FLOOD RISK ASSESSMENT OF CLIMATE CHANGE ADAPTATIONS IN TAIPEI CITY

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Abstract- Land use change due to the population growth and urban development causes the impact on urban drainage water infrastructure. As a result, the severe flooding events happened in the recent years. The traditional structural measures are difficult to reconstruct in the existed urban area. Urban floods endanger the people of casualties and causing serious property losses. Therefore, the other flood measure using adaptation strategies of risk assessment in urban area becomes an important issue. In this way, a series of alternative plans were studied and compared by the flood risk assessment to get suitable prevention and adaptation in order to reduce the impact of disasters. In this paper, the adaptations for climate change are green roofs and detention ponds installation which can reduce the peak discharge and delay time occurring storm water runoff. The 2D inundation model is employed to calculate water depth in cases of the adaptation and climate change. Furthermore, the flood risk assessment of the Taipei city of the A1B scenario for climate change by Intergovernmental Panel Change is simulated.

Keywords- Climate change, adaptation, green roofs, risk assessment

I. INTRODUCTION

Flooding often causes many impacts, including damage to individual properties and to the wider economy. They are among the most recurring and devastating natural hazards, impacting upon human lives and causing severe economic damage throughout the world [8]. It is understood that flood risks will not subside in the future, and with the onset of climate change, flood intensity and frequency will threaten many regions of the world [7]. Flood hazard is expected to increase in frequency and severity, through the impacts of global change on climate, severe weather in the form of heavy rains and river discharge conditions [3].

Many countries have endeavored to improve their understanding of flooding such that decision makers can adopt adequate measures to reduce flood damage [5, 15]. The effectiveness of these alternatives is usually evaluated through the reduction of risk after implementing the measures.

Green roof is effective measure to intercept rainfall and reduce the runoff to avoid flooding. Scholz-Barth [9] shows that the installation of 10-15 cm green roofs could keep 75% of annual rainfall in Chicago, Philadelphia and Portland in US. Carter and Rasmussen [1] found that the green roofs have advantage performance of detention in relative weak rainfall; other research also represent the efficiency of green roofs depends on the intensity of rainfall event [6, 11].

White developed to synthetic depth-damage curves (DDCs) [13] through a hypothetical analysis to represent flood damage. Some studies combined the loss estimation model with flood inundation model to estimate the flood damage [14]. McBean et al. 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 [9].

In this paper, we applied the adaptation of green roofs and detention ponds to evaluate the flood impact under current and future climate conditions.

II. METHODOLOGY

2.1 Flood Hazard Analysis

To evaluate the flood hazard of a flood adaptation measure in the future, a 2D inundation model [2] was applied for the flood situations of both current and future climate conditions.

$$\frac{\partial d}{\partial t}+\frac{\partial (ud)}{\partial x}+\frac{\partial (vd)}{\partial y}=q \tag{1}$$

$$-\frac{\partial h}{\partial x}=u\left[\frac{n^2\sqrt{u^2+v^2}}{d^{4/3}}\right] \tag{2}$$

$$-\frac{\partial h}{\partial y}=v\left[\frac{n^2\sqrt{u^2+v^2}}{d^{4/3}}\right] \tag{3}$$

where Eq. (1) is the continuity equation, and Eq. (2) and (3) are momentum equations in Cartesian horizontal directions; d is the depth of flow [m]; h is the water stage [m]; u and v are the velocity component in x and y directions [m/s]; q is the source or the sink per unit area [m/s], and n is Manning's roughness [s/m$^{1/3}$].

The Storm Water Management Model (SWMM) [4] was adopted to solve the sewer system. The discharges drained by pumping stations are considered as the lateral outflows of the model, and the surcharges of manholes are regarded as point sources in the model. The average flood depth of each village is used for the flood hazard categorization,

which is based on the flood depth-induced level and shown in Table 1.

Table .1 Flood hazard categorizations

Hazard zone	Hazard Level	Inundation depth (m)
Very low	1	0.0 - 0.3
Low	2	0.3 - 0.5
Medium	3	0.5 - 1.0
High	4	1.0 - 1.5
Very high	5	Above 1.5

2.2 Vulnerability Analysis

The methodology used to assess the social vulnerability index (*SVI*) is based on selected sets of indicators for the population feature, rescue equipment and placement agency. These indicators are gathered by questionnaire investigation and shown in Tables 2. The weighting factor of each indicator is obtained by Analytic Hierarchy Process (AHP).

The procedure for calculating *SVI* starts by converting each identified indicator into a normalized and dimensionless number (from 0 to 1) using its mean and standard deviation. Eq. (4) shows the expression used for normalization.

$$Z = \frac{(x - M)}{SD} \tag{4}$$

where Z represents the normalized value of the indicator, x is indicator value of each village, M is the mean value, SD is standard deviation.

$$SD = \sqrt{\frac{\sum (x - M)^2}{n - 1}} \tag{5}$$

where n is the total number of villages.

Eventually, Social Vulnerability (*SV*) is computed as a summation of each weighted normalized value.

$$SV = k_1 \cdot z_1 + k_2 \cdot z_2 + \ldots + k_n \cdot z_n \tag{6}$$

where k_i represents the weighting factor of the indicator.

Finally, the *SVI* can be obtain by Eq. (7) and categorized into 5 levels (Table. 3)

$$SVI = \frac{SV - SV_{\min}}{SV_{\max} - SV_{\min}} \tag{7}$$

Table .2 Indicator of vulnerability

	Indicator	Weighting factor k_i
population feature	People aged 65 above	+0.0745
	People aged 14 under	+0.0618
	Elderly living alone	+0.1791
	Disabled people	+0.1577
rescue equipment	Rubber boat	-0.0553
	Fireman	-0.1208
placement agency	Asylum	-0.1630
	Nursing home	+0.1878

Table .3 SVI categorizations

SVI zone	SVI Level	SVI value
Very low	1	0.0 - 0.2
Low	2	0.2 - 0.4
Medium	3	0.4 - 0.6
High	4	0.6 - 0.8
Very high	5	0.8 – 1.0

2.3 Flood risk Analysis

The term risk has different meanings. Risk might be defined simply as the probability of a hazard contributing to a potential disaster. Therefore, with regard to natural disasters, risk can be determined by hazard and vulnerability.

In this study, flood risk is classified into 5 level (Table 4) and the risk matrix is used to evaluate the flood risk based on semi-quantitative analysis in which the flood hazard and social vulnerability index was used to defined the risk level shown in Table 5.

Table .4 Flood risk categorizations

Risk zone	Risk Level
Very low	1
Low	2
Medium	3
High	4
Very high	5

Table .5 Flood risk matrix

Flood hazard	Social vulnerability index				
	1	2	3	4	5
1	1	1	2	3	3
2	2	2	3	4	4
3	3	3	4	4	5
4	4	4	5	5	5
5	5	5	5	5	5

III. MODEL APPLICATION

3.1. Study area

Central Taipei City is located at the downstream floodplain of the Danshuei River Basin. Fig. 1 shows the southeast region of Central Taipei City is mountainous; the other part is alluvial floodplain with elevation below 10 m. Central Taipei City developed quickly between 1968 and 1991, which consequently attracted more investment and residents.

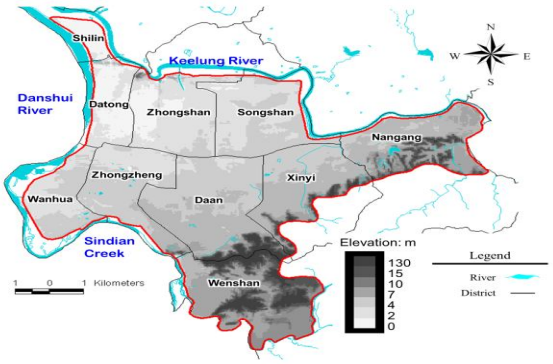


Fig.1. Topography of Central Taipei City

3.2. Precipitation scenario

According to the government report by the Water Resources Agency, Taiwan [12], we chose the 24-hour designed rainfall of Taipei station with return periods of 10-, 25-, 100-, and 200-year to serve as the rainfall input of 2D inundation model. According to the report, the rainfall under different climate change scenario can be obtained by means of GCM model. The total rainfall of baseline and future climate change scenario (A1B) in the period of 2020-2039 are shown in Table 6. The total rainfall is applied to generate the new hyetographs that represent the rainfall patterns under the future climate change scenarios.

Table .6 Designed Rainfall of baseline and climate change scenario

Return Period(year)	Baseline(mm)	A1B(mm)
10	305.73	342.42
25	380.24	425.87
100	490.75	554.55
200	545.35	621.70

3.3. Green roof experiment

The settlement of green roof experiment in this study is as show in Fig. 2. Total thickness of 8cm, 15cm and 20cm. are implemented to evaluate the green roof efficiency. The slope of roof is 1, 3 and 6 degree depend on the design protocol in Taiwan. The optimum detention capacity is obtained from the experiment which is shown in Table. 7. In this study, the 20cm green roof can maintain about 57.92 mm/m^2 rainfall and this result were adopted to evaluate the green roof effect.



Fig.2. Side view of experiment

Table .7 Optimum design of green roof

Cover	Grass
Thickness	20 cm
Slope	1 degree
Material ratio	20% Peat 80% Perlite
Total loading	89.70 kg/m²
Detention depth	57.92 mm/m²

3.4. Adaptation strategy

According to the guideline for future urban planning of Taipei City Government, the regulating outflow discharge of park and school is 1.73x10-5 m^3/s/m^2, equivalent to 62.8 mm/hr. The hourly rainfall exceeds 62.28 mm/hr under climate change will be hold and discharge in the next hour which rainfall is less than 62.8 mm/hr to avoid the flood damage caused by peak rainfall.

The optimum detention capacity of green roofs is 16.20 mm/m² which is obtained by experiment with different material settings. The 28.3% of total area of Taipei City is able to install green roofs to reduce the designed rainfall. Therefore, 28.3% of hourly rainfall will be captured by green roofs until total captured rainfall accumulated to 16.2mm.

The original and adapted rainfall of A1B scenarios are listed in Table 8. It is noted that the 16.2mm of rainfall is reduced by green roofs from the beginning and the peak rainfall captured by park and school are 6.57mm、23.35mm、70.78mm、101.97mm of 10-, 25-, 100-, and 200-year return periods. The shadow area represents the rainfall which is adjusted by adaptation strategies.

IV. RESULT AND DISCUSSION

The simulation result of climate change scenario is list in Table 9. The inundation area of 10 year return period is 807.99 ha which is 11.7% of study area and decreased to 326.2 ha under adaptation strategy. The decreased ratio of inundation area is 1.0, 1.1, 6.6 and 11.2 of 10-, 25-, 100-, and 200-year return periods, respectively. The result shows that the adaptation strategy of this study can reduced inundation impact, especially in high return period.

Social vulnerability Index of A1B in 2039 indicates higher vulnerability in Shilin, Datong, Wanhua and Wenshan District on account for the variation of age composition, insufficient fire budget and members, also the lack of shelters. (Fig. 3)

The high risks of 200-year return period were concentrated in Zhongshan, ZhongZheng and Wunshan District, otherwise, obvious risk variations occurred in Songshan, Xinyi, and Nangang District.

Flood risks of 200-year return period were more severe than others whether the adaptation was applied or not. Nevertheless, flood risks were apparently reduced after adaptation

CONCLUSION

The decreased ratio of inundation area in 100-, and 200- year return period were 6.6 and 11.2 %. The results show that the adaptation strategy of this study can reduce inundation impact, especially in higher return period.

Although the higher vulnerabilities appear in Shilin and Wanhua District, but the flood risks didn't increase with return periods. In contrast, the flood risks increased in Zhongshan, Datong and Songshan District which have higher flood hazards.

Green roofs and detention pond were effective to intercept rainfall and reduce the runoff to avoid flooding in urban area.

ACKNOWLEDGMENTS

The authors appreciate the Ministry of Science and Technology for the grant support (MOST 105-2625-M-002-023).

Table .8 Adapted Rainfall of climate change scenario

	Return Period (year)							
	10		25		100		200	
Hour	A1B	Adapted	A1B	Adapted	A1B	Adapted	A1B	Adapted
1	2.91	2.09	3.62	2.60	4.71	3.38	5.28	3.79
2	3.77	2.70	4.68	3.36	6.10	4.37	6.84	4.90
3	2.05	1.47	2.55	1.83	3.33	2.39	3.73	2.67
4	3.87	2.77	4.81	3.45	6.27	4.49	7.02	5.04
5	5.85	4.20	7.28	5.22	9.48	6.80	10.63	7.62
6	5.44	3.90	6.77	4.85	8.82	6.32	9.88	7.09
7	6.33	4.54	7.88	5.65	10.26	7.36	11.50	8.25
8	11.64	8.35	14.48	10.38	18.85	16.51	21.14	20.47
9	18.93	14.58	23.55	22.09	30.66	30.66	34.38	34.38
10	23.56	23.56	29.30	29.30	38.15	38.15	42.77	42.77
11	42.11	42.11	52.38	52.38	68.20	62.28	76.46	62.28
12	68.85	62.28	85.63	62.28	111.51	62.28	125.01	62.28
13	48.10	54.67	59.83	62.28	77.91	62.28	87.34	62.28
14	29.58	29.58	36.79	57.69	47.91	62.28	53.71	62.28
15	16.30	16.30	20.27	20.27	26.39	62.28	29.59	62.28
16	11.40	11.40	14.18	14.18	18.46	38.98	20.70	62.28
17	9.28	9.28	11.54	11.54	15.03	15.03	16.85	35.99
18	6.20	6.20	7.71	7.71	10.04	10.04	11.25	11.25
19	5.85	5.85	7.28	7.28	9.48	9.48	10.63	10.63
20	5.68	5.68	7.07	7.07	9.20	9.20	10.32	10.32
21	4.76	4.76	5.92	5.92	7.71	7.71	8.64	8.64
22	4.45	4.45	5.54	5.54	7.21	7.21	8.08	8.08
23	3.15	3.15	3.92	3.92	5.10	5.10	5.72	5.72
24	2.33	2.33	2.90	2.90	3.77	3.77	4.23	4.23
Total	342.39	326.2	425.88	409.69	554.55	538.35	621.7	605.52

Table .9 Inundation area of climate change scenario

	Return Period (year)							
	10		25		100		200	
Hour	A1B	Adapted	A1B	Adapted	A1B	Adapted	A1B	Adapted
0.3~0.5	318.48	261.15	465.88	426.65	864.37	601.89	1,053.74	545.05
0.5~1.0	489.51	474.31	493.35	506.16	690.56	530.46	850.14	762.91
1.0~1.5	0	0	140.21	87.12	298.48	267.77	406.57	334.02
1.5+	0	0	0	0	23.00	23.00	69.65	35.77
Total	807.99	735.46	1099.44	1019.93	1876.41	1423.12	2380.10	1677.75
Ratio(%)	11.7	10.7	15.9	14.8	27.2	20.6	34.5	23.3
Decreasing Ratio(%)	-	1.0	-	1.1	-	6.6	-	11.2

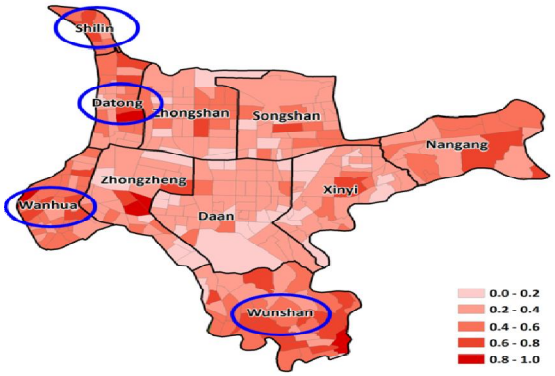


Fig.3. SVI map of Central Taipei City

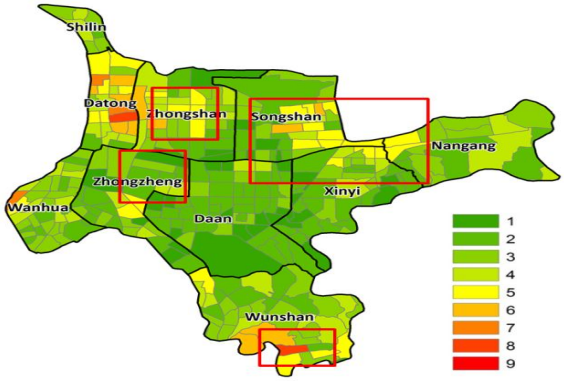


Fig.4. Flood risk map of A1B in Central Taipei City

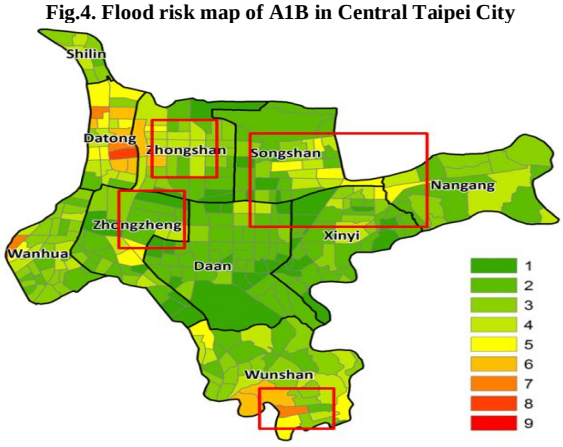


Fig.4. Flood risk map of adaptation of A1B in Central Taipei City

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