based on the Santa Cruz meteorological station in Mumbai.

4.2   Causes

Several meteorological causes of the 2005 extreme rainfall over Mumbai have been suggested by previous literature:
   1) low pressure area forming at the top of Bay of Bengal
   2) wind: merging of north and northeastern winds and circulation above Mumbai
   3) abnormal strong temperature gradient and high precipitable water regionally
   4) a sea vortex forming near Mumbai

5) geography [15].

On 26 July, in 24 hours, there was a rainfall level of 944 mm in Mumbai [16]. The extreme rainfall happened since approximately the midnight of the 26 July to the early morning of 27 July [16]. The India Meteorlogical Department classified the rainfall to be "very heavy" as the level was more than 200mm per day [13].

3/5 of the area in Mumbai was flooded [13]. 100,000 buildings and 30000 vehicles were impaired [13]. There were terminations in public transport, communications, and power services such as electricity [17]. All flights from the Mumbai airport were cancelled [16; 17].

In the following landslides and flash floods, there were 419 deaths and 16,000 deaths of cattle [13]. Flood related diseases took away the lives of 216 people [13].

Water borne diseases were a threat in the aftermath of flooding. The Mumbai Corporation of Greater Mumbai (MCGM) disposed bodies of dead animals, including thousands of sheep and goats [13]. Waste in the city was removed, and disinfectants and insecticides were used widely [13]. 300,000 patients were treated by MCGM's medical care services [13].

4.3   Analysis of the Incident

The following were suggested to be the main issues during the disaster, in categories of governance, environment, and infrastructure [16-18].

Governance: The cooperation between government departments were complex, the disaster was poorly forecasted, and the government did not consider the slum population in flood mitigation management [18].

Environment: Mumbai had loss of ecosystems, coastal mangrove regions, and detention basins, which were helpful for water management.

Infrastructure: Some areas of the city lacked or had poorly managed storm water drains, which had issues of clogging due to solid waste, and some were not functional [17]. In Colaba, Mumbai's city centre, there were drains with a history of more than 100 years [17]. The drains were problematic, often leak into drinking water drains. In addition, during monsoons, the pipelines would flood, mixing with sewage [17]. The rapid urbanization in the city led to more concrete roads and houses being constructed, reducing land permeability [17]. Unauthorized construction such as slums and unauthorised destructing/drying up drainage and natural water bodies were disadvantageous for flood mitigation [17].

Slum dwellers have been considered to be the most vulnerable group in natural disasters such as floods [17]. Mumbai has a large slum population, with more than half of Mumbai's residents resided in slums in 2005 [17]. Due to the large influx of population to Mumbai, there was also lack of housing in the city, leading to illegal settlements [17]. The slum population lived close to important drainage areas, which restricted drainage abilities [17]. Last but not least, many slums are located low geographically, which made them more vulnerable to flooding [17].

4.4   Suggestion of Solutions

Some solutions have been suggested after the Mumbai 2005 flood, in terms of governance and planning [18].

In terms of governance, it has been suggested that India should consider implementing a policy which prevents urban overdensification and a programme to reduce pressure on larger cities, and to also educate the population [18]. It is also suggested that an expert-led organisation Disaster Management Authority should be set up [18]. It is advised that the central government needs to support cities financially and punctual communication in the government is required [18].

In terms of planning, it is suggested that the Indian government to place more emphasis on planning for vulnerable states, and cities to create climate action plans (CAPs) and put them into practice, providing budget and assigned roles to departments [18]. States could modify regulations to make CAPs planning compulsory [18]. Urban legislation should also maintain permeability and flood resilience infrastructure such as rainwater harvesting tanks in all constructions [18]. Also, it is advised that green infrastructure initiatives should be established [18].

4.5   Evaluation

Both crises were caused by similar causes and required similar solutions. It is suggested that most issues in both cases were in the aspects of governance, infrastructure, environment, and education. Governance entails mainly disaster management and control. Infrastructure refers to the need to improving drainage systems. Environment is connected to environmental conservation. Lastly, education to the public not only improves disaster awareness, which improves cooperation between individuals and institutions and enhancing mitigation efficiency but is also essential for them to save themselves when an unpredictable flood disaster happens.

Drainage is a significant issue that cities such as Zhengzhou and Mumbai need to tackle, including reassessment of drainage systems in the city in dealing with urbanisation-caused changes in urban floods.

To improve urban flood resilience, in terms of urban design, it has been demonstrated that gray-green strategies in flood mitigation can be useful for reducing the amount of water in the pipe system and to transport water without surface overflow [19]. The study suggested that an effective blue-grey-green infrastructure requires the collaboration of leadership and the population on the infrastructure's application and upkeep [19]. Chen et al. also found that green-grey infrastructures, with suitable combinations, are more suitable for urban flood mitigation. It was also discovered that both deep tunnels and pipe system upgrades, grey infrastructures, can only reduce urban inundation to a small extent [2].

Suitable urban planning can reduce the repercussions of urban flooding, Hemmati et al. suggested that more space for living, and protection will be provided if rational and resilience is integrated into urban planning [8]. In order to start the assessment of risk mitigation resilience, cities can evaluate its current advantages, drawbacks, and poten-

tiality and plan practices in terms of adaptive capacity criteria. Efficient flood mitigation measures should also integrate risk communication in order to prepare families for flood disaster. In addition, due to the impoverished population experiencing more repercussions from flooding, Moulds et al. advocates for pro-poor flood mitigation and urban planning which acknowledge urban informal communities [12].

The sponge city could be an effective measure in tackling urban flooding. The sponge city, an idea which originated in China, is combining green infrastructure, such as green roofs, permeable pavements, and water detention ponds, with innovative gray infrastructure together to absorb rainwater and release when needed, transferring the city to a "sponge". The sponge city has a six-character description, which can be translated as infiltration, delay, storage, purification, usage, and drainage. In 2021, there were 30 pilot sponge cities in China, including Zhengzhou, which had been a pilot city before the "7.20" flood. The flood led to some questioning of the effectiveness of the measure, where the Zhengzhou government had spent more than 50 billion RMB on the sponge city measure [20]. There have been some urban waterlogging incidents in other sponge cities as well [20]. However, Hu Gang, the president of the Urban Research Association of South China, commented that it was due to Zhengzhou's rare rainfall being unable to be endured by the pipeline system [20]. He believed sponge cities only allow the infiltration of regular rainfall. In the cases of extreme rainfall, other measures such as underground tunnels need to be taken into account for the mitigation [20].

Adequate emergency responses can be useful for flood mitigation. A study done by Fekete et al. reveals that the involvement of disaster risk reduction (DRR) differs between and inside countries, while abilities, willingness, and responsibilities are prevalent problems in the studied countries discovered to limit participation [20]. Through a model-based investigation by Zang et al, it is suggested that the government should be ready for waterlogging rescue and publicise early warning punctuatedly particularly in residential and business areas due to the population density in these regions [16-20].

Community collaboration can also be important in improving urban flood resilience. Prana et al. demonstrated through a case study of Jakarta, Indonesia that collaboration of communities and institutions will accommodate the policies to those most impacted by flooding, improving flood management regulations [11]. In order to improve community involvement, flood risk education to the population can play an important role. This study recommends the adoption of parent-child synergy in children's education of flood dangers as it has been demonstrated that this could improve children's comprehension of disasters. However, while citizen science can be helpful in terms of statistical collection, danger awareness and community participation, it is inadequate for solving the structural problems of current vulnerabilities. Therefore, citizen science projects are advised to be supported by inclusive planning.

With the rapid advance of Artificial Intelligence (AI) technology, it has been suggested that they can play a crucial role in flood mitigation. Comes suggests the use of AI in urban crisis planning, with focus on AI flexibility in crises response, flexibility in crises responsibility, and planning for vulnerable groups [14]. The study by Comes emphasize the need for translating human principles into information that AI could understand in crises, and the need for AI to be "sensitive to their [the already vulnerable or

marginalized] needs" in order to help the groups in need to be able to voice their opinions [14].

Machine learning (ML) and digital twins can also play important roles in flood mitigation. A systematic review literature (SLR) done by El baida et al. demonstrated that among the 2018-2023 machine learning (ML) models employed for urban flood hazard mapping (UFHM), ensemble classifiers, decision trees, and artificial neural networks are those which worked most effectively, with naive Bayes and k-nearest neighbors having poorer performance here [3]. A review done by Sharifi et al demonstrated that most current literature agree on the benefits of smart technology on stormwater management, and that digital twins can be used for drainage systems in cities [13]. However, the implementation of digital twins in urban flooding mitigation still faces challenges such as complexity and cybersecurity [13]. Therefore, several collaboration solutions have been advised, such as to create sophisticated statistics frameworks, set up uniformed standards, combine digital twins with new technology such as AI, integrate high-level machine learning methods, and to concentrate on digital twins and sustainability [13]. In addition, on coastal cities' urban flooding mitigation, there had been developments, but challenges still exist [13]. In particular, it has been suggested that the shift from 2-dimensional to 3-dimensional simulations require advancements [13].

5   Conclusion

Looking back at the research question "How can cities enhance their resilience to pluvial flooding through urban planning and policy measures?", this study investigated into two case studies of urban pluvial flooding, Zhengzhou "7.20" Flood and the Mumbai 2005 Flood, looking at the causes of the incidents, analysis of the issues exposed during the disasters, and suggested potential solutions. The key analysis in the study is that both cases were caused by similar reasons and similar solutions in terms of management, infrastructure, environment, and education are required. It is also suggested that innovative flood mitigation strategies, from the structural sponge cities and gray-green infrastructure to the smaller rescue facilities and devices, can increase mitigation efficiency significantly. This study provides some future references towards the common issues of the two cities and urban pluvial flooding mitigation strategies. However, this study has weaknesses in terms of depth and scope, as it only compared the cities Zhengzhou and Mumbai, and did not include comparisons of other cities on other continents. To improve these shortcomings, future studies could take a deeper analysis into the cases of Zhengzhou and Mumbai, or perhaps analyze from a new perspective, and to compare more cities which experienced urban pluvial flooding in other parts of the world. By conducting this research into cities, it is possible to make future cities more resilient towards urban pluvial flooding and a better urban future could be built.

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