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FLOOD IMPACT ASSESSMENT UNDER CLIMATE CHANGE SCENARIOS IN CENTRAL TAIPEI AREA, TAIWAN

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ABSTRACT

Providing effective information regarding flood control for responding climate change is essential to future flood risk management for cities. This study simulated and assessed the impacts of flooding for future climate change scenarios in Taipei city, Taiwan. We modelled rainfall events, generated by general circulation models, with different return periods. The flood extents and damage in the Central Taipei Area for the A1B climate change scenarios were compared to the ones, caused by the rainfall events with same return periods, without climate change (baseline scenario). The proposed approach provides potential flooding maps and flood damage assessment for climate change scenarios as useful information for flood risk management in urban areas.

KEYWORDS

Climate change; flooding potential maps; hydraulic modelling.

1. INTRODUCTION

Flooding often causes both tangible and intangible damage. Many countries have endeavoured to improve their understanding of flooding such that decision makers can adopt adequate measures to reduce flood damage (James & Hall,1986). The effectiveness of these alternatives is usually evaluated through the reduction of risk after implementing the measures.

The spatial and temporal distributions of risk are typically non-homogenous. To investigate risk in a large area, we need to understand how the hazard and damage can vary temporally and spatially. Field survey or remote sensing, during or after an event, or computer modelling are often applied to assess flood damage. White (1945) was among the first researchers to develop and apply depth-damage curves (DDCs) to represent flood damage. White (1964) developed to synthetic DDCs through a hypothetical analysis. Some studies combined the loss estimation model with flood inundation model to estimate the flood damage (Dutta et al. 2003; Smith, 1994). McBean et al. (1988) argued that flood damage functions should include other flood damage influencing factors, such as the existence of effective, timely flood early warning, duration of flooding, and flood velocity, and suggested correcting the flood damage based on weighted DDCs; in contrast, Grigg (1996) thought DDCs should be applied to estimate damage without any correction for these additional factors.

In Taiwan, the National Science and Technology Center for Disaster Reduction (NCDR) has established the national flood potential database (Chen et al., 2006), which was aimed to help the government developing flood disaster mitigation strategies. Nevertheless, the flood potential information only indicates possible locations of flood hazard under certain scenarios. A further investigation is required to convert hazard information into risk, by taking the effect of climate change into account, such that the decision makers can easily determine and prioritize the strategies to prevent hazards and mitigate the impacts.

2. CASE STUDY AREA

Taipei City is located at the downstream floodplain of the Danshuei River Basin. The Digital Elevation Model (DEM) of Taipei City shown in Figure 1 displays that the northeast region is mountainous with elevation above 400m, the southeast and south areas have few hills, and the northwest part is alluvial floodplain with elevation below 5m. The Danshuei River and its tributary, the Sindian River, flow along the west boundary of Taipei City. Another tributary, the Keelung River, passes through Taipei City from east to west and converges into the Danshuei River.

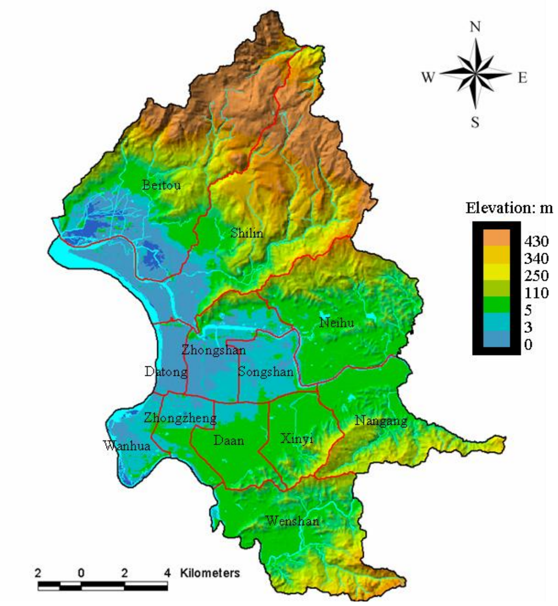


Figure 1 Digital Elevation Model, river system, and administrative districts in Taipei City

Taipei City developed quickly between 1968 and 1991, which consequently attracted more investment and residents. The population rose fast and reached the peak 2.72 million in 1991. Table 1 lists the land zoning for urban development planning of Taipei City. Only 134 km^2 is flat land suitable for urban development. The remaining areas are covered by hills, slope land and low-lying land, which were not adequate for urbanisation.

Table 1 Land zoning of the Taipei City based on urban development plan

Land Zoning		Area (ha)	Total area (ha)
For urban development	Residential zone	3,837	13,394
	Industrial zone	452	
	Commercial zone	919	
	Public facilities zone	7,123	
	Others*	1,063	
Not for urban development	Agricultural and scenic zones	804	13,786
	Conservation zone	11,351	
	Water covering zone	1,631	

** Including Administrative zone, cultural and education zone, zone for specific purposes, airport, recreation zone and others*

High raised levees were built along the banks of rivers in order to protect the Central Taipei Area (CTA) from the 200-year flood. The high density of houses alongside the banks of the Danshuei River prevented the broadening plan. Therefore, utilizing flood diversion, the Erchong Floodway was constructed to mitigate the floods of Sindian River and Dahan River.

The storm sewer system, shown in Figure 2, is composed of 26 main drainage networks which were designed for a rainfall of 5-year return period. During storm events, the water stages in rivers are typically higher than the stages of storm sewer and overland flows. Draining the surface runoff by gravity is not possible such that pumping stations were constructed at the outlets of drainage networks. The total capacity of the pumping stations is around 840 m^3/s. Although the CTA is protected against the river flooding as large as 200-year return period, surcharging from storm sewers may cause serious inundation if the precipitation is more than 5-year return period. Based on earlier studies (Hsu,1992), Manning's roughness coefficient had been calibrated by land use. The grid size of the inundation model is 40 m x 40 m.

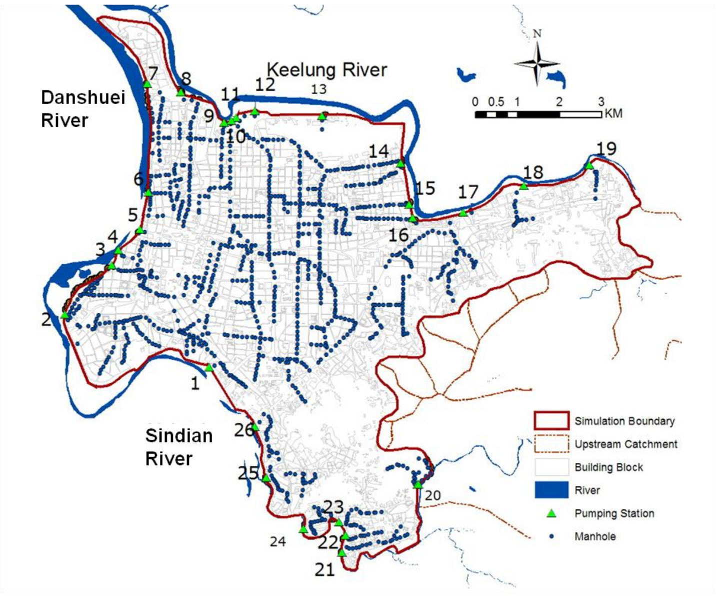


Figure 2 The storm drainage system in the Central Taipei City

3. METHODOLOGY

3.1 Modelling tools

This study is part of the Collaborative Research of Flood Resilience in Urban Areas (CORFU) and we adopted the modelling framework developed within CORFU for flood impact assessment. The DHI's MIKE FLOOD model was applied to hydraulic modelling in this study. The MIKE FLOOD contains various modules for solving different hydrodynamic problems, including rainfall-runoff, pipe flow, overland flow, pollution transport, etc. The 1D flow dynamic in sewer networks is solved by the MIKE URBAN while as the 2D overland flow is simulated by the MIKE 21. The 1D sewer and the 2D overland flows are coupled to simulate the complex flow movements between the drainage system and the ground surface in urban environment. The modelling results from the MIKE FLOOD can be directly fed in to the tool developed by Hsu et al. (2012) to estimate the damage of corresponding flood events.

3.2 Model verification

On 16 and 17 September 2001, Typhoon Nari swept through Taiwan with a historical-high rainfall record in northern Taiwan. The torrential rainfall caused the most serious flood damage in Taipei for decades. The flash flood of the Keelung River flowed from a levee gap near the pumping station No. 19 and flooded the downtown Taipei. Many pumping stations were submerged by flooding water, and were paralysed. Figure 3 shows the flooded areas, which are more than 30 cm in water depth marked with dark colour, released by the Taipei City Government (2001).The lowlands along the Keelung River were almost entirely inundated. Thousands of building basements and the two subway systems, the Taipei Rail Transit System and the Mass Rapid Transit System, were filled by the deluge. The total amount of damage was estimated to be 45.34 million USD (Chang, 2004). The hourly rainfall records of the gauges nearby the CTA were used in numerical simulation. The simulated flooded area shown in Figure 4 is close to the surveyed area.

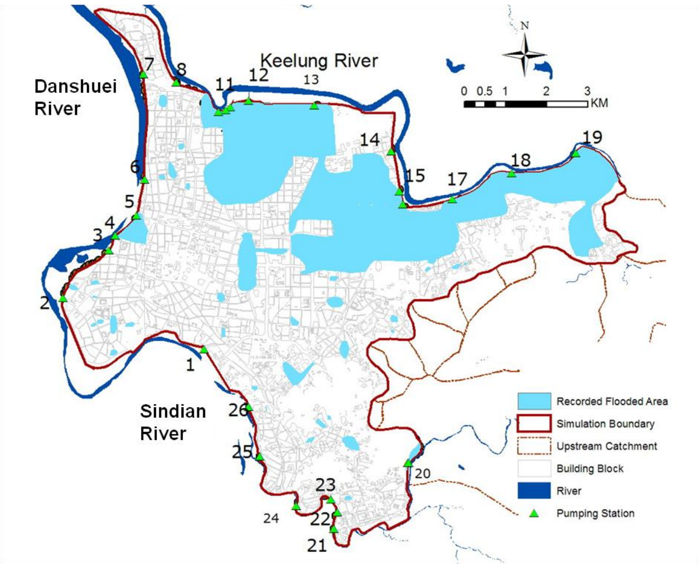


Figure 3 Investigated flooded areas of typhoon Nari in CTA

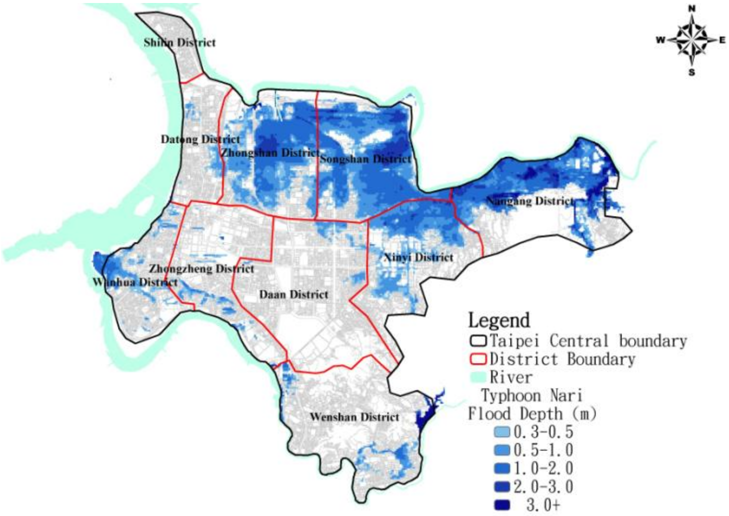


Figure 4 Simulated flooded areas of typhoon Nari in downtown Taipei

3.3 Precipitation frequency analysis

According to the government report (WRA, 2011, we chose the design rainfall of the Taipei station with return periods of 10, 25, 100 and 200-year, as shown in Table 2, as the rainfall input of urban flood model. Based upon the report, GCM model was adopted to simulate CO2 emission under difference scenarios. The adjustment factors of hourly rainfall for future climate change scenarios to baseline in the period of 2020-2039 are shown in Table 3. The rainfall depth and the adjustment factors are applied to of design rainfall to generate the new hyetographs that represent the rainfall patterns under the future climate change scenarios.

Table 2 Rainfall depth (mm) for different durations and different return periods at Taipei Station

Duration	Return Period (year)									
(hr)	1.1	2	5	10	20	25	50	100	200	500
24	105.2	167.2	247.8	305.7	362.2	380.2	435.7	490.7	545.3	616.9
48	135.6	199.3	295.7	368.3	440.7	464.1	536.4	608.8	681.0	776.6
72	153.1	219.2	321.7	399.4	477.3	502.4	580.4	658.4	736.4	839.6

Table 3 Climate Change factors for hourly rainfall under different return periods

Scenario	Return Period (year)							
	2	5	10	20	25	50	100	200
A2	1.21	1.18	1.17	1.17	1.17	1.17	1.18	1.20
A1B	1.14	1.12	1.12	1.12	1.12	1.13	1.13	1.14
B1	1.05	1.03	1.03	1.03	1.03	1.03	1.03	1.04

4. MODEL APPLICATION

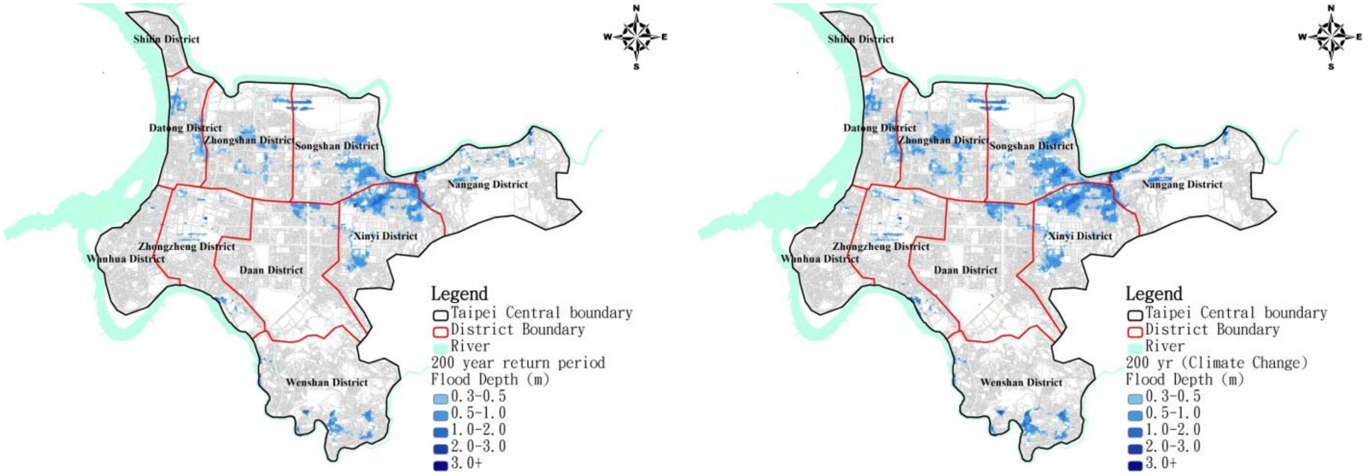
4.1 Flood hazard assessment

We simulated the design rainfall events with return periods of 10, 25, 100 and 200-year for both baseline and A1B scenarios, assuming no urban growth. The water depth 0.3m was used to illustrate the flooded area. The flood extents, as shown in Table 4, of 10 year event for the baseline and the A1B scenarios were 101 and 135 ha, respectively. The flooding area for the A1B climate change scenario was 33% more than the baseline scenario, due to the 12% increase of total rainfall for the 10 year return period event. The maximum change of flooding extents, which was 42%, between the baseline and A1B scenarios occurred for the 100 year event, caused by 13% increase of total rainfall. For the 200 year event, although the total rainfall was 14% more for the A1B scenario, the increased flood extent was only 39%. It was due to the total rainfall of baseline scenario had exceeded the design standard and resulted in extensive flooding area. Although the A1B scenario had 13% more of total rainfall and caused 205 ha increase in flooding area, the relative change of flood area was less than the 100 year event, because the baseline scenario had a larger flood area.

Figure 5 shows that, for the 200 year event, the flooding areas in Zhongshan, Songshan and Xinyi districts increased more significantly than other districts for the A1B scenario. The areas, shown in Table 5, increased by 79 % In the Zhongshan district, 59% in the Songshan district, and 16% in the Xinyi district.

Table 4 Flood area and percentage with different return periods in CTA

Return period	Flooded Area (ha)		Relative increase of flooded area
(year)	Baseline	A1B scenario	
10	101	135	33%
25	191	266	39%
100	385	548	42%
200	526	731	39%



baseline climate change

Figure 5 Flood map of 200-year return period under baseline and climate change conditions

Table 5 Flood area with different Districts in CTA

Districts	Flooded Area (ha)	
	Baseline	A1B scenario
Wanhua	2.24	6.08
ZhongZheng	22.72	35.84
Daan	26.24	37.92
Wenshan	45.76	57.92
Xinyi	159.04	184.32
Nangang	52.80	68.00
Songshan	103.36	164.16
Zhongshan	65.12	116.80
Datong	45.44	55.36
Shilin	3.20	4.48
Total	525.92	730.88

4.2 Tangible damage assessment

We considered that human activities, which are related to the types of land use, are the major factor that affects the level of loss once a flooding is occurring. Wang (2003) collected the data of a field survey from the flooded areas in Taipei city, and of flood loss claims for tax relief from the government revenue office after a major typhoon event in 2001. Wang associated the damage information with the land use types, which were classified into residential, commercial (retailer, service), industrial (manufacturing, wholesaler) and cultural zones, and developed the DDCs shown in Figure 6.

We evaluated the flood damage for both climate scenarios and different return periods using the DDCs and the flood maps as mentioned in the previous section. Figure 7 shows the flood damage map for 200 year event of the baseline. There is obvious flooding damage in the Datong, Zhongshan, Songshan and Xinyi districts because these districts have more flooding areas than others. The Xinyi district has large business and commercial zones such that the flood damage is the worst.

To evaluate the increase of flood impact due to climate change, we compared the hydraulic modelling and damage assessment results. The simulated flood area are summarised in five depth groups, and Table 6 shows that flood areas for the 200 year event of the A1B scenario in all groups are higher than the areas for same return period event of the baseline scenario. Table 7 shows the total direct flood damage of different return period events in the CTA for both the baseline and the A1B scenarios. The climate change could increase the direct flood damage by 8%, 19%, 24% and 25% for 10, 25, 100, 200 year events, respectively.

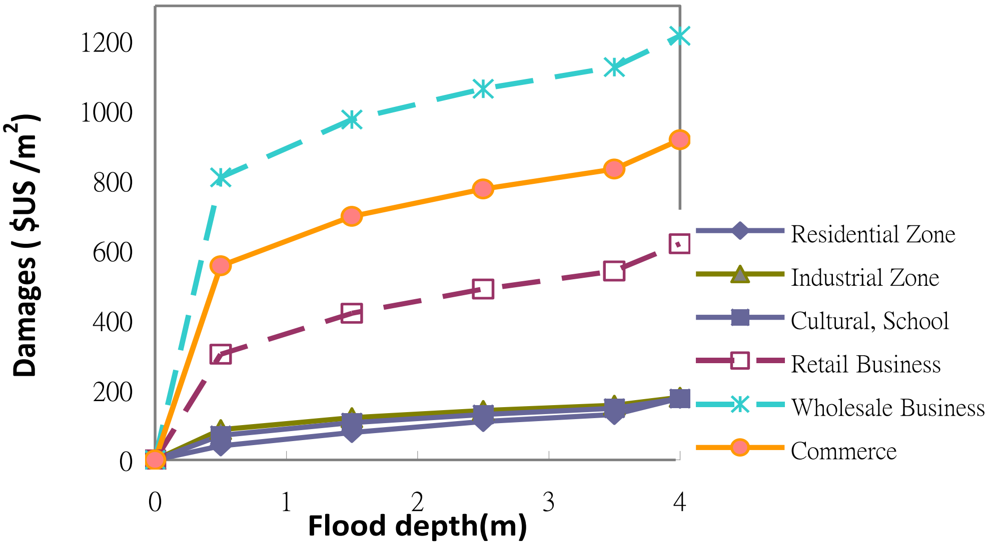


Figure 6 Depth-damage curves for residential, commercial, industrial and cultural zones in Taipei City (Wang, 2003)

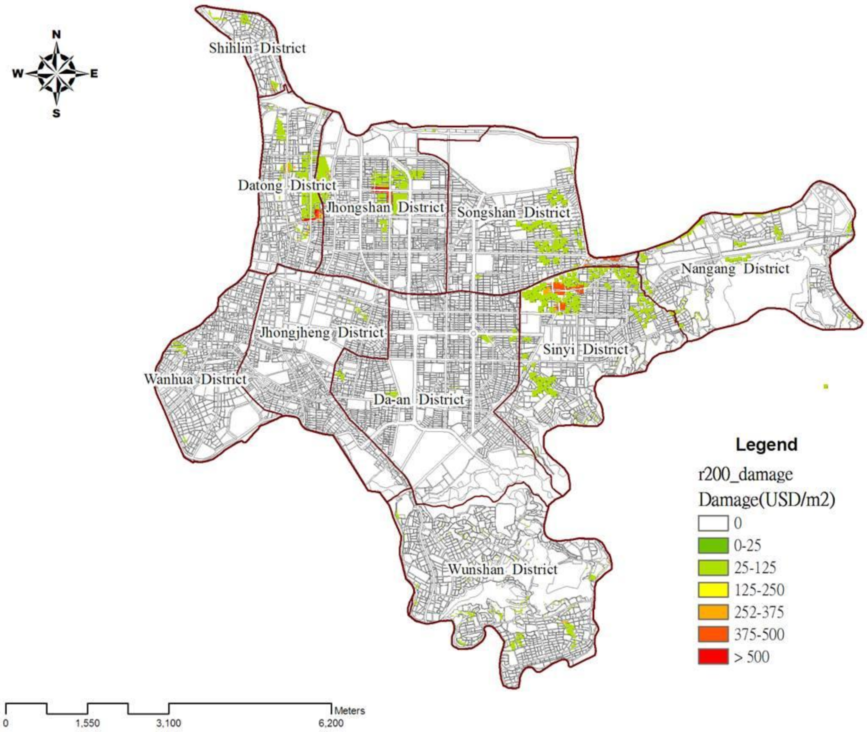


Figure 7 Flood damage map with 200-year return period

Table 6 Flood area with different depth of 200 year event in CTA

Flood depth (m)	Flooded area (ha)		Relative increase of flooded area
	Baseline	A1B scenario	
0.3-0.5	284.00	366.24	29%
0.5-1.0	207.52	304.96	47%
1.0-2.0	30.08	52.80	76%
2.0-3.0	2.24	4.16	86%
3.0+	2.08	2.72	31%
Total	525.92	730.88	39%

Table 7 The Total direct flood damage with different return periods in CTA

Return period (year)	Total direct damage (million USD)		Relative increase of damage
	Baseline	A1B scenario	
10	32.5	44.7	38%
25	63.4	92.7	46%
100	135.7	198.1	46%
200	194.6	279.4	44%

5. CONCLUSIONS

In the study, we compared the pluvial flooding extents and damage of the CTA under the baseline and the A1B climate scenarios. The hydraulic modelling was carried out by using the DHI MIKE FLOOD model, which integrates the 1D sewer network and the 2D overland flow models. The flood damage was evaluated using the hydraulic modelling results and the CORFU flood damage assessment tool. Rainfall events with different return periods for both the baseline and the A1B scenarios were adopted for modelling. The results show that the flooded area could be up by 40% and the damage would be 37.5 – 45% more due to the increased rainfall due to the climate change. This methodology can be combined with envisaged changes in urbanisation and with any resilience measures, to analyse possible future impacts more comprehensively.

6. ACKNOWLEDGEMENT

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