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Editorial introduction

Special issue on Environment Management and Spatial Planning

Guest Editors

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This special issue is a collection of papers presented in the 2017 Workshop on Urban Planning and Management held in Tokyo, Feb. 18-19, 2017. The fourteen papers have been selected to be published with IRSPSD International as two issues, which can be grouped around three pillars. Namely, Water dimension, Social dimension in urban study and Energy dimension in urban studies.

In this workshop, authors touched a variety of issues ranging from water quality index, urban flooding, public-private partnership for urban river management, rural to urban transitions, outdoor space transformation, community development, regional heritage and smart houses. The target areas span from China, Thailand, Bangladesh, Europe and Brazil as well. The research methodologies presented in this issue varied from field survey, data analysis to numerical simulation and software application. These studies contributed to better understanding of spatial planning and sustainable development from various perspectives. New insights gained from these works are significant, and they serve as fuel for further in-depth research in integrative urban planning and sustainable development. This selected papers in this workshop will be published in two issues.

The first issue includes papers on the two dimensions, which are water and energy. Sound water management is vital to well-beings of the society. Water quality has been a focal point in river management in recent years. Consequently, evaluating water quality is becoming increasingly important for policy makers, planners, academia, and other stakeholders to achieve sustainable development. In this special issue, [Zhang \(2017\)](#) compared the performance of a number of water quality index at different parts of the Liao River in Liaoning, China. Out of the four methods used, the Comprehensive Water Quality Identification (CWQII) is found to be the most suitable as they combine multiple information in one analysis. Results showed that pollution loading from factories such as petroleum is responsible for the low water quality in certain areas. It indicates that further work of water quality assessment methods needs to be carried out to improve and protect the water quality worldwide. On the other hand, flood disasters have been inflicting on people in many countries and regions, and are getting even more seriously under climate change. [Chanthamas, Anantasuksomsri, and Tontisirin \(2017\)](#) studied climate change adaptation with urban planning management to reduce urban floods in Pathumthani Province, Thailand. Based on the Sieve

Analysis and Geographic Information Systems techniques, the level of flood risk in Pathumthani was examined under climate change scenario. Specifically, comprehensive factors, including land cover change, are taken into account, weighed and scored for analysis. Three major high level risk areas in Pathumthani and an overall higher flood risk under climate change scenario are analyzed from the view angle of urbanization and urban sprawl.

Better water management requires the participation of all stakeholders. Along this line of thinking, [Guo \(2017\)](#) tried to illustrate the framework of Public Private Partnership (PPP) for water management through a case study of Chu River in Wuhan. In this case, Wuhan government and Wanda Group establish a partnership that manages the Chu River dynamically and achieves a sustainable win-win development mode. The achievement and mistake of the Chu River project was analyzed with the goal of presenting experiences of urban river management that can be applied in similar cases.

This issue also includes the work by [Zhou et al. \(2017\)](#), who investigated the irrigation water consumption, fertilizer utilization and soil quality in both Stevia and maize cultivating fields in order to explore the possibility of adopting Stevia as a new cash crop for sustainable agricultural management in Zhangye Oasis. Furthermore, [den Hartog \(2017\)](#) studied rural to urban transitions at Shanghai's fringes. Chongming Eco-Island was used as a case study to analyze the urban push on Shanghai's rural fringes while utilizing the Layers-Approach technique to see the relationship between the spatial planning and economic potentials. Based on the results, recommendations were made for minimizing the impact of urban development on the existing natural wildlife and residents in that area.

In addition, regarding energy dimension in urban study, energy efficiency and reduction of energy consumption are indispensable for sustainable urban development. [Puteri Fitriaty et al. \(2017\)](#) analyzed Photovoltaic (PV) installation potential on residential building envelope in equatorial region. It proposed a practical method for photovoltaic potential evaluation employing 3D insolation color rendering which can be easily implemented on the building design stage by building designers. It concluded that for optimal PV power generation, a simple roof design and a building form that avoids self-shading potential is highly recommended.

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Different methods for the evaluation of surface water quality: The Case of the Liao River, Liaoning Province, China

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Key words: Water Quality Index, Liao River, Water Quality Management

Abstract: The water-quality index is a grading system for presenting water-quality data and comparing water of varying quality. It can be used in water quality trend analyses and presents valuable information to policy makers, managers, and other nontechnical people. For exploring water quality and identifying the main pollution parameter in the lower reaches of Liao River, Single Factor Evaluation (SFE) method in the form of a Comprehensive Water Pollution Index (CWPI), the Nemerow-Sumitomo Water Quality Index (NWQI), and the Comprehensive Water Quality Identification Index (CWQII) method were used to evaluate water quality in lower reaches of Liao River, Liaoning province, China. The results proved that at Zhaoquan river and Wailiao river the water quality status was good, and Pangxiogou river and Qingshui river showed unsatisfactory water quality status. The major pollution indicator in lower reaches of Liao River was petroleum, and compared with the other assessment methods, CWQII was found to give more useful and objective information, and it is worth further promoting water quality inspections in lower reaches of Liao River. Finally, according to the distribution of industry in the Liao river basin, this study makes some relevant suggestions for sustainable development in the future.

INTRODUCTION

Water is a very important resource for living organisms and human society ([Huang, 2015](#)). Without water, existence of man would be threatened ([Danquah, Abass, & Nikoi, 2011](#)). The quality of deteriorating water has been a growing source of concern for the international community ([Gyamfi et al., 2013](#)). The issues of water quality have become a common challenge to many countries ([WEPA Secretariat \(Institute for Global Environmental Strategies \(IGES\), 2015](#)). In order to prevent water pollution, many countries have issued policies to address its sources, and one very significant link was the evaluation of water environment quality ([Ouyang, 2005](#)). In recent years in Asian countries, evaluation of surface water quality has become a critical issue ([Yan et al., 2015](#)). According to the Outlook issued by Water Environmental Partnership in Asia (WEPA), the evaluation methodologies applied in Asian countries can be divided into three types ([WEPA Secretariat \(Institute for Global Environmental Strategies \(IGES\), 2015](#)). The first type is the water

quality monitoring data that are directly compared to water quality standards, thus judging whether the water can be used. In Asia, this method has been used by Vietnam and Cambodia because it is simple and easy to utilize, but this is only a primary stage of water quality evaluation. The second type is used by countries like Korea, the Philippines and Japan, whose governments determine whether or not the quality of a water body satisfies the Environmental Quality Standard and is expressed as a percentage. The third type are countries like the People's Republic of China, Malaysia and the



Kingdom of Thailand, and involves categorizing monitoring sites based on the results of water quality testing and the sites are classified according to the water quality standard.

Figure 1. Water quality evaluation methodology in Asian countries

China began to evaluate surface water quality in the 1980s. The first environmental standard of surface water quality was issued in 1983 ([Wang et al., 2014](#)). After three revisions, a new standard was formulated in 2002 ([Pong, 2007](#)). According to the National Standard of Environmental Quality, the Ministry of Environmental Protection (MEP) issued technical specification requirements for environmental quality assessment of surface water in 2004 and 2012 ([The Ministry of Environmental Protection of the People's Republic of China \(MEP\), 2002](#)). In these technical requirements, the Single Factor Evaluation (SFE) method was used to evaluate surface water quality. However, because this method only considers the single most significant factor, the SFE method is limited in its ability to characterize the conditions of surface water quality ([Ji, Dahlgren, & Zhang, 2016](#)). Even when general water quality is improved, this method may not identify improvements in water quality, and cannot provide effective bases for formulating environmental protection rules and regulations ([Xu, Z.-X., 2005](#)).

Water quality evaluation is one of the basic tasks of an environmental protection administration, and researchers have designed numerous approaches for evaluating surface water quality. The comprehensive evaluation of water quality has attracted a lot of interest in recent years ([Xu, S., Wang, & Hu, 2015](#)). The pollution index method is a kind of water quality evaluation method stemming from the 1970s ([Prati, Pavanello, & Pesarin, 1971](#)), The pollution index methods include a single factor pollution index method and comprehensive pollution index method ([Abbasi & Abbasi, 2012](#)). [Liu et al. \(2011\)](#) used a pollution index method to evaluate the water quality in the coastal waters of Bohai and both Chemical Oxygen Demand (COD) and phosphate were main pollution factors. However, this method cannot judge water quality class according to Chinese national standards ([Yin & Xu, 2008](#); [Ban et al., 2014](#)).

The Nemerow-Sumitomo Water Quality Index method (NWQI) was put forward by Dr. Nemerow and Sumitomo in the 1970s ([Nemerow, 1974](#)). Until now, this method was also used for water quality evaluation of underground water by China's environmental protection department (GB/T 14848-93 n.d.). From 2015, the Guangzhou Environmental Protection Bureau started to apply the Nemerow-Sumitomo index of water quality evaluation for surface water. In a paper by [Xu, B., Lin, and Mao \(2014\)](#), the single factor method and Nemerow-Sumitomo index method were used to analyze the water quality of Taihu Lake. They found that the Nemerow-Sumitomo index method was more suitable to for reflecting the comprehensive situation of water quality. However, the overall water quality condition's classification is not identified by Nemerow-Sumitomo pollution index intuitively and cannot judge surface water quality when the water quality is worse than a class 5 ([Li, Y.-S. et al., 2009](#); [Ji, Dahlgren, & Zhang, 2016](#)).

In addition to the methods mentioned above, there are other methods, such as the principal component analysis method ([Ouyang, 2005](#)) and the fuzzy analysis method ([Gao & Jin, 2005](#)), however these cannot be used to determine whether the composite water quality allows for the environmental functions of surface water nor to identify which water quality parameters exceed the Chinese national standards, and cannot reflect the practical situation of river water quality in China ([Xu, Z.-X., 2005](#); [Ji, Dahlgren, & Zhang, 2016](#)).

[Xu, Z.-X. \(2005\)](#) proposed a water quality identification index method in 2005. This method can be used to judge whether water polluted by a single pollutant can meet the water quality evaluation requirements of current policies, and also judges comprehensive water quality ([Yan et al., 2015](#)). [Qun et al. \(2009\)](#) used this method to evaluate the water quality of Dagu River and found this method can be used to evaluate water quality qualitatively and quantitatively. [Hao et al. \(2013\)](#) used this method to assess the water quality of Jinchuan River, Beitang River, Qingan River and Xiyandapu River in Jiangsu. The main pollution factors were Dissolved Oxygen (DO), ammonia, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD5) and Total Phosphorus (TP).

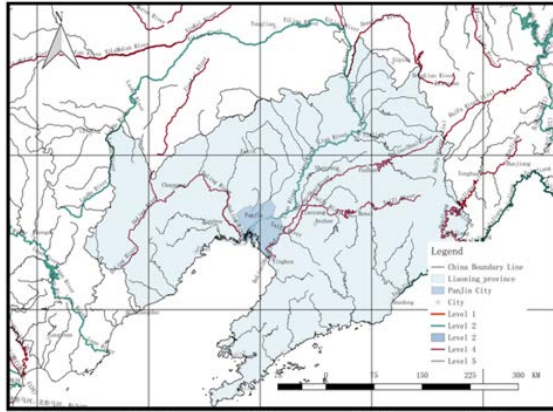
This study uses 11 monitoring sites in the lower reaches of Liao River basin. To compare the advantages and disadvantages of these methods and seek a better method fit for Liao River, an SFE-based Comprehensive Water Pollution Index (CWPI) method, Nemerow-Sumitomo index method, and Comprehensive Water Quality Identification Index (CWQII) method were all used to evaluate the water quality in the lower reaches of Liao River. The results of which may be helpful for water pollution governance of Liao River.

RESEARCH AREA AND DATA SOURCE

2.1. Research Area

The research area is Liao River, an important river in the Northeast of China (see Figure 2) ([Pavlovska, 2014](#)). Since the 1990s, Liao River has been seriously polluted as the development of urbanization and industrialization has grown ([Wei et al., 2009](#)). From 2005, due to the "Control Planning of Water Pollution in Liao River" ([Shao et al., 2006](#)), the water quality in Liao River has improved. However, compared with other rivers like Chang Jiang River and Zhujiang River, water quality in the Liao River basin has still been poor,

especially, in its lower reaches (Li, Y. L. et al., 2012). The reason is that there have been many pollutants in the industrial wastewater and domestic water from the upper reaches of the basin that have accumulated in its lower reaches (Ma et al., 2015). In this study, six parameters were monitored in 11 sections (see Table 1) from 2011–2013 downstream of Liao River in Panjin City (see Figure. 3). Three methods were used to assess water quality in the lower reaches of the Liao river system in Panjin City: an SFE-based Comprehensive

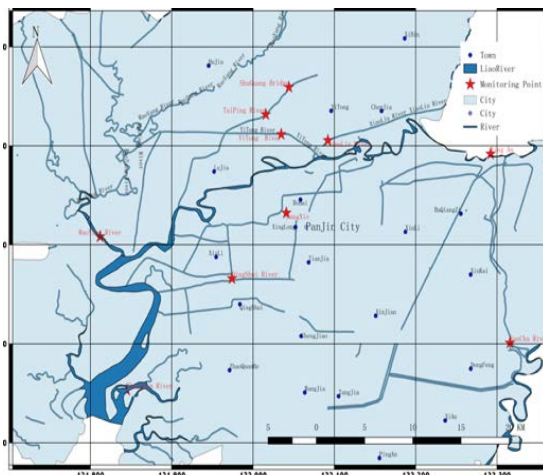


Water Pollution Index (CWPI) method, Nemerow-Sumitomo Water Quality Index method (NWQI), and Comprehensive Water Quality Identification Index method (CWQII) were used.

Figure 2. Lower Reaches of Liao River

Figure 3. Lower Reaches of Liao River

Table 1. Sampling locations of Liao River in Panjin City



Sample	Name	Latitude	Longitude
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A1	Xingan River	41.1918	122.292
A2	Shuguang River	41.2588	122.03416
A3	Zhaoquan River	40.953301	121.844699
A4	Sancha River	41.004205	122.418441
A5	Raoyang River	41.102409	121.82899
A6	Pangxie River	41.132216	122.040859
A7	Yitong River	41.192631	122.018654
A8	Xiaoliu River	41.202074	122.093107
A9	Taiping River	41.234874	122.013327
A10	Qingshui River	41.065906	121.974067
A11	Wailiao River	41.162663	122.371668

2.2. Data Source

Water quality data from 11 monitoring sites was collected between 2011 and 2013 from the Liao River basin. The municipal environmental department of local government's water quality parameters include COD, petroleum, BOD5, ammonia nitrogen, Total Phosphorus and the Permanganate Index. According to the goals of the 'Water Pollution Prevention Action Plan' proposed by China, the proportion of Class 3 water available should be higher than 70%. So this paper adopted the Class 3 criteria as the preferred water quality standard.

METHODS AND MATERIALS

For water quality evaluation, the SFE method is used according to the maximum membership class's principle (Ji, Dahlgren, & Zhang, 2016). This determines that if only one parameter exceeds the standard, all functions of the water body will be lost. The formula for the SFA method is:

$$F = F_a \max$$

F is the class of surface water, which is classified into classes 1 to (see Table 2). The value of the Surface Water Standard Concentration (The Ministry of Environmental Protection of the People's Republic of China (MEP), 2002) for each of the five classes is shown in Table 3. F_a is the class of parameter a and $F_a \max$ is the maximum class for all of the parameters (from classes 1 to 5).

Table 2. Water Environmental Quality Standard GB3838-MEP

Class I – Mainly applicable to the national nature reserves.
Class II – Mainly applicable to class A water source protection area for centralized drinking water.
Class III – Mainly applicable to a water source protection area
Class IV – Mainly applicable to water bodies for industrial water supply in which there is not direct human contact with the water.
Class V – Mainly applicable to agricultural water supply and landscape requirements.
Class V+ - Essentially unusable.

Data from: China's Ministry of Environmental Protection (MEP)

Table 3. Value of Surface Water Quality Standard Concentration in China (mg/L)

	Class 1	Class 2	Class 3	Class 4	Class 5
Permanganate Index (mg/L)	2.0	4.0	6.0	10.0	15.0
COD (mg/L)	15.0	15.0	20.0	30.0	40.0
BOD5(mg/L)	3.0	3.0	4.0	6.0	10.0
NH ₃ -N (mg/L)	0.15	0.5	1.0	1.5	2.0

TP(mg/L)	0.02	0.1	0.2	0.3	0.4
Petroleum (mg/L)	0.05	0.05	0.05	0.5	1.0

Data from: China's Ministry of Environmental Protection (MEP)

3.1. Comprehensive Water Pollution Index (CWPI)

The Single Factor Evaluation (SFE) method is used to create a Comprehensive Water Pollution Index (CWPI). The SFE (excluding DO) increases with the pollutant's concentration, and its equation is as follows:

$$I_a = \frac{C_a}{S_{oa}}$$

where the pollution index of water quality index a , C_a (mg/L), was the measured concentration of water quality index a , and S_{oa} (mg/L) was the concentration limit of water quality index a .

F_{cpi} referred to the arithmetic mean of n water quality indexes. The equation was as follows:

$$F_{cpi} = \frac{1}{n} \sum_{n=1}^n I_a$$

n is the number of selected pollutants. In this research $n=6$.

3.2. Nemerow-Sumitomo Water Quality Index (NWQI)

The Nemerow-Sumitomo Water Quality Index (NWQI) is a weighted-type water quality index (excluding DO) which takes into account the average and maximum, and its calculation formula is as follows.

$$F_{nwqi} = \sqrt{\frac{\max(I_a)^2 + \text{avg}(I_a)^2}{2}}$$

$$\text{avg}(I_i) = \frac{1}{n} \sum_{i=1}^n I_a$$

3.3. Comprehensive Water Quality Identification Index (CWQII)

As a relatively new method, the CWQII could be used to evaluate the water quality of surface water. The Single Factor Identification Index (SFII) is a basic part of the CWQII, and its equation was as follows (excludes DO).

$$P_{SFI} = P_1 P_2$$

Where P_1 is between 1 and 5, corresponding to its water quality, from Class 1 to 5.

When the index was not the index for dissolved oxygen (DO), the equation was as follows.

$$P_2 = \frac{C_a - S_{ab}}{S_{abmax} - S_{abmin}} * 10$$

C_a is the concentration of the a th water quality index, and S_{abmax} and S_{abmin} are the upper limit and lower limit of the concentration interval of Class b water in the a th index, respectively. The equation is as follows:

$$P_C = P_1 P_2 P_3 P_4$$

$$P_1 P_2 = \frac{1}{6} \left(P_{COD_{mn}} + P_{BOD_5} + P_{NH_3-N} + P_{Tp} + P_{petroleum} + \frac{1}{n} \sum_{a=1}^n P_a \right)$$

$P_{COD_{mn}}$, P_{BOD_5} , P_{NH_3-N} and P_{TP} are the P_{SFI} of COD, BOD5, NH₃-N and TP. a refers to other indexes incorporated in the comprehensive water quality evaluation.

P_a was the single factor identification index. P_3 refers to the number of water quality indexes that were worse than the water quality for functional areas in the urban water environment. If $P_3=0$, the indexes incorporated in the evaluation all meet the water quality standard for functional areas. If $P_3=1$, one index does not achieve the functional area standard. If $P_3=2$, two indexes do not meet the standard, and so on. P_4 was used to judge whether the comprehensive water quality was worse than that of water in a functional area. If the comprehensive water quality was better than that in a functional area, $P_4=0$. If the water quality exceeded the standards, then:

$$P_4 = P_1 - f_a$$

Where f_a refers to the water quality category for water in functional areas of the urban water environment. If $P_4=1$, the water quality is one level higher than the standard. If $P_4=2$, the water quality is two levels higher than the standard.

RESULTS AND DISCUSSION

4.1. Descriptive Statistics of the Water Quality

The descriptive statistics of the water quality are shown in Table 4 below. The average concentration of COD_{mn}, COD, BOD5, Petroleum, NH₃-N and TP were 7.78 (Class 4), 25.56 (Class 4), 6.29 (Class 5), 0.33 (Class 4), 1.19 (Class 4) and 0.18 (Class 3), respectively. For COD_{mn}, 97% of the samples were Class 3 and only 3% exceeded Class 4 (Class 5), The lowest concentration of COD_{mn} was 6.24 mg/L and the highest was 10.67mg/L. COD was worse than COD_{mn}, only 15% of the samples were Class 3 and 70% were Class 4, while 15% had Class 5 water quality standards. The lowest was 17.87mg/L and the highest was 36.63mg/L. For BOD5, 3% of the samples were Class 3, 49% were Class 4 and 48% were Class 5 water quality standards. The lowest concentration of BOD5 was 3.70mg/L and the highest was 8.67mg/L. For Petroleum, 0% of the samples were Class 3, 97% were Class 4 and 3% were Class 5. The lowest concentration of Petroleum was 0.16mg/L and the highest was 0.64mg/L. For NH₃-N, 49% of the samples were Class 3, 27% were Class 4 and 15% were Class 5. 9% were worse than Class 5. The lowest concentration of NH₃-N was 0.44 mg/L and the highest was 3.90mg/L. For TP, 3% of the samples were Class 1, 79% were Class 2, and 18% were Class 3. The lowest concentration of TP was 0.07mg/L and the highest was 0.63mg/L.

Table 4. Descriptive statistics for six parameters (mg/L)

	COD _{mn}	COD	BOD5	Petroleum	NH ₃ -N	TP
Number of samples	33	33	33	33	33	33
Average	7.78	25.56	6.29	0.33	1.19	0.18
Standard Deviation	1.02	4.95	1.38	0.11	0.67	0.10
Minimum	6.24	17.87	3.70	0.16	0.44	0.07
Maximum	10.67	36.63	8.67	0.64	3.90	0.63

4.2. Single Factor Evaluation (SFE) Method

Depending on the results of the SFE method (Figure 4), the level of water quality is determined by the worst index. All rivers in the Liao River basin were inferior, Class 4, and the worst water quality was found in the SanCha River (A4) in both 2012 and 2013, and Pangxieyou River (A6) in 2012. The water quality was worse than Class 5 because the surface water quality standard for the concentration of $\text{NH}_3\text{-N}$ was Class 5. In addition, the concentration of TP was Class 5 in Pangxieyou River (A6) in 2011. However, this method only considered the most prominent factor ($\text{NH}_3\text{-N}$) and other factors were weakened, not all factors were considered in the result of water quality evaluation.

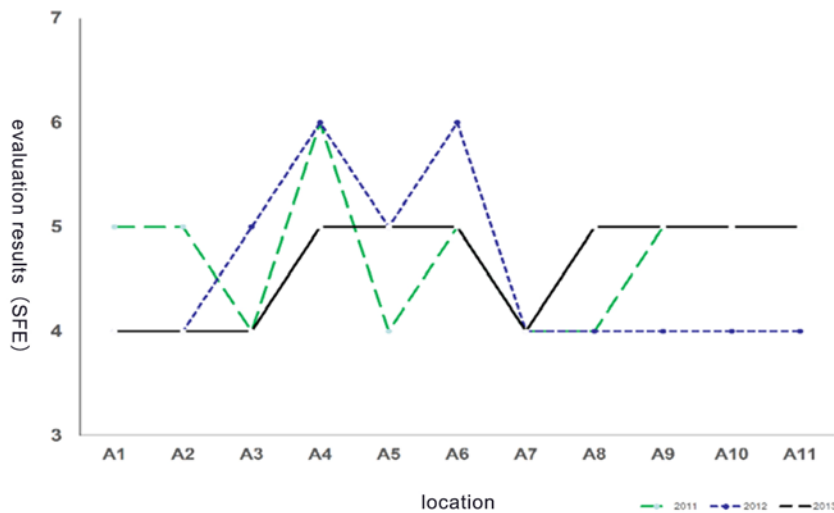


Figure 4. Single Factor Evaluation (SFE) method results

4.3. Comprehensive Water Pollution Index (CWPI) Method

Results of the Comprehensive Water Pollution Index (CWPI) are shown in Figure 5 below. These results show the period between 2011-2013. The comprehensive water quality in Pangxieyou River (A6) was the worst, however, according to the CWPI of Pangxieyou River (A6), the level of pollution lightened to a certain extent from 2011-2013 (the CWPI was 2.373, 1.803 and 1.482 in 2011, 2012 and 2013, respectively). The CWPI in Zhao Quan River (A3) was best, and in 2013 the CWPI of Zhao Quan River was 0.851.

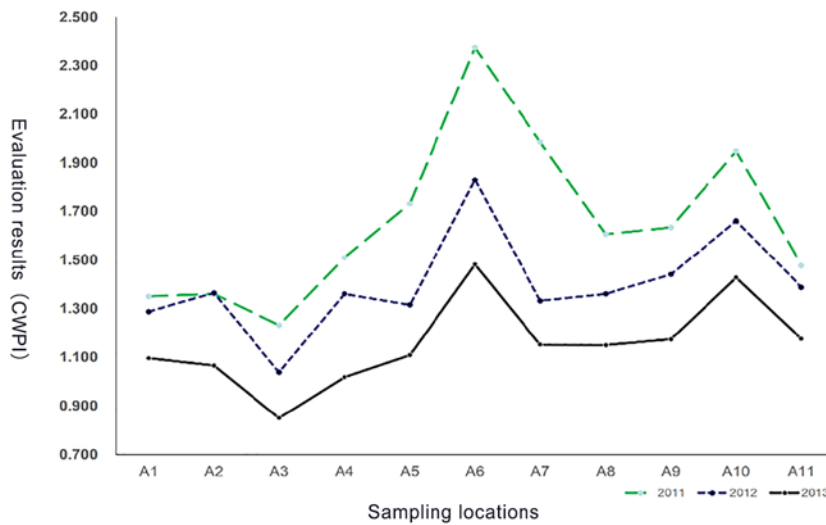


Figure 5. Comprehensive Water Pollution Index (CWPI)

Although the CWPI provides a comprehensive water quality status, this method could not determine the water quality classes according to the surface water environment standards. Moreover, because in the CWPI method all factors have the same contribution to the overall water quality, this method cannot reflect a genuine decrease of water quality.

4.4. Nemerow-Sumitomo Water Quality Index (NWQI) Method

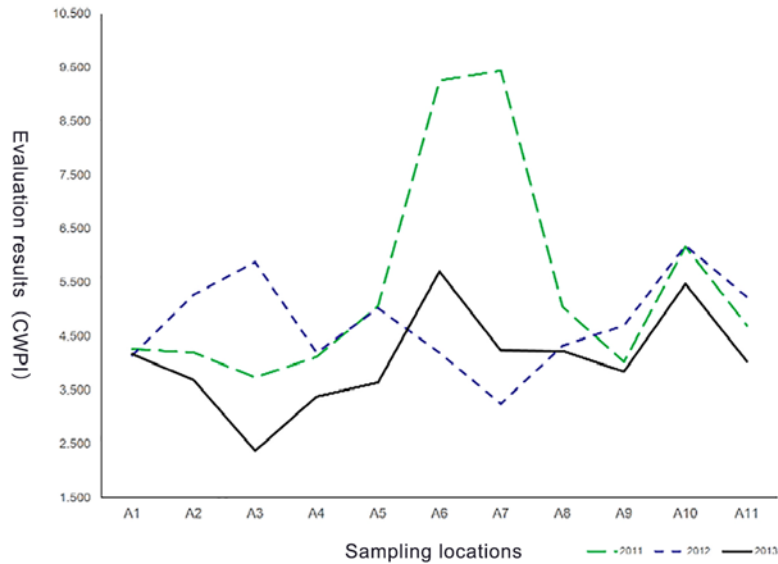


Figure 6. Nemerow-Sumitomo Water Quality Index

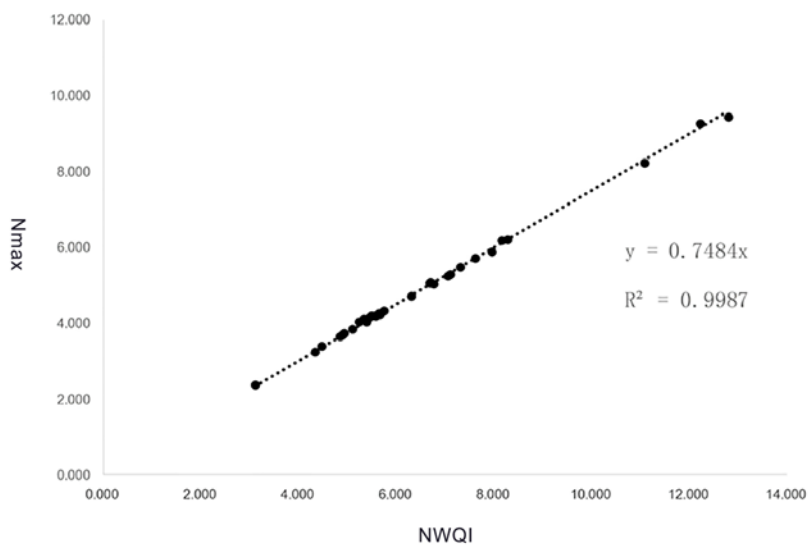


Figure 7. The correlation between Nmax and NWQI

The results of the NWQI are shown in Figure 6. Based on the results, the water quality index of YiTong River (A7) in 2011 was the worst and the water quality of Zhao Quan River in 2013 was the best (NWQI was under 1.0). Compared with the SFE and CWPI, the maximum and average factor contributions of all factors are considered in the NWQI. From the correlation seen between the maximum factor and Nemerow-Sumitomo Index in Figure 7, it can be seen that this method tends to overemphasize the influence of the maximum evaluation factor (N_{\max}). When one factor is much higher than the

others, the NWQI will be increased. Like the CWPI, this method could not determine the water quality classes according to the surface water environment standards.

4.5. Comprehensive Water Quality Identification Index (CWQII) Method

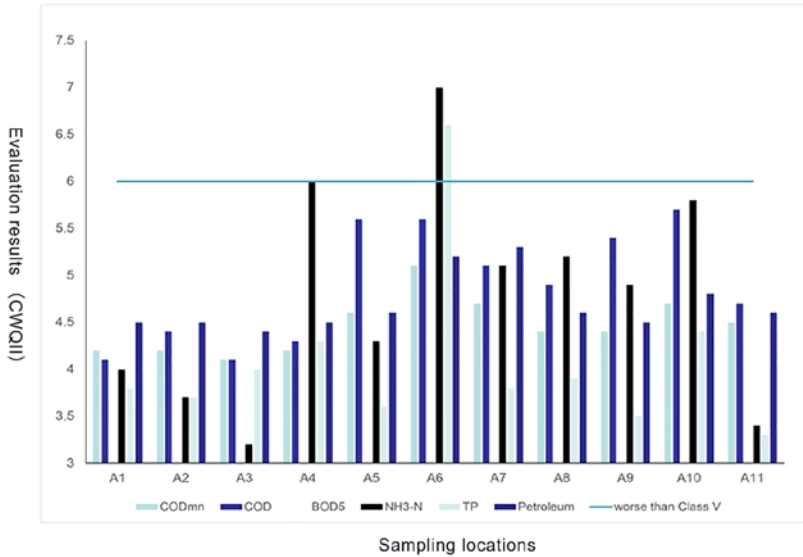


Figure 8. The result of water quality assessment using CWQII on Liao River in 2011.

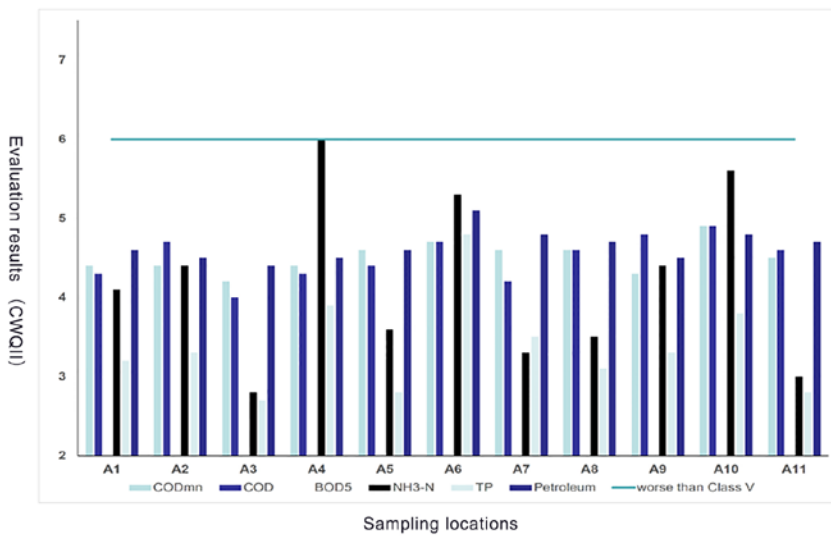


Figure 9. The result of water quality assessment using CWQII on Liao River in 2012.

The water quality classification for each factor was determined according to the CWQII method. The results are shown in Figures 8-10. Like for the SFE method, NH₃-N in the SanCha River in 2011 and 2012 and in the Pangxiogou River (A6) in 2012 were Class 5 pollutants, as was the TP of Pangxiogou River in 2011. The CWQII of Petroleum and BOD5 showed Petroleum and organics

contamination in Liao River and its tributaries. For Petroleum, the lowest concentration of was 0.16mg/L and the highest was 0.64mg/L, three times and 12.8 times Class 3, respectively.

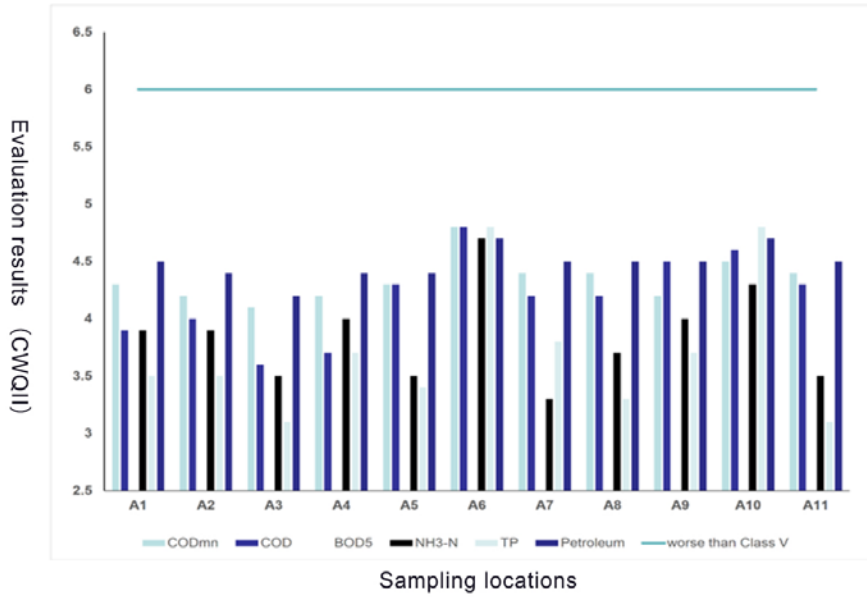


Figure 10. The result of water quality assessment using CWQII on Liao River in 2013.

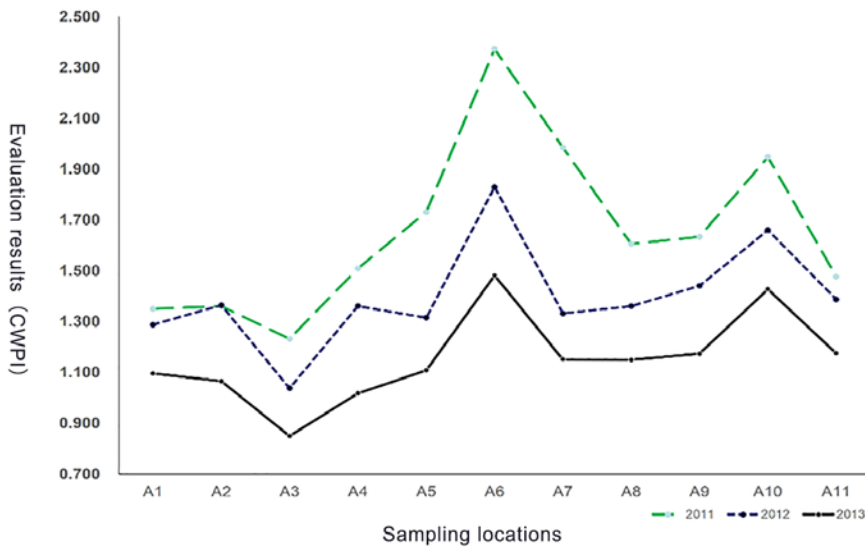


Figure 11. The results of CWQII from 2011-2013.

According to the results of the water quality evaluation by using the CWQII method, the comprehensive water quality of the Zhaoquan River was the best and was the worst for Pangxiogou River (Figure 11). Pangxiogou River was the most polluted water body of Panjin City, where water quality was affected by industrial and domestic sewage. Zhaoquan River is located in the Wetlands Reserve of Liaoning province's delta area and local government have taken a series of important measures to protect the water quality of the wetlands, like creating the Wetland Protection Plan of PanJin City.

Year to year variation from 2011-2013 is shown in Figure 12. From 2011-2013, except for Shuguang River in 2011-2012, the water quality improved in all sections. Pangxieyou River, Yitong River (2011-2012) and Sancha River (2012-2013) showed significant improvement (13.4% 14.4% and 14.7%, respectively). It means that the government has done something useful to protect the environment. However, in order to achieve the environmental targets of the 'Water Pollution Prevention Action Plan' by 2020, petroleum and COD5 controls need be improved.

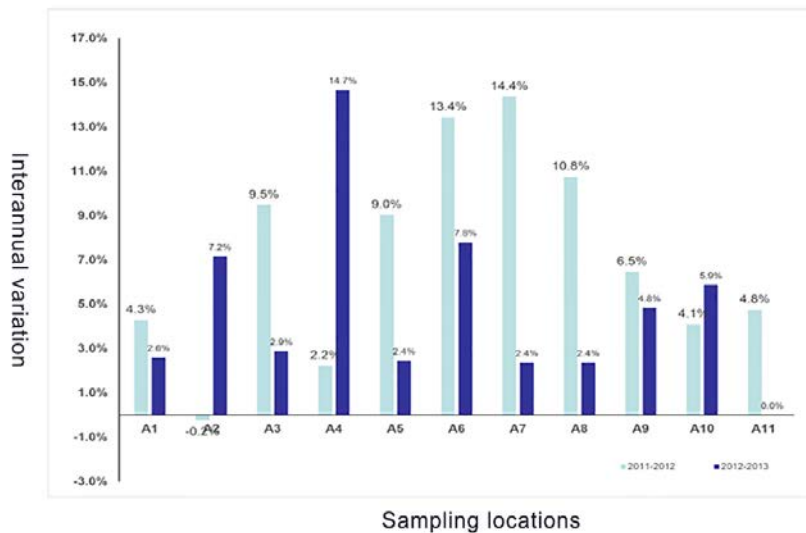


Figure 12. Comprehensive water quality change from 2011-2012 and 2012-2013.

Table 5. Comparison of different methods for the evaluation of surface water quality

	Considers a group of factors instead of using the worst evaluation factor	Compares single and comprehensive water qualities within the same class	Assesses the comprehensive water quality qualitatively and quantitatively
Single Factor Evaluation (SFE) Method	×	×	×
Comprehensive Water Pollution Index (CWPI) Method	✓	×	×
Nemerow-Sumitomo Water Quality Index (NWQI) Method	✓	✓	×
Comprehensive Water Quality Identification Index (CWQII) Method	✓	✓	✓

According to evaluation of the CWQII method, the results showed this method was considered the best method for evaluating the water quality conditions of Liao River and its tributaries, as shown in Table 5.

Firstly, this method can evaluate water quality by using a group of evaluation factors instead of using the worst evaluation factor, so compared with the single factor method, the result of the CWQII is more reasonable. Secondly, compared with other methods, the CWQII can also be used to compare single and comprehensive water qualities within the same class and can also evaluate water quality when the water quality is lower than a Class 5. Thirdly, this method can assess the comprehensive water quality qualitatively

as well as quantitatively. This method is suitable for assessing water quality in Liao River and can provide useful information for water quality protection.

CONCLUSIONS

Comparing four methods of evaluating surface water quality, the CWQII is a feasible method for evaluating the water quality conditions of Liao River and its tributaries. The SFE method only considers the most prominent factor and not all factors are considered in the resulting water quality evaluation. This means that the SFE method is limited in its ability to characterize the comprehensive water quality condition. Because of overemphasizing the influence of the maximum factor, the Comprehensive Water Pollution Index method and Nemerow-Sumitomo Water Quality Index method cannot effectively evaluate the comprehensive water quality condition. Moreover, these methods could not determine the water quality classes according to the surface water environment standards of China. The CWQII method was the best method because this method used a group of evaluation factors instead of using only the worst evaluation factor, giving a more balanced result. The CWQII can also be used to compare single factor and comprehensive water quality within the same classification and can evaluate water quality when the classification is lower than a Class 5. This method can also evaluate the comprehensive water quality qualitatively and quantitatively.

According to this method, the $\text{NH}_3\text{-N}$ of SanCha River and Pangxieyou River, and the TP of Pangxieyou River, were all lower than Class 5. However, from 2011 to 2013, petroleum and BOD5 were the main pollutants in Liao River. The CWQII showed that the comprehensive water quality of Zhao Quan River was better than in other rivers, and the water quality of Pangxieyou River was worse than other rivers. This is because Pangxieyou River was the most polluted industrial area of PanJin City, where water quality is affected by industrial and domestic sewage. Zhao Quan River is located in the Wetlands Reserve of Liao River delta where local government has adopted a series of measures to protect water quality of the wetland area.

Water quality improved in all rivers except Shuguang River. Pangxieyou River, YiTong River and SanCha River all showed significant improvement. This means the government has done something useful to protect the environment, however, in order to achieve the environment targets of the 'Water Pollution Prevention Action Plan' by 2020, water quality management policies and water environmental controls need to be improved. The CWQII method is an efficient tool to classify the water quality of the river and give rapid and precise information about the situation of the river that can provide useful information for water quality management and decision making.

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Study on Agricultural Management for Sustainable Agriculture in Zhangye Oasis, Middle Reaches of Heihe River Basin

A case study in Linze County

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Abstract: Proper management of irrigation and fertilizer for different crops is beneficial to the sustainable development of agriculture. Zhangye Oasis, which is an arid region surrounded by water dependent agricultural areas with canal-type irrigation systems, has been utilising the majority portion of the discharge of Heihe River. Maize is the dominant cash crop, while the cultivation of a new cash crop, stevia, has also been under expansion in recent years. This study was conducted with both a social survey approach and science experiment approach, aiming to comprehensively understand the management of irrigation, fertilizer and soil data, simultaneously. The water consumption, fertilizer application and soil condition of stevia and maize fields in Linze County were investigated and compared. The social survey on the perception of farmers revealed that the cultivation of stevia, which had greater cash ability, required less fertilizer than maize cultivation, while water consumption showed little difference. The nitrate and ammonium contents of stevia fields were higher than those of maize fields, indicating that stevia fields could be cultivated with less chemical fertilizer. The result that the nitrate contents in the middle and lower soil samples were higher than those in upper soil samples, suggests nitrate leaching. According to the results, it is suggested that less chemical fertilizer can be applied and less water used for irrigation in stevia fields of the Zhangye Oasis, and there is therefore a good opportunity for adopting stevia as a new type of cash crop for sustainable agriculture, with improved management of irrigation and fertilizer usage.

1. INTRODUCTION

1.1 The contradiction of water scarcity and water consumptive agriculture in Zhangye Oasis

Zhangye Oasis is located in the middle reaches of Heihe River Basin, Gansu Province in the Northwest of China. As reported by [The State Council](#)

[Information Office of the People's Republic of China \(2015\)](#), 95% of the arable land, 91% of the population, 83% of the water consumption and 89% of GDP of the region is concentrated in Heihe River Basin. It is surrounded by arid and irrigated agricultural areas and has developed into an important base for maize and vegetable cultivation in China. The large expansion of agriculture in this region requires a great amount of water for irrigation. Annual precipitation is under 200 mm, while annual evaporation is above 2000 mm ([Yang, R. & Liu, 2010](#); [Huang, 2015](#)). The 1800 mm difference between evaporation and precipitation means that this region suffers from water scarcity. This also explains why the impact of water use for agriculture is high in this region.

Although natural water scarcity is obviously one of the biggest problems in this region, excessive irrigation in agricultural practice occurs ordinarily, resulting in significant inefficient use of water. It has been reported that more than 75% of the water resources from the discharge of Heihe River is used for irrigating the cultivated land ([Nian et al., 2014](#)). Since the irrigation system, which is a unique canal irrigation system, is easily accessed and there is no mechanism to improve farmers' awareness of saving water, the phenomenon of a "communal watering system" has become very common and the water resources are used regardless of need ([Xu et al., 2014](#)). The current use of the irrigation system appears to be irrational because the irrigation efficiency is low and only 52% of the total irrigated amount was used to fulfil the plant evapotranspiration requirement in 2012 ([Wu et al., 2015](#)). Because of the development of agriculture, especially in maize cultivation, coupled with the situation of water scarcity, this region has been consuming a huge amount of the Heihe River water resource for irrigation and has even resulted in drought issues in the downstream areas, such as the drying up of the terminal lake ([Xiao et al., 2004](#)). Under the contradiction of water scarcity and water consumptive agriculture, there is an urgency to develop sustainable agriculture that can preserve the Heihe River water resource in the Zhangye Oasis.

1.2 Overuse of chemical fertilizer in agriculture

Excessive irrigation rates and use of chemical fertilizer are considered conventional agricultural practice in the middle reaches of the Heihe River Basin ([Yang, R. & Wang, 2011](#)). Overuse of chemical fertilizer, especially nitrogen fertilizer, is considered another serious issue in the area. Nitrogen fertilizers have been assisting agricultural cultivation for more than 100 years, since two German scientists developed a way to transfer nonreactive atmospheric nitrogen to reactive ammonium, which forms the base of nitrogen fertilizer ([Smil, 2004](#)). Overuse of nitrogen fertilizer in agricultural activities could cause serious environmental issues and human hazards. Large quantities of nitrate leaching from soil to groundwater caused by the application of chemical fertilizer can result in high levels of nitrate concentrated in groundwater ([Addiscott, Whitmore, & Powlson, 1991](#)) and high levels of nitrate accumulating in foods and drinking water, which is the source of dietary nitrate that can cause human health disorders, as had been found decades ago ([Wilson, 1949](#); [Meah, Harrison, & Davies, 1994](#)). The concentration of nitrate in foods is primarily attributed to overuse of nitrogen fertilizer ([Addiscott, Whitmore, & Powlson, 1991](#); [Good & Beatty, 2011](#)).

In China, the use of fertilizers has been increasing dramatically since the 1970s ([Jiang & Li, 2016](#)). It has been reported that nitrogen fertilizer was applied in enormous amounts, from 500 to 1900 kg nitrogen ha⁻¹ year⁻¹ in

locations with a high nitrate concentration in the ground water ([Zhang, W. et al., 1996](#)). Nitrate concentration has been observed increasing in Zhangye agricultural areas as well. In 2005, the total amount of nitrogen fertilizers applied on maize fields was more than 300 kg ha⁻¹ year⁻¹, and was more than 450 kg ha⁻¹ year⁻¹ more recently ([Su, Zhang, & Yang, 2007](#)). Effects of long-term fertilization on soil productivity and nitrate accumulation in the Zhangye region have been researched by [Yang, S.-M. et al. \(2006\)](#). They found that the accumulation and distribution of nitrate in soil were significantly affected by annual fertilizer application and fertilizer led to nitrate accumulation in most subsoil layers. They also suggested that it was of great importance to manage the application of chemical fertilizer and organic fertilizer in order to protect the soil and underground water from potential nitrate contamination while sustaining high productivity in the oasis agro-ecosystem. With the development of agriculture, Zhangye Oasis has recently grown into the largest maize production area in China. However, it is quite clear that the overuse of chemical fertilizer in the cultivation of maize is not sustainable.

1.3 Current agricultural management in general

In the Zhangye Oasis, large scale agriculture activities are carried out during the farming period from March to November ([Yin & Wang, 2015](#)). During this period, water resources from the discharge of Heihe River are delivered by a unique canal type irrigation system to each individual area of farmland in the Zhangye Oasis. More than 75.6% of all the villages have canals passing through ([Jiao & Ma, 2002](#)). There are five levels of canals: the main, branch, lateral and field canals, and field ditch. Annually, irrigation activities are conducted about six times (every 20 days from early June to September). For preventing leakage from irrigation canals and to improve water efficiency given the limited water resources, a high proportion of the canals has been paved with concrete. As of 2013, the main and branch canals had extended to 4,700 km and had been paved, the total length of the lateral and field canals had reached 14,000 km, and the lateral canals had almost been completely paved, while only 30% of the field canals had been paved ([Wang et al., 2013](#)). According to [Xu et al. \(2014\)](#), since accesses to water resources for local residents is easy to take advantage of in the Zhangye Oasis, by all water users and to any extent, and with no mechanism to improve water users' awareness of saving water, the phenomenon of water wastage has become serious.

Chemical fertilizer application, as well as irrigation, is also conducted during the farming period. Conventionally, some of the farmers apply organic manure to fertilize the soil at the first stage of farming before cultivating crops. Then, two or three times, chemical fertilizer is applied following cultivation. Nitrogen fertilizers, such as urea and ammonium phosphate, other phosphorus fertilizers, and potassium fertilizers are used. Cases of using mixed fertilizer are also not rare. In rural areas of this region, farmers are relatively lowly educated and tend to apply chemical fertilizer based on either their own experiences or on recommendations from other farmers. In this kind of situation, farmers tend to overuse chemical fertilizer to make sure that their fields obtain enough nutrients. As a matter of fact, in each village of Zhangye, there are Agricultural Technology Stations which are expected to take responsibility for teaching farmers how to manage irrigation and fertilizer, and spreading other farming knowledge. Surprisingly, these stations have deferred to being retailers of fertilizers for

profit, which is obviously contradictory to the responsibilities of the farmers who run them, and will become an obstacle to the sustainable development of agriculture in the Zhangye Oasis.

Excessive irrigation and chemical fertilizer application may result in low efficiency of applied resources and lead to soil and groundwater contamination ([Al-Kaisi & Yin, 2003](#)). With the urgency to conserve water resources and prevent soil contamination, the economic investment in all kinds of water conservation projects in Gansu province had reached almost 7 billion RMB by 2012 ([Xu et al., 2014](#)); the government is also gradually making efforts to reduce excessive chemical fertilizer application.

1.4 Stevia as a new cash crop for irrigated agriculture in Zhangye Oasis

In Zhangye Oasis, maize cultivation, which accounts for over 25% of the total planting area in the basin, expanded to be the dominant cash crop from the 2000s ([Huang, 2015](#)), while the cultivation of vegetables, which require green houses and a large amount of water and fertilizer for cultivation because of the frigid winter climate in winter, and some medicinal herbs, have also showed high cash ability in recent years.

Stevia is a perennial, calorie free naturally sweet herb that belongs to the family *Asteraceae* ([Ahmed et al., 2007](#); [Ojha, Sharma, & Sharma, 2010](#)). It is native to South and Central America ([Debnath, 2008](#); [Jackson et al., 2009](#)). The first commercial cultivation of stevia started in Paraguay around 1964 (Sumida, 1968; Katayama et al., 1976). Currently it is found cultivated in Japan, Taiwan, Philippines, Hawaii, Malaysia and overall South America for food and pharmaceutical products ([Kassahun et al., 2012](#)). The economic value of stevia is much higher than maize. According to [The Statistics Portal \(2017\)](#), the global market for stevia was estimated to have a value of 336 million U.S. dollars in 2014, and the latest estimated value increased to 578 million U.S. dollars in 2017.

In Zhangye Oasis, it was found that the soil in Linze County is suitable for cultivating stevia and the cultivation of stevia (*Stevia rebaudiana* L. Bertoni) started in 2007, in only several scattered fields at first ([Zhou et al., 2009](#)). The price of stevia leaves has kept increasing in recent years. It was reported to be 7 RMB kg⁻¹ by [Zhou et al. \(2009\)](#), and the profit was 150-2800 RMB per 1mu (1/15 hectare, Chinese unit of area) field. Then, in 2015 and 2016, as reported by the [Zhangye Agriculture Bureau \(2015\)](#) and [Zhangye Audio and Visual Network \(2016\)](#), the price rose up to 10 RMB kg⁻¹, and the profit also rose to 3650-4000 RMB mu⁻¹. In good cases it was as high as 4600 RMB mu⁻¹. Through this study, it is proposed that cultivating more stevia and reducing maize cultivation in order to save water, reduce chemical fertilizer application and gain better economic benefits, might be a new solution for developing sustainable agriculture in the Zhangye Oasis.

1.5 Significance

Although irrigation and chemical fertilizer greatly increase agricultural production potential, in Zhangye Oasis the high water consumption, negative impact on the soil environment, related groundwater pollution and other issues could not be justified. The Ministry of Water Resources (MWR) of China initiated a pilot project in Zhangye City in 2002, the Building Water Saving Society ([Huang, 2015](#)). Considering that the agricultural

management of irrigation and fertilizer may be conducted improperly by local farmers, the present study aims to capture a comprehensive understanding of the current condition of agricultural management and also intends to identify the feasibility for stevia as a new cash crop for more sustainable agriculture, by revealing the management information and soil data of cultivation fields. The results of this study, revealing evident proof of the current soil condition, responds to the government policy of the Building Water Saving Society and can contribute to reduced chemical fertilizer application for sustainable agriculture in the Zhangye Oasis.

2. MATERIAL AND METHODS

2.1 Study area

Zhangye Oasis, as shown in *Figure 1*, is located in the middle reaches of Heihe River Basin, which flows from Yingluoxia Valley to Zhengyixia Valley. In this region, around 70% of the land was reportedly used as agricultural land (Yang, R. & Liu, 2010). In Linze County, as reported by Linze Government Network (2017), the population is 146,000 and work for 86% of the population is directly related to agriculture activities. Stevia is cultivated densely and the total area cultivated until 2016 was around 35,000 mu, stated by the Zhangye Audio and Visual Network (2016). Yanuan Town in Linze County is one of the areas that first attempted stevia cultivation in 2007 and this attempt turned out to be a great success (Zhang, B., 2016), and significant expansion of stevia cultivation has since been witnessed. Until 2016 in Yanuan Town, the total area of stevia cultivated reached 24,000 mu, of which was 10,000 mu in 2015, according to the Zhangye Government Network (2016). Consequently, the study area is set to be Yanuan Town.

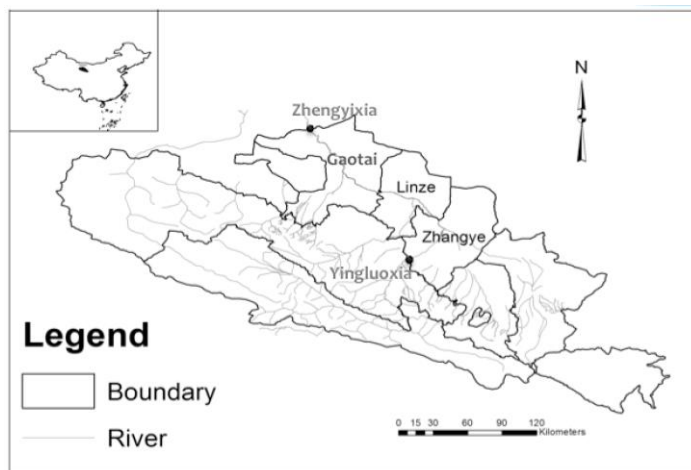


Figure 1. Middle reaches of Heihe River Basin

2.2 Methods

The present study was conducted using a social survey approach, as well as a scientific experimental approach. The study period is August 1st to August 15th 2015, with fertilization having been finished prior to the study period. Interviews with stevia and maize farmers were designed to find out

about the current agricultural management practices and farmers' perceptions of fertilizer and water consumption. Experiments were conducted to investigate the soil data (pH, nitrate concentration, nitrification potential, etc.) of stevia and maize fields in order to reveal the soil conditions, and also for comparison.

2.2.1 Social survey approach

A social survey for achieving a comprehensive understanding of the current management practice in the study area was performed. In the Linze County of Zhangye Oasis, 44 valid interviews of stevia farmers, who were cultivating maize at the time or who had experiences of cultivating maize, were interviewed, mainly in Zhaowu Village and Nuanquan Village of Yanuan Town, Linze County.

2.2.2 Experimental approach

Soil samples were collected from stevia and maize fields using a root auger (4 cm diameter; Daiki Rika Kogyo Co. Ltd., Kounosu, Japan) and divided into three categories: Upper (0-10 cm), Middle (10-30 cm) and Deeper (30-60 cm). Five points were randomly picked from each field for sampling. The attributes of soil experiments and sampling methods are listed in *Table 1*, below.

Table 1. Soil attributes and experimental methods

Attributes	Experimental methods
Soil Hardness	Soil hardness is measured using a digital penetration type soil hardness tester (DIK-5531; Daiki Rika Kogyo Co. Ltd., Japan).
Percolation Rate	Set a cylinder on the ground and pour the set amount of water through fully. The volumes of the penetrated water into the ground per minute are measured 10 times. Percolation rate is estimated using the average of stable values from 6 to 10 times.
pH	Soil sample (10 g) is added to deionized water (25 mL), and shaken for 60 minutes. pH is measured using a LAQUA twin water quality analyzer (Horiba Ltd., Japan).
NO ₃ ⁻ Concentration	Soil sample (5 g) is added to deionized water (25 mL), shaken for 30 minutes and filtered. NO ₃ ⁻ concentration was measured using an RQ flex plus 10 reflectometer (Fujiwara Scientific Co. Ltd., Japan).
NH ₄ ⁺ Concentration	Bremner Method: Soil sample (2 g) is added to 2 M KCl(aq) (20 mL), shaken for 60 minutes and filtered. NH ₄ ⁺ concentration is measured using RQ flex plus 10 reflectometer.
Nitrification Potential	NO ₃ ⁻ concentration in soil sample (5 g) is detected first. Another part of the soil sample (5 g) is added with (NH ₄) ₂ SO ₄ (9.4 g, 0.07 mol), shaken, and incubated for two days at room temperature. Then the same samples are added to deionized water (25 mL), shaken for 30 minutes and filtered. The difference between NO ₃ ⁻ concentration before and after incubation reflects the soil nitrification potential.
K ⁺ Concentration	Soil samples (1 g) are added with 1.0 M CH ₃ COONH ₄ (aq) (20 mL), shaken for 30 minutes and filtered. K ⁺ concentration is measured using RQ flex plus 10 reflectometer.

3. RESULTS AND DISCUSSIONS

3.1 Current water and chemical fertilizer management

The results of the current management of irrigation and fertilization from the social survey are listed in *Table 2*.

Table 2. Current water and chemical fertilizer consumption

Variable	Stevia	Maize
Water consumption (m ³ /mu)	>1000	>1000
Chemical fertilizer (kg/mu)	< 64	64

According to the results of the interview, usually, irrigation activities were conducted about six times a year (every 20 days from June to September). For both maize fields and stevia fields, average costs of irrigation water were a little more than 100 RMB year⁻¹ for a 1 mu field. Since the market price was 0.1 RMB m⁻³, this implies that the water consumption was more than 1000 m³ year⁻¹ in a 1 mu field. Stevia crop evapotranspiration for the total cycle (80 days) was estimated through a microlysimeter by [Fronza and Folegatti \(2003\)](#) and was found to be 464 mm. Thus, in a 1 mu field, the mean water demand for cultivating stevia is calculated to be 309.5 m³, meaning the current irrigation may be 690.5 m³ more than demand.

The application of chemical fertilizer (nitrogen, phosphorus and mixed fertilizer) in stevia cultivation is found to be smaller than that for maize cultivation, which is around 64 kg mu⁻¹ year⁻¹. The result is much larger than the amount of nitrogen fertilizer application that Su, Zhang et al. (2007) found, implying that there is a good possibility that chemical fertilizer in the study area has been overused, but almost all the farmers interviewed claimed that they would not reduce their chemical fertilizer use despite this because they might feel insecure with less chemical fertilizer application.

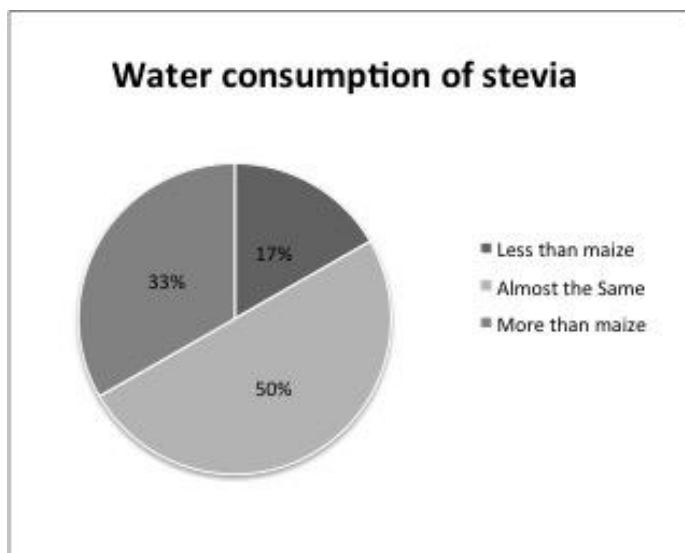


Figure 2. Farmers' perception of water consumption when cultivating stevia

Figure 2 shows the farmers' perception of irrigating fields considering the different cultivation types. The results show half of them answered that they irrigated both stevia and maize fields with the same amount of water, indicating the difference between the water consumption of stevia and maize

was not significant in current management. However, 1/3 of them answered that stevia fields might consume more water, while only 1/6 of them answered stevia fields might save water.

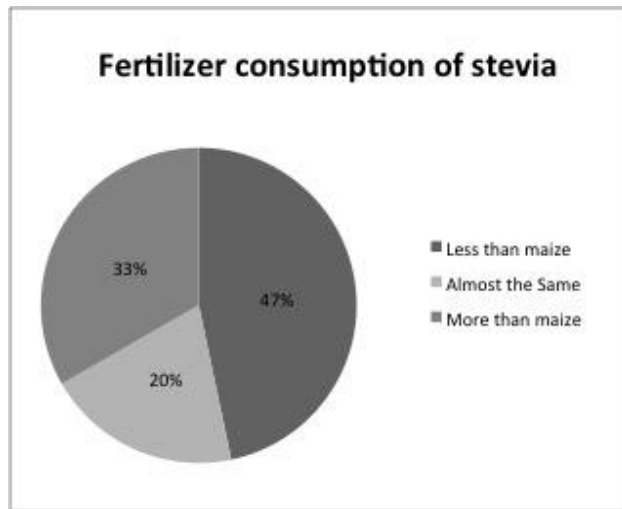


Figure 3. Farmers' perception of fertilizer consumption when cultivating stevia

Figure 3 above shows the farmers' perception of applying chemical fertilizer considering the different cultivation types. The results show that nearly half of all interviewees apply less chemical fertilizer to stevia fields than to maize fields, indicating that stevia cultivation might require less chemical fertilizer than maize.

According to the [Ministry of Agriculture of the People's Republic of China \(2015\)](#), the usage of pesticide is more than 2,000 tons every year in the Zhangye Oasis, with the average amount of 0.583 kg mu^{-1} , while a reasonable amount is only 0.307 kg mu^{-1} . As a result, about 0.276 kg mu^{-1} of pesticide is over used and, incredibly, the total amount of 1,000 tons of pesticide is over used every year. On the basis of the social survey, the study team also found that compared to maize cultivation, which was always the subject of pest issues, the cultivation of stevia suffered less from pest issues, implying stevia cultivation could be eco-friendlier by reducing a large portion of the associated pesticide use. Unlike for maize contracted cultivation, in which the purchasing price is set to be 2000-2400 RMB mu^{-1} under the contract of the purchasing company (from interviews), the stevia farmers could get paid as soon as the products were purchased and the price would increase along with the market price rising. Moreover, the stevia farmers also mentioned that the cultivation of stevia required a lower demand on physical labour compared to maize cultivation, which made their life easier and granted them more time to be involved in other industries, or to cultivate of other crops, as well as to have more time for their social life.

3.2 Soil data

The soil data of stevia and maize fields is investigated with experiments. Table 3 shows that the Percolation Rate, pH and Nitrification potential of soil from maize and stevia fields did not show much difference. The nitrification potential of soil from stevia fields (NO_3^- $32.3 \text{ mg kg}^{-1} \text{ dry soil day}^{-1}$) was slightly higher than that of maize cultivated soil (NO_3^- $31.1 \text{ mg kg}^{-1} \text{ dry soil day}^{-1}$).

Naturally, the root of normal crops grows in the soil layer between 0 and 15 cm ([Karizumi, 2010](#)). It has also been found that the root length of stevia

grows to 14 cm (Singh & Verma, 2015). The study conducted by Nakatsu (2004) showed that the roots of crops could not grow when soil hardness became higher than 2000 kPa. Figure 4 and Figure 5 below show that when the soil hardness was 2000 kPa, the soil depth of a stevia field was 23 cm and that of a maize field was 25 cm, meaning both of the fields were suitable for crop roots to grow naturally.

Table 3. Soil data results

Variable	Maize	Stevia
Percolation Rate (mL/min)	8	9
pH	8.3	8.4
Nitrification potential (NO ₃ ⁻ mg/kg dry soil/day)	31.1	32.3

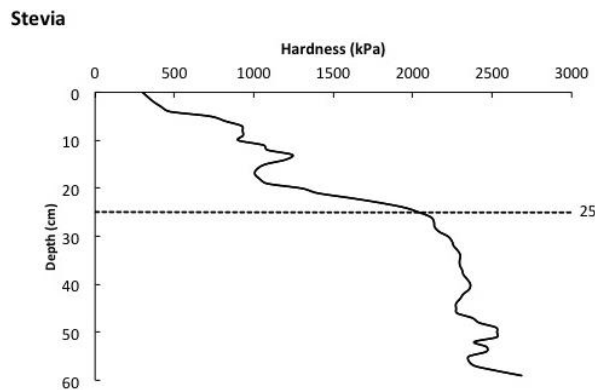


Figure 4. Soil hardness data of stevia field

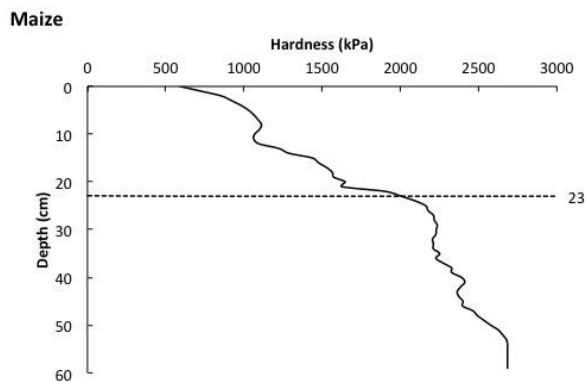


Figure 5. Soil hardness data of maize field

The nutrients (nitrate, ammonium, potassium) in the upper (0-10 cm), middle (10-30 cm) and lower (30-60 cm) layers of stevia and maize soils were also detected and the results were as shown in Figure 6, Figure 7 and Figure 8, below.

The accumulation of nitrate and ammonium in all layers of stevia soil was much higher than that in maize soil. This indicates that the nitrogen nutrients in stevia soil are richer than for those in maize soil. Combining these results with the perception of stevia farmers', that cultivating stevia consumed less chemical fertilizer, the study team conclude that much less chemical fertilizer application than the conventional amount could be enough for stevia soil. However, further study is needed for determining the optimal amount.

In addition, nitrate leaching into subsoil layers was also found. Since the nitrate contents in the middle and lower layers are higher than for those in the upper layer of stevia soil, and the nitrate contents in the lower layer are higher than those in the upper and middle layers of maize soil, the result was identical to the results of a long-term study by [Yang, S.-M. et al. \(2006\)](#) and the study by [Su, Zhang, and Yang \(2007\)](#).

Ammonium concentration in the upper and middle soil layers is found to be higher than that in the lower layer. This is because the ammonium, which is a component of the urea and ammonium fertilizer that is applied to the surface of soil in this region, easily binds to particles and is retained in the soil.

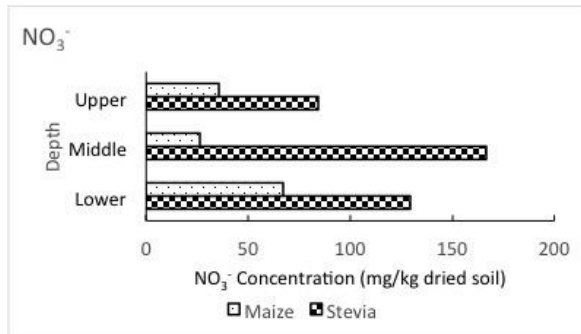


Figure 6. Nitrate concentration in soil layers of stevia and maize fields

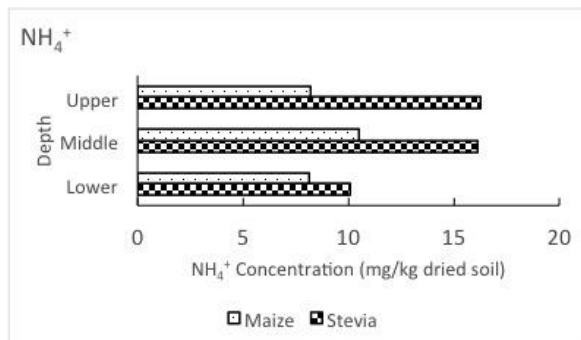


Figure 7. Ammonium concentration in soil layers of stevia and maize fields

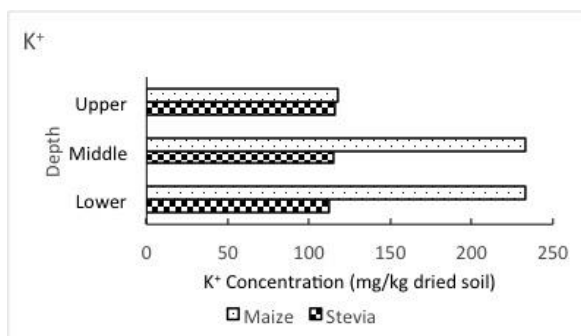


Figure 8. Potassium concentration in soil layers of stevia and maize fields

The potassium concentrations in the middle and lower layers of stevia soil are lower than for those in the maize soil. In considering only the potassium concentration in maize fields, the middle and lower layers concentrated much more potassium, possibly because of leaching induced by overuse of both fertilizer and irrigation water.

[Su, Zhang, and Yang \(2007\)](#) also found there was no evident difference in water content in the 0-160 cm soil layer across three levels of irrigation treatment: conventional treatment, 10% water saving treatment and 20% water saving treatment, indicating that conventional irrigation treatment cannot conserve soil water for any longer of a period than water saving irrigation treatments. Considering over-irrigation induces nutrient leaching, it is reasonable to comment that reducing the volume of irrigation water to an optimal amount would contribute to sustainable agricultural management in the study area.

4. CONCLUSIONS AND SUGGESTIONS

The three pillars of sustainability are characterized as the environment, the economy and society. The present study, combining a social survey with scientific experiments, investigated the current agricultural management of irrigation and chemical fertilizer application and explored the possibility of adopting stevia as a new cash crop for the sustainable development of agriculture in the Zhangye Oasis.

Economically, stevia has showed high cash ability and is more profitable than the conventional cash crop, maize. Socially, a lower demand on physical labour during stevia cultivation can allow farmers to have sufficient time for other agricultural or industrial activities, or for their social lives. Most importantly, regarding environmental sustainability, stevia cultivation is found to have a relatively lower necessity for chemical fertilizer and water for irrigation, which can result in conservation of the water resources of the Heihe River Basin and reduced soil contamination by reduced application of chemical fertilizer in the Zhangye Oasis. Stevia has the potential to be a new cash crop, and developing more areas of stevia cultivation can contribute to more sustainable agriculture. However, it is found that chemical fertilizer is overused in stevia fields and irrigation is also possibly exceeding the optimal amount in its current agricultural management. This study suggests reducing irrigation and chemical fertilizer application for stevia cultivation and increasing farmers' awareness of soil environment conservation for developing better, more sustainable agricultural management.

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Application of Public Private Partnerships on Urban River Management in China: A Case Study of Chu River

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Abstract: Urban river management is a critical factor in an urban planning blueprint. However, such management includes various influences from political, financial and environmental aspects. This article tries to illustrate a solution through a case study of Chu River in Wuhan. Through the framework of a Public Private Partnership (PPP), the Wuhan government and Wanda Group establish a partnership that manages the Chu River collaboratively and achieves a sustainable win-win development outcome. By analyzing the achievements and mistakes of this case, we hope to present some experiences of urban river management that can be applied in similar cases.

1. INTRODUCTION

The Public Private Partnership (PPP) is a popular financial method in government infrastructure construction and providing public service. The Chinese government has wanted to increase the number of PPP programs since 2013. The Chu River program is one of the early PPP programs in China and stands as a good example for research. The article will begin with an introduction of PPP. After the introduction of PPP, an analysis of the Chu River program will reveal its positive outcomes and shortcomings. Based on the analysis, some problems from the bigger picture will emerge when comparing the Chu River program with a more current event. Finally, the article will give some suggestions based on the analysis.

2. WHAT IS PUBLIC-PRIVATE PARTNERSHIP?

Public Private Partnership (PPP) has become a relatively popular choice of the financial method when it comes to infrastructure construction. However, the definition of PPP can be either wide or narrow. For the wider definition, the Asian Development Bank (ADB) gives a broad definition of public-private partnership as “a range of possible relationships between

public and private entities in the context of infrastructure and other services” (ADB Public Private Partnership Handbook, 2015). However, that definition includes traditional financial methods such as “Build-Operate-Transfer (BOT)” or “Transfer-Operate-Transfer (TOT)”. Nevertheless, the ADB’s PPP handbook gives a narrower definition right after, containing three key points:

1) The PPP must form a framework. Inside such framework, all potentially interested parties can have a place. For example, nongovernment organizations (NGOs) and/or community-based organizations (CBOs) have their place under this framework, so it will not be a two-party agreement like a BOT or TOT.

2) Unlike Private Sector Participation which contracts transfer obligations to the private sector, the PPP is more about shared responsibility.

3 If the “framework” comes in the form of a company, then the private sector and public sector will each have part of the ownership of the company.

With all these unique characteristic, PPP has the potential to fit the construction needs of environment-related programs. Environmental programs usually require a long period from planning to completion. [Klijn et al. \(2008\)](#) indicate in their research that the PPP model fits well with multiple environment-related programs. In this case, a company under a PPP protocol is more likely to continue running over a number of years, and such a company will usually give more consideration to long term strategy and keeping the business running. On the other hand, for example, a government-owned program may be shut down during a budget cut. The framework’s characteristics also guarantee the full participation of each party at a certain level. The community-based organization has less chance to join a BOT program, even when the program is next to their community. NGO’s usually play an advisory role and do not have a decision-making position. [Zhang \(2005\)](#) demonstrated in his research how to find a combination of suitable partners for a PPP program. Following the ideas of his research, PPP has a more flexible framework. At the same time, experts from different fields can join the framework, meaning an expert can be brought in from the public sector with the experience of running environmental programs and an expert in business from the private sector who knows how to run a company can also be involved. [Osborne \(2002\)](#) stated in his book that these types of cooperation help in fixing the shortcomings of both the public and private sector. Finally, PPP’s help to solve funding issues. As previously mentioned, government-owned programs rely heavily on government budgets and can be ceased due to lack of financial support. Therefore, in this case, a long-run self-profitable program has a better chance of survival. If people want to reach the goal of sustainable development, then a program must be not only environmentally sustainable but also economically sustainable.

Despite the advantage that a modern PPP framework has of being well-suited to environmental programs, the disadvantages of a PPP framework may cause some problems. The management of a PPP is complicated, due to its complex framework ([Akintoye, Beck, & Hardcastle, 2002](#)). The leadership of this framework needs to be clearly set at the beginning of a project, otherwise, people from different parties will only follow the orders of their previous superior. In addition, different parties within the framework may have different interest. Sometimes, these interests could be against one and another, especially when there are both financial and non-financial interests ([Mota & Moreira, 2015](#)). Private sector parties join PPP programs

in order to gain financial benefits, therefore private sector parties would request a certain amount of profit in return, and public sector parties may want to spend money elsewhere. Finally, not all programs fit the requirements of PPP framework. The private sector will not invest in a program that will not generate profit, and not all environmental programs do. Therefore, a PPP is not always the best solution.

3. DEVELOPMENT OF CHU RIVER PROGRAM

After explaining the PPP framework, it is time to see how the Chu River program operates as a PPP. According to the evaluation report, “Big East Lake water network program”, the Chu River is a channel to connect the East Lake and Sand Lake ([Water Conservancy Committee of Yangzi River, 2007](#)). The “Big East Lake water network program” is an environmental program to connect major lakes in Wuhan through a man-made channel. Chu River is located geographically at the center of Wuhan City. The area of the sites, called “Shuiguo Hu” (Fruit Lake), acts not only as the center of Wuchang district but also of Wuhan city. Fruit Lake is a 0.12 km² sub-lake of the East Lake. A small bridge separates this lake and the main part of East Lake. This lake (or a pond to be precise) is also the connection between East Lake and Sand Lake. The East Lake has a water surface size of 32.5 km² with several sub-lakes. The East Lake is also the biggest urban lake in China. Sand Lake has a surface size of 3.2 km². The six major lakes have a total surface area of 62.6 km². In the past years, these lakes have faced serious pollution, with most of the lakes having water quality below the level 5 standard of National Environmental Quality Standards for Surface Water. The water bodies of lakes exchange relatively slowly, so lakes are hard to clean up once they have been polluted. Thus, the Water Conservancy Committee and Wuhan government came out with a planned to connect these lakes through an artificial channel to accelerate the exchange of the water bodies. In addition, channels will be connected to the Yangzi River, so fresh water from the Yangzi River will flow in and out of the water network. Only polluted water exchanging between polluted lakes is simply meaningless. After researching and evaluating the program, the Water Conservancy Committee and Wuhan government gave a green light to the program. This type of design has some obvious disadvantages, however. According to Chen and Yang’s ([2006](#)) study on the building height and the distance from building to the river, the ratio of the height and the distance should be 1:1. The buildings in Han Street are too close to the river and do not follow the 1:1 rules. In addition, over commercialization issues cause the Chu River program to lose its own characteristics ([Hu, Duan, & Zeng, 2013](#)). The shopping street has a theme called “Han culture”, yet contains international brands such as Starbucks and McDonald’s. These shops do not match the theme of this program at all. However, the developers still put these famous brands into the shopping street to attract customers. This over commercialization issue will be further discussed in the Discussion section.

Once the program had been decided, the Wuhan government wanted to build an organization to handle the financing and investment issues related to the program. The Wuhan Water Resources Development Cast Time Group established in May 2009 and Wuhan government gave the company the authorization to be in charge of water resources related to investment (Wuhan Water Resources Development Cast Time Group, 2010). According to the company’s report, the Water Resources Development Group invested

a total amount of 8.9 billion RMB into four areas: pollution control (3.1 billion), ecosystem restoration (2.05 billion), water network connection (3.6 billion), and finally the water quality monitoring system (0.15 billion). The first subprogram of the water network connecting program is the “Chu River and Han street” program. This program contains two parts: the Chu River as a canal to connect East Lake and Sand Lake, and the Han Street as a commercial street to contain an entertainment function. Wuhan city is the capital city of Hubei province, and the provincial government’s building is located just a few blocks away from Han Street. Many other government agencies and their old staff dormitories are also built in this area. Therefore, the Chu River and Han Street program has also faced old town reconstruction issues. With that amount of construction work and the amount of money required, the Wuhan government felt the burden might be too heavy to take on by itself. Hence, the Water Resources Development Cast Time Group has outsourced the development and construction of Han Street to Wanda Group ([Shao & Ji, 2012](#)). In return, Wanda Group owns the property rights of Han street. The Wanda Group has invested 50 billion RMB into the Han street program. The street includes shops, restaurants, one cinema theme park, several commercial residents and one seven-star luxury hotel with a total area of 1.8 km². The construction was completed in eight months with Han Street being opened to the public in September 2011.

The Chu River program is a typical PPP program with a framework (i.e. Water Resources Development Cast Time Group), sharing obligations and sharing ownership. Wanda Group hoped to gain profit from this program and the Wuhan government, on the other hand, wanted to gain environmental and community benefits.

The Chu River program is a relatively young and small program. Therefore, the Chu River program has had limited influence on the improvement of water quality in East Lake. The final goal of this program expected to reach the national level 3 standard ([Water Conservancy Committee of Yangzi River, 2007](#)), however, research stated that people could still sense a nasty smell from East Lake and the water quality in Sand Lake was still lower than the national level 5 standard ([Xiong, 2010](#)). In fact, this 2010 article by Xiong may be too critical of the program’s longer term environmental benefits given the Chu River had just finished its construction in 2010. The water quality will not change in a short period. Although Xiong’s study might be too severe on the program, one fact is that the water quality had not had any obvious improvements at that time, due to the construction of Chu River.

In Table 1, below, data from the Wuhan Environmental Annual Report from 2007 to 2014 has been compiled. The “5-” represents “lower than level 5 standard”. “5” and “4” represent their level standard accordingly. The 2010 data from Sand Lake has been excluded because the monitoring station was dismantled to build the canal and then the station was rebuilt in 2010. The data of East Lake did present a slight improvement. Meanwhile, the water quality in Sand Lake and Shuiguo Lake (where a small sub-lake connects Sand Lake and East Lake) improved in the first two years after the construction of Chu River. Nonetheless, from 2013 the water quality in both lakes began to worsen. Although detailed reasons remain unknown, Xiong’s ([2010](#)) research mentioned that rain could sabotage the water quality very quickly and mentioned Wuhan has a huge rainfall capacity. In general, further study is required on the water quality issue to determine the reasons for this pollution.

Table 1. Water quality of East Lake, Sand Lake, and Shuiguo Lake.

Year	East Lake	Sand Lake	Shuiguo Lake
2007	5-	5-	5
2008	5	5-	5
2009	5	5-	5
2010	5	X	5
2011	4	4	4
2012	4	4	4
2013	4	5-	5
2014	4	5-	5

Source: Wuhan Environmental Protection Bureau, 2015

The riverbank design is a feature of this program. The planning and riverbank construction had its own advantages but also contained some shortcomings. Chu River has a modern, but practical water-accessible river bank design. People can reach the water with their hands. This design is different from hydrophilic terraces found in other similar rivers in China, like Suzhou River in Shanghai. The Chu River design gives people true access to the water, instead of seeing it from a terrace. The Chu River program has another advantage: Han Street. People can do something else, other than walk alongside the river. In fact, the concept of combining a shopping street and the river had already been developed years previously ([Wang, Jianguo & Lu, 2001](#)). This combination gives people an opportunity to combine water viewing with other activities, like enjoying afternoon tea. In addition, the shopping street with a riverside walking corridor allows people to enjoy the river view in any weather condition. This feature also brings a unique experience to tourists. The Chu River fulfills its purpose as a place for local people to relax and enjoy life.

As for its economics, the Chu River program achieves a remarkable result by both earning a profit and providing opportunities. In fact, its PPP program related to real estate has a framework rarely used worldwide, with its PPP heavily involved in infrastructure construction ([Singewar & Deshmukh, 2016](#)). Successful cases are even rarer. However, the Chu River program successfully proved itself as an economic booster. First, this program had a direct impact on local real estate prices. According to Figure 1, presented below, the Chu river area had average real estate prices lower than the Wuhan city's average price in 2006 and 2007. Then, the price began to climb in 2008. The program conducted relocations of original residences and old town reconstruction in 2009 and 2010 (Wuchang District, 2013). After the program finished in 2011, the real estate prices in that area rocketed. The price rose 214% from 2008 prices in the Chu River area. The average price of Wuhan real estate rose 33% from 2008 to 2011. Therefore, ignoring the 33% growth caused by the economic trend, this program still brought an additional 181% of growth to the developer over two years. The real estate price in the Chu River area stayed two times higher than the average price of Wuhan in the following years. This undeniable truth proved the economic success of this program. In addition, most of the business

activities on the new shopping street belong to tertiary industries. This means another source of tax income to the government. In addition, tertiary industry businesses incidentally provide job opportunities and help to solve unemployment issues without creating as much pollution as many of the heavy industries. Therefore, economically, the Chu River program achieved its original purpose and has developed a good business model.

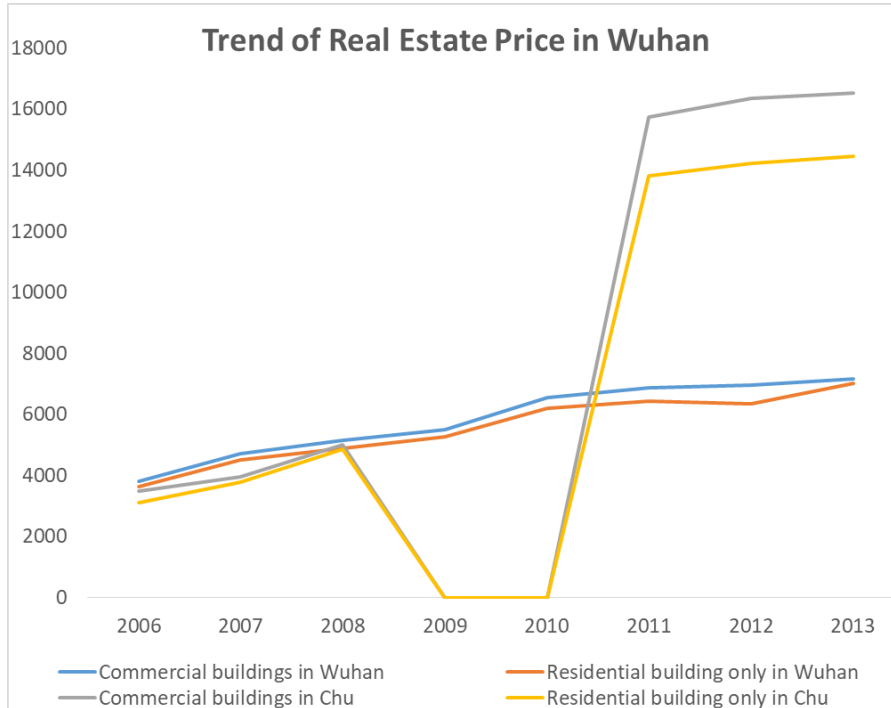


Figure 1. Real Estate Price Comparison in Wuhan from 2006 to 2013, Source: Wuhan Licheng Real Estate Appraisal Co., LTD., 2014

Although the Chu River program has been economically successful, it somehow does not show the PPP program's advantages of full participation of all relevant parties. [Wang, Jin \(2004\)](#) mentioned that public participation has many practical issues when it comes to enforcing such participation. Even though years passed after Wang's article, the situation in the Chu River program is still severe. According to the material from Wuchang district, the district in charge of Chu River, the district published the plan for a public inquiry (Wuchang District, 2013). What this material did not mention was that the public only obtained 10 days for any inquiry ([Xiong, 2010](#)). This short period did not give the public much chance to participate. Although the Chu River program set up a PPP framework, the participation of third party organizations/individuals is little to none at this point. The reason behind this is simple. It is easy to ask advice from third-parties, yet it is difficult to allow them to join the decision-making stage. If the framework is a company, the public sector and private sector each have their priority share of stock because they either provide land as capital or invest money.

4. POST-CHU RIVER PERIOD AND PPP PROGRAM IN CHINA

As one of the early PPP programs in China, the Chu River program achieved some success and certainly gained some experience from mistakes.

PPP programs in China reached a “new boom” phase, after phases of fluctuation from 2008 to 2013 ([Cheng et al., 2016](#)). Yet the success of the Chu River program cannot prevent or alter certain problems that are beyond a single program. People need to see the big picture and address these problems before they worsen.

One conspicuous problem is the imbalance of PPP program distribution in China. Investment is concentrated in south-eastern China and ignored in poor areas. Investment focuses on high-profit PPP projects (i.e. sewerage systems, urban transportation, etc.). Figure 2, below, shows that south-eastern provinces, especially those located near the coastline, have more PPP programs than other provinces. On the other hand, north-western provinces do not have many. Ironically, compared to high-income provinces such as Guangdong or Zhejiang, the provinces in north-western China have less income to support environmental programs, and therefore need PPP programs more. However, investors tend to invest their money in well-developed instead of less-developed areas. Furthermore, the government in less-developed areas have difficulty attracting talented or seasoned experts to do planning or program design. Thus, these areas do not present programs attractive enough for investors. This issue will cause damage not only presently, but also extend damages into the future.

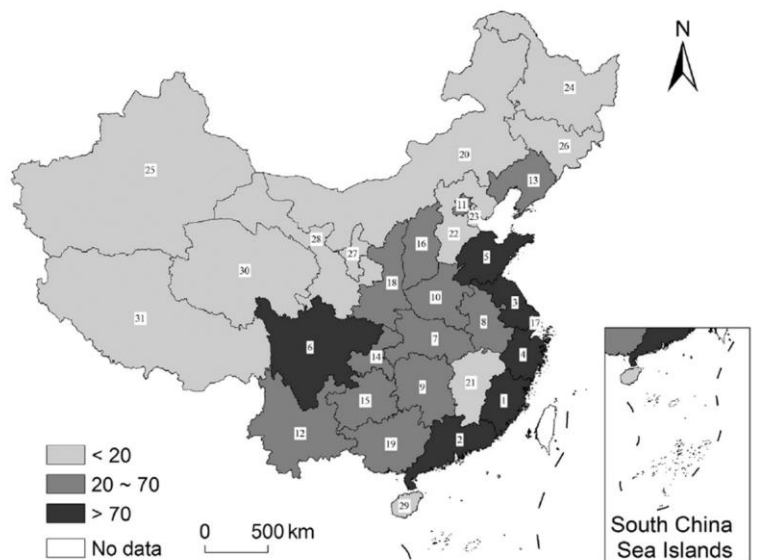


Figure 2. Number of PPP projects implemented in China by province. Source: [Cheng et al. \(2016\)](#)

The government has little interest in introducing urban river restoration projects. The Ministry of Finance of China announced its “Sample PPP program list” for the first time in 2014. Among the 30 programs inside the list, only two of them are related to water restoration. However, 10 programs were sewer plants (Ministry of Finance, 2014). The Ministry of Finance announced the second list in 2015. Out of 206 programs, only 13 of them involved water environment protection/restoration. Even though programs like the Chu River project have shown their potential for earning a profit, the government seems to think programs like sewer plants need more investment. Therefore, programs similar to the Chu River program do not have the chance to enter the recommendation list. Ironically, sewer plants can be run completely by the private sector. Public sector and investor attitudes on PPP frameworks have shifted by many factors. For example, the local government quickly lost their enthusiasm for the application of PPP

when the Chinese central government came out with a 4 trillion RMB stimulus package after the worldwide financial crisis in 2008 (Yang and Cai, 2016). The local government then did not need to work with the private sector because adequate financial support was being received from central government. The Chu River program started at the end of 2008, so its existence relied on a bit of luck. The Wuhan government did not kill the plan even after receiving the stimulus package. On the other hand, local government regained interest in the PPP model after 2013, according to research (Cheng et al., 2016). The shift between different attitudes has made investors reconsider the stability of cooperation with the public sector. Finally, PPP programs in China face unbalanced participation by different parties, with an extremely high requirement for market access. Multiple types of research (Ke et al., 2010; Cheung & Chan, 2011) indicate the high requirement for the private sector to join a PPP program in China. The requirements include the financial requirement (minimum invest amount, etc.), qualification requirement (requiring qualifications only top companies possess) and identity requirement (the company must be nationally owned). Due to these extreme, even excessive requirements, several top companies monopolize access to PPP programs in China. The Chu River program operated by Wanda Group is an excellent example. Previously mentioned research also suggests some local PPP programs should lower the barrier to PPP entry since the high requirements can be unnecessary for small PPP programs.

As previously mentioned, the public-private partnership framework is not a cure for all problems, yet PPP programs still face stress from high expectations. Each party wants different things from a PPP program. Central government expect to increase private investment through PPP (Cheng et al., 2016), local government want to pay back previous debt and get rid of deficits, the Ministry of Finance of China has even released an order that local government should not use PPP programs as a cover for financing of previous debt (Ministry of Finance of China, 2016). Environmental departments hope to solve funding issues; high ranking officers from the Ministry of Environmental Protection have made several speeches in 2016 in support of environmental PPP programs. However, they do not lead any programs by themselves. Investors rely on a high rate of return from PPP programs and are driven by profit when selecting a program. And in addition, the local community, NGOs and other industries (construction, energy, etc.) also have their own agendas. Managing these differing agendas is a true art.

5. SUGGESTION AND CONCLUSION

With so many problems to address, the following provides a constructive suggestion. People should set reasonable environmental goals for each environmental PPP program. With the goals in mind, people should interpret the program in detail by recruiting an environmental expert early in the planning stage, to clarify the goals to every participant. In the execution stage, the framework (usually a company) should increase the weight of the environmental expert's opinion in decision making. Finally, if full

participation is not achievable in the current stage, third-party supervision should be included as a minimum, with a channel for addressing suggestions.

The boom of PPP programs has arrived in China and thousands of programs appear every year. The Chu River program sets an example of a partnership between public and private sector. Although the program is not perfect, other programs should learn from the Chu River experience. The market is promising, but also potentially risky. Leaders from the public and private sector may need to discuss the big picture issues before PPP programs take on a detrimental direction.

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Review of Urban Flood Impact Reduction due to Climate Change Adaption Driven by Urban Planning Management in Pathumthani Province, Thailand

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Abstract: The Province of Pathumthani has played an important role in the Bangkok Metropolitan Region (BMR) in terms of its economics, industry, education, society, and culture in driving the urbanization process. However, the urban areas have been sprawling without control. Some urban areas have expanded to areas with risk of flooding. Especially, in the past 10 years, Pathumthani has suffered from more frequent and more severe floods, which might be affected by climate change. Together with inefficient climate change adaptation plans, the areas with risk of high impacts of flooding have expanded, making the urban settlements in Pathumthani face even higher impacts. The objectives of this research are to examine land use changes in order to understand the direction of urban expansion, to analyze the level of flood impact risk under climate change in Pathumthani by using Sieve Analysis and Geographic Information Systems, and to examine flood adaptation plans and the projections of urban development by using Scenario Analysis. The results show that the flood impact risk of Pathumthani has been higher under climate change, and the areas with flood impact risk have expanded, especially in the western side of Chao Phraya River which covers the majority of the areas in (1) Sam Khok District, (2) Mueang Pathum Thani District, and (3) Lat Lum Kaeo District. Moreover, the results suggest that the direction of urbanization is toward these three districts with high flood impact risk. Thus, climate change adaptation plans are essential for Pathumthani.

1 INTRODUCTION

Located in the north of Bangkok, the province of Pathumthani is one of the provinces in the Bangkok Metropolitan Region (BMR). The province consists of seven districts (Amphoe) (see Figure 1), which can be divided into 60 sub-districts (Tambon) with 529 villages (Mooban) (Department of Provincial Administration, 2016). In the past, agriculture was the main activity of the

province. Since the 1960's, Pathumthani has transformed from agricultural lands to residential real estate projects, factories, and industrial estates. It has played an important role in the nation's industrial and education development as well as in Bangkok's economic development. The province has been a commuter town of the BMR since past decades. Currently, approximately 25% of the population in the BMR resides in Pathumthani. Located on low-lying land in the Chaophraya River basin with the river passing through the city, the province has faced challenges with severe flooding in the past decade. Due to a 2011 flood, Pathumthani is one of the provinces with the highest loss and damage because there are many settlements in flood-prone areas. Under the context of climate change, the expansion of this unplanned urbanization and urban sprawl has created more risk-of-flood situations in Pathumthani.

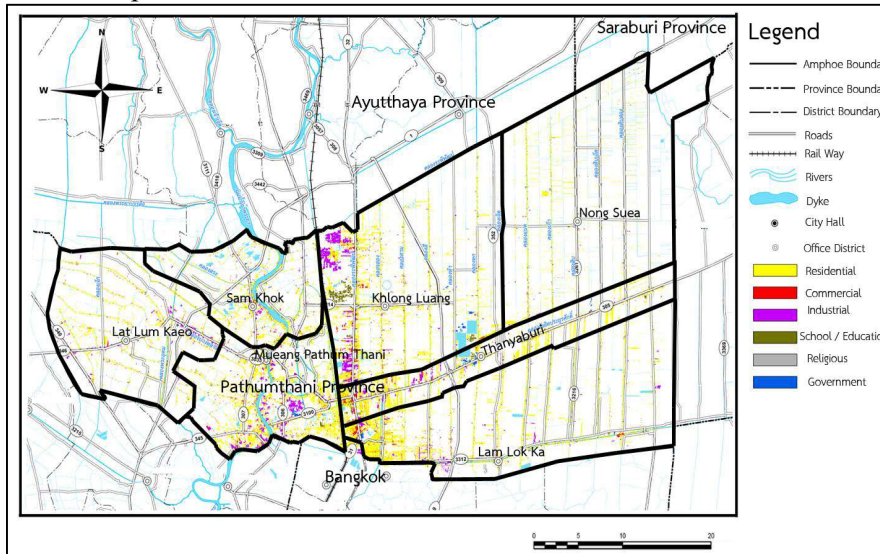


Figure 1. Districts in Pathumthani province (Source: Department of Provincial Administration, 2016)

This study analyzes the relationship of factors affecting the risk of flood impacts and related land use changes of urban areas in the province of Pathumthani, using Geographic Information Systems (GIS). It also studies the adaptation to urban flooding under climate change of communities living in the province. In addition, Scenario Analysis is used to analyze alternative futures of urban flood events in seeking appropriate responding policies. Prospective guidelines and policies on urban planning and flood management are discussed in this paper.

This research aims (1) to examine urban floods, land use changes, urbanization processes and adaptation plans in the province of Pathumthani, (2) to analyze the relationship of urbanization and urban flood impact risk under different flooding levels, (3) to provide scenarios of urban floods in response to land use changes and suggest community adaptation plans. The main hypotheses are that urban expansion and land use changes increase the flood impact risk, and the role of urban planning can help reduce the risk of flood impacts in Pathumthani. This study has two main research questions: (1) what the impacts of urban expansion and land use change on the risk of flood impacts in Pathumthani are, and (2) what the roles of urban planning on reducing the risk of flood impacts in Pathumthani are.

2 LITERATURE REVIEW

Adaptation has become one of the important issues in current literature on climate change. Adaptation to climate change usually refers to disaster response or coping capacity to natural disaster risks. Risks from natural disasters may stem from both natural and socio-economic factors (Sustainable Development Foundation, 2014). Socio-economic factors encompass a wide range of socio-economic characteristics such as income level, social vulnerability, and coping capacity (APFM, 2008). In the case of flooding in Thailand, man-made causes, in particular unsuitable land uses, and inappropriate land management, such as urban expansion onto flood-prone areas or the development of infrastructure that obstructs floodways, are found to amplify the impacts from natural disasters ([Watcharapasakorn, 2013](#)). Understanding these risk factors is an important first step to finding appropriate responses to a natural disaster. Scenario Analysis is also widely used to illustrate alternative futures and assess impacts and appropriate responses to such scenarios.

Many works on climate change adaptation in Thailand focus on land use and land management strategies (Thailand Action Aid International, 2006). For example, [Kornissaranukul \(2013\)](#) found that land use changes in Punpin County in Suratthani could lead to higher risk of flood impacts and proposed a method to determine spatial risk factors using Potential Surface Analysis (PSA). The analysis led to the creation of guidelines that support the community to manage future flood-associated risks.

The research herein is different from other studies on flood impacts regarding land use change in the context of climate change as it conducts a Scenario Analysis to provide input into the study areas' plans and policies for flood management. A map is developed to illustrate the extent of flood impacts and provides a tool for reducing vulnerabilities. The result contributes to capacity building for communities within the study area under development, based on a variety of different parameters.

3 METHODOLOGY

This research is part of a larger research project partially funded by the Thailand Development Research Institute (TDRI). Overall, the research project consists of four main components:

Part 1: Examining urbanization process of Pathumthani province

- Physical data and time line of land use changes to compare two period times, Year 2001 and Year 2011, using Geographic information systems (GIS) with a Spatial Analysis tool.
- Analysis on trends of land use changes and urbanization comparing two time periods, Year 2001 and Year 2011, using GIS with a Spatial Analysis tool.

Part 2: Identifying flood risk areas

- Collect and analyze data to find flood risk areas using three factors: built up areas, urban communities and land use activities; with two co-factors: Flood Boundary and Flood Depth; and overlay mapping of all data with a Sieve Analysis.

Part 3: Proposing a design by Scenario Analysis

- Set recommendation guidelines with flood adaptation options, under the conditions of the worst case of flooding in 2011.

- Set Scenario Analysis using urban planning guidelines under the following three scenarios:
The first scenario: develop Zoning and Building code in risk area zones.
The second scenario: defined catchment area and drainage.
The third scenario: develop structural (hard structure) measures.
- Bring risk map from Part 2 and combine with Flood Boundary and Flood Depth using overlay analysis to classify and specify risk area zones.

Part 4: Reviewing plans, policies and urban management with infrastructure and non-infrastructure measures:

- Collect land use and building use data, including plan, policy and ordinance regulations for analyzing and estimating.
- Collect water management data and guidelines, including plan, policy and ordinance regulations for analyzing and estimating.
- Analysis of potential and limitations of each plan and/or policy, including experts’ interviews to summarize the guidelines for most efficient urban planning guidelines and coping situations for flooding in the study area.

For the purpose of completing this research, Part 2 will be the focus of this paper. The analysis utilizes Potential Surface Analysis or Sieve Analysis to identify areas with a high level of flood impact risk in Pathumthani province. It incorporates both physical and socio-economic factors, taking into consideration urban growth and flood prone areas. There are six factors including (1) slope, (2) soil type, (3) land use, (4) access to communities, (5) elevation, and (6) population density. These factors are illustrated in *Figure 2 – Figure 7*.

Weighting and scoring of these factors are derived from interviews with experts. They can be described as follows:

(1) Slope

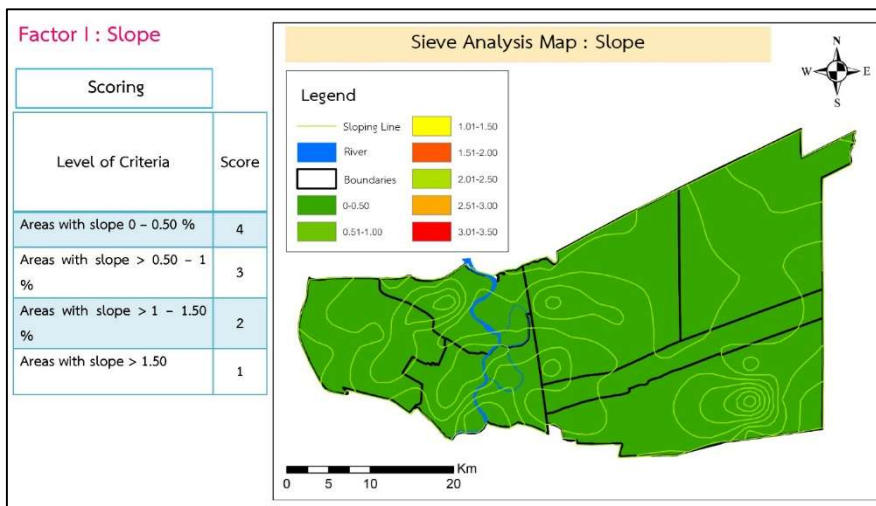


Figure 2. Methodology: Factor for Sieve Analysis (Slope)

Slope is an important factor for identifying flood risk areas as slope can affect how fast the flood waters can be drained. Areas with a small incline (0-0.5%) are considered as high flood risk and scored 4, while areas with an incline greater than 1.5% are categorized as low flood risk and scored 1. Areas with an incline of 0.5-1% and 1-1.5% are scored 3 and 2, respectively.

(2) Soil Type

The type of soil can affect the rate of infiltration. In Pathumthani province, there are two major types of soil: type 8 and 11. Areas with soil that has a lower infiltration rate are categorized as high risk. Soil type 11 has a lower infiltration rate, so it is scored 4, while soil type 8 is scored 1.

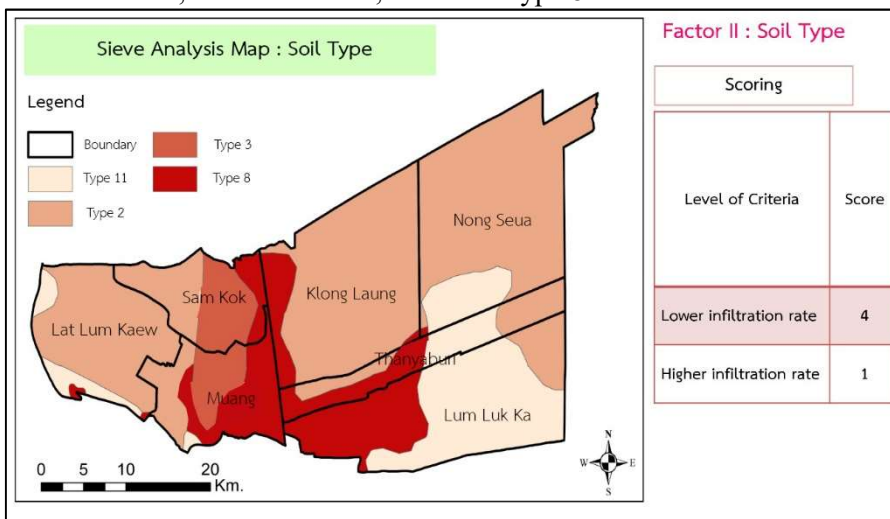


Figure 3. Methodology: Factor for Sieve Analysis (Soil Type)

(3) Land Use

Different land use types can impose different levels of water usage and drainage. Residential areas are considered to have the highest flood risk (and are scored 4), followed by commercial (scored 3), manufacturing (scored 2), and agricultural (scored 1) land uses consecutively.

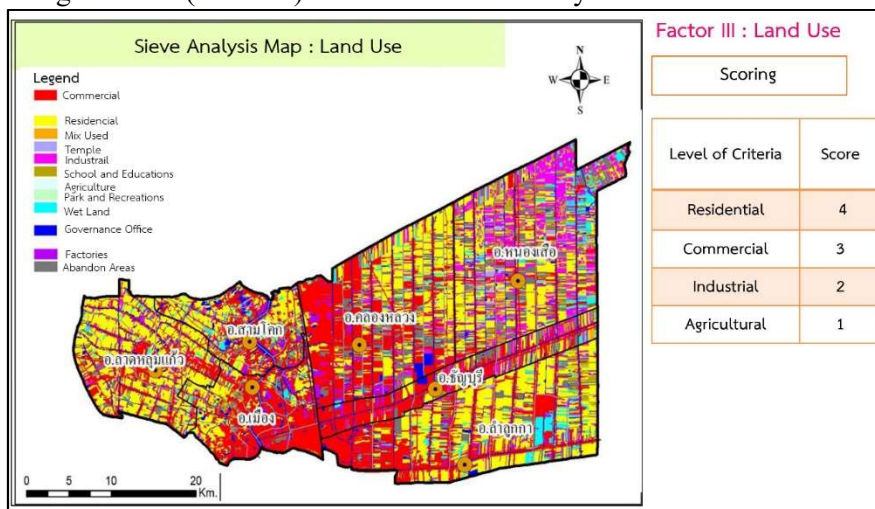


Figure 4. Methodology: Factor for Sieve Analysis (Land Use)

(4) Access to Communities

This factor classifies distances from main roads to assess community accessibility. Communities that are located near the main roads have lower risk than communities that are farther away. Communities located farther than 3 kilometers from main roads are scored 4. Communities near main roads (distance between 0-20 meters) are scored 1.

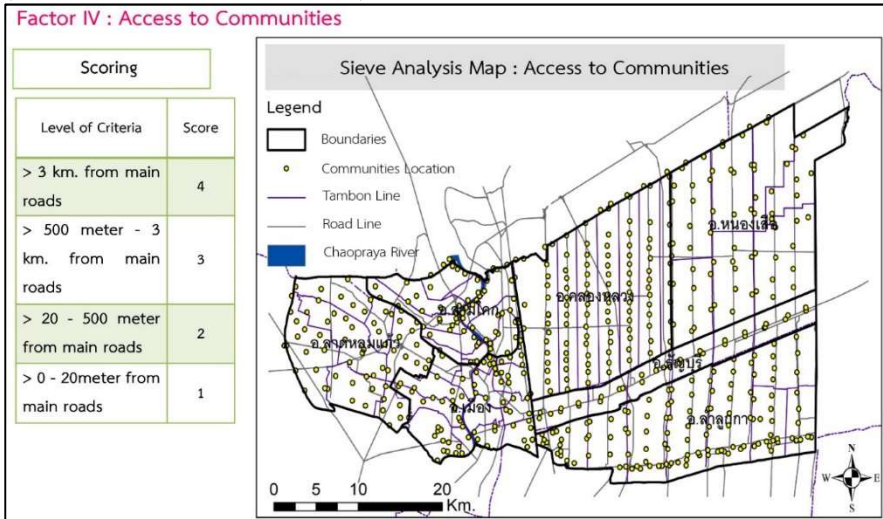


Figure 5. Methodology: Factor for Sieve Analysis (Access to Communities)

(5) Elevation

Elevation plays an important role in the flood risk of an area. Areas with higher elevation have a lower level of flooding. High elevation (150 meters above sea level) is scored 1, while the lowest elevation is scored 4.

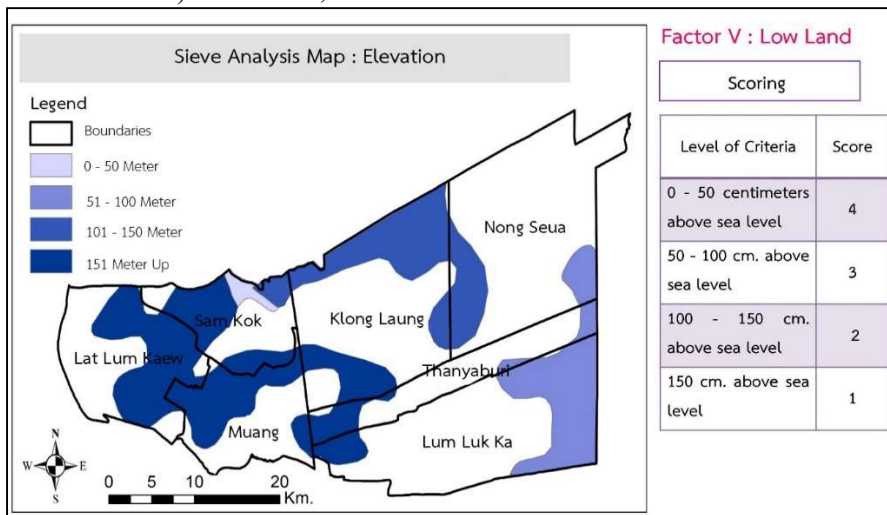


Figure 6. Methodology: Factor for Sieve Analysis (Elevation)

(6) Population Density

Areas are ranked and scored based on population density. Areas with high population density are considered at high risk of flood impact. High density

areas are scored 4, followed by large (scored 3), medium (scored 2), and small settlements (scored 1).

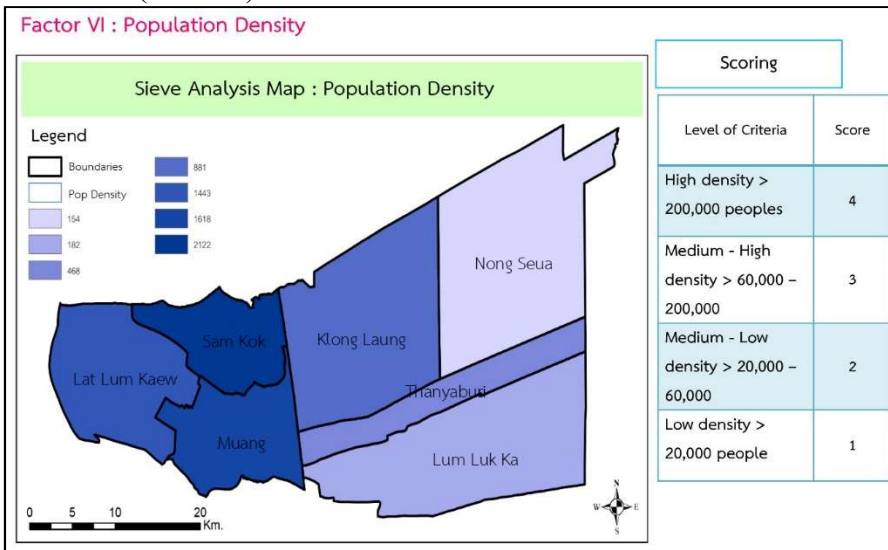
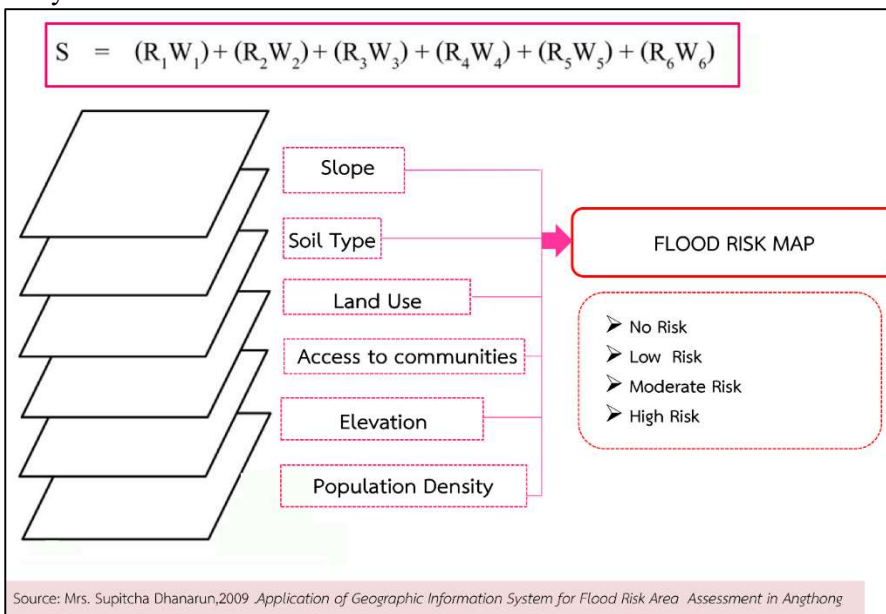


Figure 7. Methodology: Factor for Sieve Analysis (Population Density)

The Sieve Analysis method to analyze flood risk areas using an overlay analysis can be described as follows:



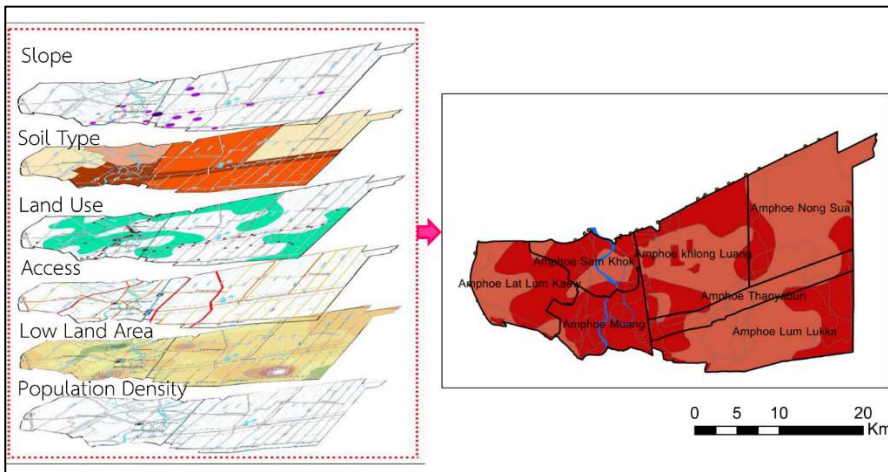


Figure 8. Methodology: Sieve Analysis

The research framework in *Figure 9* below describes the analysis process used to develop urban and regional planning measures in Pathumthani province.

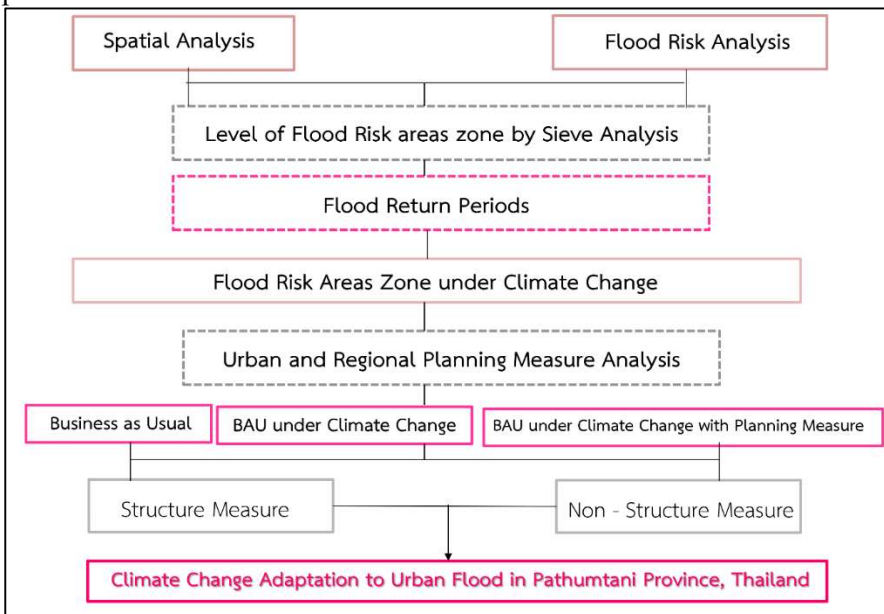


Figure 9. Research Framework

- (1) Analytic Hierarchy Process (AHP): Pair-wise comparison by two experts, an Urban Planning Expert and Geo Information Systems Expert
- (2) Pair-wise comparison matrix

Table 1. Structure of pairwise comparison matrix.

Pair - Wise Comparison Analysis							
Flood Areas Zone							
Score	Elevation	Soil Type	Land Use	Access	Flood Return	Population Density	
Expert Interview I	0.207	0.095	0.282	0.235	0.112	0.069	
Expert Interview II	0.129	0.182	0.372	0.186	0.077	0.054	
Total	0.336	0.277	0.654	0.421	0.189	0.123	
Conclusion	0.168	0.139	0.327	0.211	0.095	0.062	
							1.000

Source: Weighting and scoring by experts.

Table 2. Results of Weighting and Scoring

Factors	Index	Weighting		Scoring
		(W)	(R)	
Land Use	Built – up areas	32.7	4	130.8
	Commercial areas		3	98.1
	Industrial areas		2	65.4
	Agriculture areas		1	32.7
Access	> 3,000 meter from road line	20.5	4	82
	> 1,000 meter from road line		3	61.5
	> 500 meter from road line		2	41
	< 500 meter from road line		1	20.5
Slope	< 0 – 0.5	19.9	4	79.6
	> 0.5 – 1.0		3	59.7
	> 1.0 – 1.5		2	39.8
	> 1.5 UP		1	19.9
Elevations	Higher 0 – 50 meter	10.1	4	40.4
	Higher 50 – 100 meter		3	30.3
	Higher 100 – 150 meter		2	20.2
	Higher 150 meter Up		1	10.1
Soil Type	Rangsit soil type	9.5	4	38
	Thonburi soil type		1	9.5
Population Density	> more than 150,000	7.3	4	29.2
	> 100,000 – 150,000		3	21.9
	> 50,000 – 100.000		2	14.6

	< 50,000 Down		1	7.3
The level of flood impact risk				
Non Risk	represent	1	point	
Minor Risk	represent	2	point	
Moderate Risk	represent	3	point	
Major Risk	represent	4	point	

Built up areas are effected by floods categorized into four flood return periods:

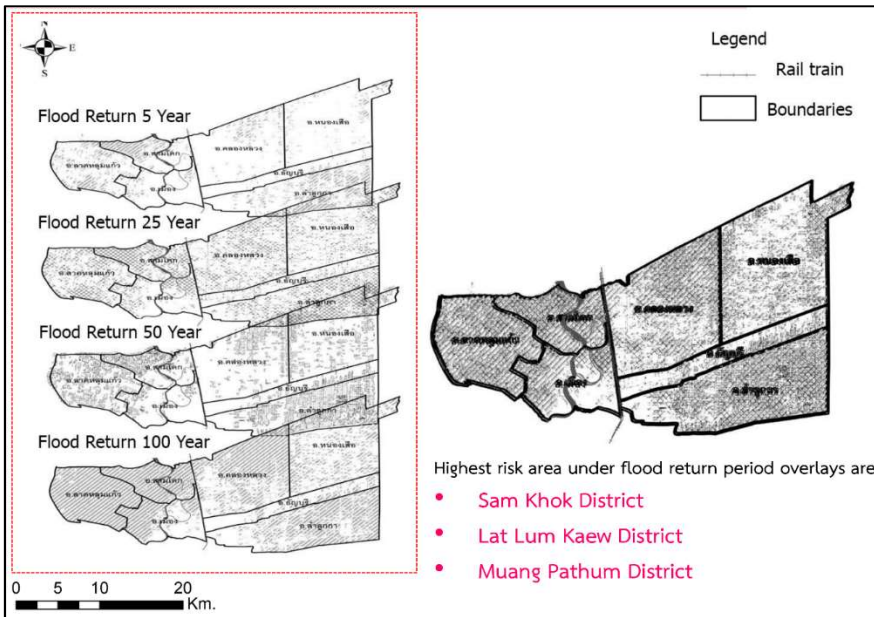


Figure 10. Flood return period in Pathumthani province.

4 THE RESULT MAP

The Sieve Analysis, done using the reclassify tools of ArcGIS, shows the risk of an area being exposed to a flood situation. From the result in Table 1, the main risk factors are land use activities, access and slope. The results in Table 2 also support this finding, with the less influential factors being elevation, soil type and population density.

The results map, see Figure 11, shows the risk classification for areas in Pathumthani, obtained through the Sieve Analysis completed using Spatial Analysis Tools. This research found the spread of flood impact risk to be mostly moderate or high risk areas. It is likely that under climate change conditions risk will only increase, in particular, the frequency of typically low frequency events will increase. Further research will use the results map to identify planning measures that can reduce flood impact risk and be used as a basis for adaptation planning for communities in Pathumthani.

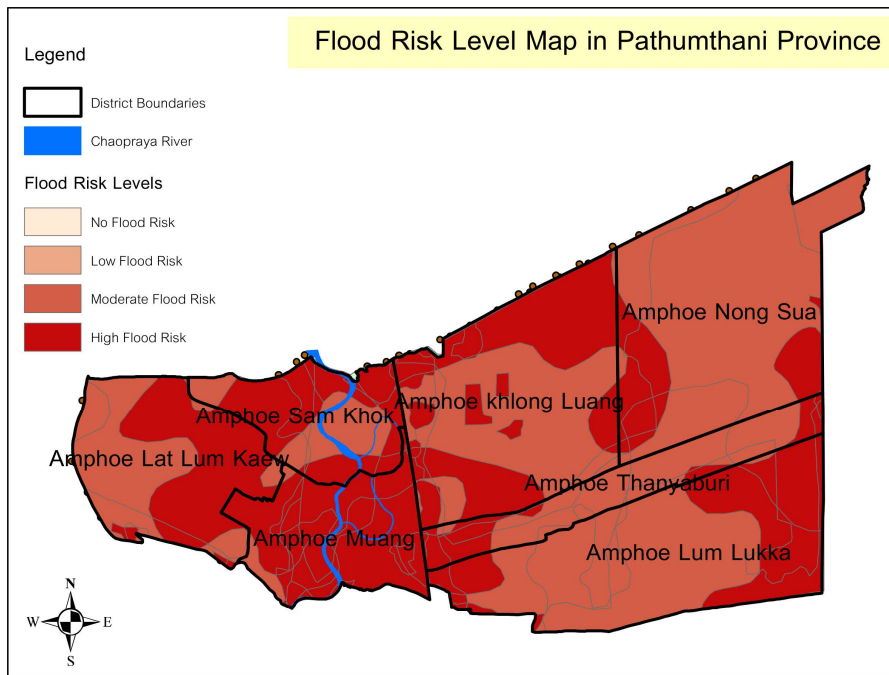


Figure 11. Result Map from Sieve Analysis

Finally, all factors weighted and scored are combined and overlaid to identify the most significant factors contributing to flood impact risk. The result map provides a useful tool and opportunity to raise awareness and enable sustainable development incorporating public participation at the local level. The results map shows areas that could most safely be settled, with the research identifying the high risk areas as the Sam Khok District, Muang District and Lat Lum Kaew District.

5 EXPECTED OUTCOMES

The results of this study will be used as guidelines for policies on urban planning for Pathumthani. The guidelines will shed some light on climate change adaptation plans for the province. The results will classify the types of land use changes, identify directions of urban growth, and estimate the risk of flood impacts under climate change in three scenarios:

- (1) Improve and develop zoning and building code,
- (2) Stipulate flood way and catchment area, and
- (3) Develop and present hard structure development projects.

The application of the study will suggest some revisions to local building codes and comprehensive plans of Pathumthani.

6 CONCLUSION

Pathumthani has increased high flood risk under a climate change situation caused by rapidly expanding urbanization and urban sprawl uncontrolled. The agriculture and wetland areas have been transformed to accommodate built communities and infrastructure; the inability for existing planning measures and also local plans and policy to control and cope with this land use change is the main concern of the people and policy makers. This research analyzed

the flood risk areas under climate change to assist in the development and planning of improved local plans to manage and serve as the basis of effective planning policy or planning measures to reduce flood impacts and improve adaptation for communities in these areas.

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Rural to Urban Transitions at Shanghai's Fringes

Explaining spatial transformation in the backyard of a Chinese mega-city with the help of the Layers-Approach

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Abstract: Delta's are strategic, but at the same time vulnerable ([Ke, 2014](#); [Balica, Wright, & van der Meulen, 2012](#)). This paper will explore the (spatial) consequences of urban pressure on Shanghai's rural fringes, focusing on the case of Chongming Eco-Island, which belongs administratively to Shanghai. The current top-down policy to transform Chongming into an Eco-Island is not yet working as promised in various policies. Via field observations, interviews with more than twenty-five stakeholders, and policy reviews, this paper explores to what extent the plans of the national government on Chongming Eco-Island are being implemented and how it is possible to steer the developments into a more sustainable direction. To be able to mitigate the negative impacts for the natural and man-made environment a transition in spatial planning and design approaches is urgently needed. For this to occur, it has to be made clear which factors can explain the process of seemingly unbridled urbanisation at Shanghai's fringes, and which role planning processes play in this development. The so-called Layers-Approach will be used to visualize this complexity of different spatial claims and interest. This approach has been proven to be useful as a tool for classification to be able to distinguish priorities and responsibilities for policy choices. Based on this, some recommendations will be made in this paper to steer the spatial development into a more resilient direction and hopefully mitigate the collateral damage for nature and society caused by current spatial planning and design practices.

1. INTRODUCTION

1.1 Extreme urbanisation in the context of a vulnerable delta

While in most parts of the world the majority of the population lives in urban areas, most of the people in Asia and Africa still live in rural conditions ([United Nations, 2014](#)), but this is changing rapidly. Unprecedented numbers of housing and urban infrastructures are appearing on former rural lands. A big share of this urban expansion occurs in river

deltas, which have always been strategic locations for trade and fertile grounds for food supply. However, deltas are also extremely vulnerable due to loss of fertile agricultural land, the loss of natural diversity, and flood risk, being key concerns that threaten life in urban deltas ([Campanella, 2014](#)).

Without doubt the most extreme and unprecedented examples (in terms of rapid and large-scale urbanisation) can be found in China, with millions of people on the move, currently cumulating in the formation of urban mega-regions ([Friedmann, 2005](#); [United Nations, 2014](#)) and ruralopolises ([Qadeer, 2000](#)). These new mega-regions are mainly economically defined without much consideration for underlying natural and historical landscapes.

Within China the Yangtze River Delta Region is currently the largest urban mega-region ([World Bank and the Development Research Center of China's State Council, 2014](#)) and nicknamed 'Head of the Dragon': opening its mouth to the world, with the Yangtze River as its body and tail. This accumulation of economic power and concentration of people in the Yangtze River Delta has deep historical roots ([King, 1911](#)); it is here where tensions between economic, spatial, and ecological interests are currently in an almost apocalyptic state.

During the last two decades, cities in the Yangtze River Delta have been expanding explosively with many hundreds of square kilometres of new urban areas built yearly, usually right on top of fertile agricultural and natural grounds of the delta. In terms of physical scale and economic impact Shanghai is the key player, centrally positioned in the Yangtze Estuary: economically strategic, but also extremely vulnerable when it comes to ecology, fertile agricultural lands, and flood risk ([Balica, Wright, & van der Meulen, 2012](#); [Brown, 1995](#); [Den Hartog, H., 2013](#); [Ke, 2014](#); [Wang, 2012](#)). An urgent concern is land scarcity, and this is worsened by a seemingly uncontrolled urban expansion and spatial fragmentation, causing inefficiency and even more loss of fertile land. A series of on-going land reclamations released the pressure temporarily; though they bring collateral damage to existing eco-structures and wetlands and increase the flood risk.

The confrontations are the most extreme and pressing in the urban fringes, due to the temporary transition zone between rigid urban expansion and still existing natural capital and rural values. For this paper Chongming Island in Shanghai is chosen as an illustrative case for the enormous urban pressure. First of all Chongming Island is a very pure, almost virgin case with high natural and agricultural values, since it has been isolated as an island until recently. Since 2009 it has been connected by a bridge-tunnel combination – before that it used to be hardly accessible. This has resulted in rapid changes in landscape, infrastructure, land use and lifestyle. Secondly Chongming Island has been appointed by the Central Government in Beijing as an Eco-Island since 2001: a National showcase and pilot to show the world how sustainability can be achieved. Thirdly, Chongming Island was the last rural county within Shanghai's direct-controlled municipality (equal to a province), and has received urban status since January 2017. The status quo of the island's rural to urban transition is rather unique and can clearly illustrate the current tensions in different spatial claims and ambitions regarding rural to urban transitions.

The island has a long history of urban influences and large-scale spatial interventions (e.g. large scale land reclamations and state farms in the 1960s, large scale relocation projects late last century and more recently the planning of a series of new towns). The island plays a main role in regional and even international eco-systems, especially as a resting place for migratory birds (the eastern tip of the island contains two Ramsar zones,

which were appointed in 2002 by the Convention on Wetlands of International Importance, on behalf of several UN agencies and international non-governmental organizations). In short the conflicts in land use and occupation are extremely felt here.

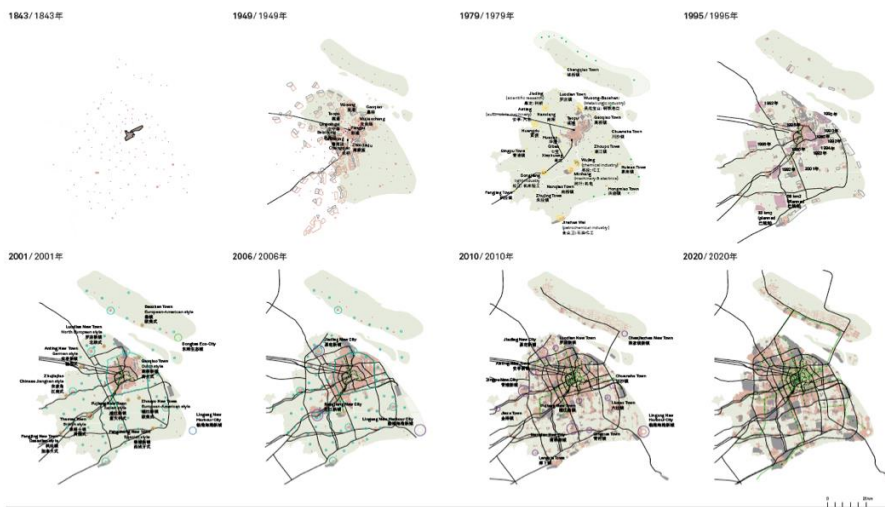


Figure 1. Urban growth of Shanghai's direct-controlled municipality (maps by author)

1.2 Sectorial and mechanical approach

Large-scale urban expansion requires good planning and good governance. Worldwide urban development processes have been dominated by modernism. Especially during the post-war part of last century the common idea was that blueprint planning could control social and physical processes. Currently the discourse is changing due to a series of dramatic natural and social clashes (e.g. Hurricane Katrina in New Orleans, 2005, Hurricane Sandy in New York, 2012) showing that a more flexible and resilient approach is urgently needed in spatial planning and design worldwide. This aims to bring the different spatial claims and interests (agriculture, economy, ecology, housing, water safety, et cetera) into a more sustainable and resilient balance (Scheffer, 2009).

Spatial planning and design in China faces two main problems. First of all, there is a lack of transparency in spatial planning processes, and inherently a lack of insight into how different factors relate to each other (Ho, P., 2001; Ho, S. P. & Lin, 2004). Secondly the governance system seems to consequently not be steering towards resilient solutions in this complex context. Usually GDP-oriented motives are dominant in the decision-making (He, Huang, & Wang, 2012). Chinese spatial planning and design practices are usually extremely rigid in their implementation, and at the same time seemingly random, often with a lot of collateral damage for the environment and quality of life. To be able to mitigate the impact on the natural and man-made environment an extreme transition in spatial planning and design approaches is urgently needed. The question is how to achieve this and how to improve resilience, for example in the complex case of Chongming Island and in the wider context of the Yangtze Delta.

Thus, the aim of this paper is to develop a proper understanding and theorization of the phenomenon of a seemingly uncontrolled spatial development, and to be able to propose recommendations toward a more

resilient metropolitan development that is able to mitigate the negative impacts on the natural and man-made environment. To reach a proper understanding and theorization, the Layers-Approach is applied. It supports an integrated approach by describing and analysing various spatial claims and interests, aimed to clarify what should be the priorities in decision-making.

1.3 Structure of this paper

This paper will analyse and interpret the spatial impact of the seemingly uncontrolled urbanisation in the rural fringes of Shanghai during the last decade, focusing on the case of Chongming Island in the context of the Yangtze River Delta's estuary. This island has a clearly defined border, thus the impact of the urbanization can also be clearly defined. The 'isolation' of the island ended by the building of a 25.5 kilometre long bridge-tunnel combination in 2009 and additionally since January 2017 the State Council transformed the administrative status of the island from (rural) county to (urban) district. Both changes resulted in clearly identifiable urban impacts. Although, already since the end of the millennium there are increasing classifiable urban influences, Chongming Island has been the focus of various policies and studies on national, regional and local levels since the beginning of this century, in the context of being one of the world's fastest growing and largest metropolitan regions.

In the urban transitions discourse there are research gaps on the consequences of unbridled urbanisation in the Chinese context, especially regarding the interrelations between eco-system functioning, socio-economic systems, and spatial qualities (Bucx et al., 2010). There is also a gap in integral approaches to linking developments in the different layers, e.g. urban-economic and natural development (Bucx et al., 2014).

To collect the needed information, more than thirty in depth interviews have been recorded with local stakeholders, public and private: one official on Shanghai's direct-controlled municipality level, one official on a local district level, two officials at township level, two developers, several architects and urban planners involved in various planning and design projects on the island, local entrepreneurs, inhabitants and other stakeholders. Additional relevant literature studies and policy reviews have been done, and more than a dozen field visits, including three workshops with students and local stakeholders have been undertaken during the last ten years by the author of this paper.

2. ANALYTICAL FRAMEWORK AND RESEARCH METHOD

Theoretical Framework

The main question is which factors can explain the process of seemingly unbridled urbanisation at Shanghai's fringes and which roles do planning processes play in this evolution? This is tackled by analysing the process, appearance and impact of a seemingly unbridled urbanization in Shanghai's rural backyard: the case of Chongming Island.

Using the Layers-Approach in urban planning

To reach a proper understanding and theorization it is essential to analyse and evaluate the spatial transformations in the past, present, and expected future of spatial configurations and responsible governance systems. To achieve understanding and theorization, the Layers-Approach ([Dammers et al., 2014](#); [Bucx et al., 2010](#); [Bucx et al., 2014](#); [De Hoog, Sijmons, & Verschuuren, 1998](#); [McHarg & Mumford, 1969](#); [Sijmons, D. F., 1991](#); [Sijmons, D. & Feddes, 2002](#)) is used as a theoretical framework.

The Layers-Approach has been very influential in planning practices worldwide, especially in the European context where it has been further developed since the 1970s ([Kerkstra & Vrijlandt, 1990](#); [De Hoog, Sijmons, & Verschuuren, 1998](#); [Meyer et al., 2012](#); [Sijmons, D. F., 1991](#)), with several successful practical samples such as ‘Room for the River’ in the Netherlands. This was a pilot application to develop a more resilient and adaptive spatial planning approach with the help of a spatial framework that works with nature instead of competing or ignoring it. However, the approach also received a lot of criticism in the discourse ([van Schaick & Klaasen, 2011](#)). Testing its principles in a different context, which is far more extreme and complex, is adding to the criticism and contributes to the validation and critical assimilation of scientific knowledge. Hence this approach could frame this critique and needs to be developed further into a tailor-made approach for the Chinese context.

The Layers-Approach has been developed as a critique on mechanical top-down approaches of planners and engineers worldwide, who have tried to control nature, and have therefore often led to vulnerable situations ([Campanella, 2014](#)). In the Chinese context, the old-school mechanical and top-down approach is ubiquitous and even more extreme, especially since Mao’s ‘Man must conquer nature’ doctrine ([Shapiro, 2001](#)). Natural capital and rural values around Shanghai, have been neglected for a long time in favour of rapid urbanisation. Current planning practises in the Yangtze River Delta are based on a tabula rasa approach, and are usually steered by GDP-oriented motives, hence resulting in serious disturbances of the delta as a coherent system and a loss of resilience. However, recently rising problems such as subsidence and flooding, and increasing risks for natural hazards, and additional environmental pollution issues, have created more awareness in the discourse, both nationally and locally.

The Layers-Approach has its roots in the ideas of Ian McHarg, who wrote the ground-breaking book *Design with Nature* ([McHarg & Mumford, 1969](#)) in which he explained that man should conform to nature and ecology and work with it instead of competing with it. McHarg developed a mapping method that distinguished multiple aspects of a plot of land into multiple stacked layers, the so-called ‘layer-cake’. The approach has been developed further by (amongst others) [De Hoog, Sijmons, and Verschuuren \(1998\)](#).

According to [Sijmons, D. and Feddes \(2002\)](#), the Layers-Approach is meant as a “quick witted policy instrument” that is strategic in organizing priorities in spatial planning and in analysing the positions, responsibilities and interrelations of the various actors. As a strategic instrument the approach is used to explain and organize relations between three layers and to distinguish the responsibilities and actions to be taken by the various levels of governance that are connected to these layers.

On the other side, the approach is used as a tool for spatial analysis to clarify how the three layers have influenced each other through the ages, with lessons for the future according to [Sijmons, D. and Feddes \(2002\)](#).

By approaching an urban region as a complex, layered, and dynamic system it will be possible to indicate the interrelations of various spatial processes. Within this complex layered system there are interactions among its three layers: the geo-morphological base (substratum), infrastructural systems in the middle, and finally land-use patterns (occupation). These layers or subsystems have different dynamics and development speeds but influence each other (see Figure 2). Mapping provides information about the ‘behaviour’ of a complex system – e.g. a delta region – focused on the way the three layers have influenced each other during the years. Based on this analysis, urgent key-issues can be identified regarding tensions between urban-economic and natural developments, aimed to discover the behaviour and path dependency of the system as a whole.

Table 1		Design and planning tasks	Approaches
Layer 1	Substratum	- Dealing with the physical effects of climate change - Modernising the water management system	- Nature engineering - Civil engineering
Layer 2	Networks	- Strengthening the position of the Netherlands in international networks - Control and steer the growth of mobility	- Complexes approach (developing nodes for exchange of information and knowledge) - Corridor approach (developing <u>mainports and hinterland connections</u>)
Layer 3	Occupation	- Accommodating spatial claims and shrinkage in relation to values and attractivity	- ‘Ecology’-approach (An ecology defined as a locally characteristic ‘life-style-environment’) - Mold-Contramold approach (city vs. landscape)
	Coherence	- Creating synergy between interventions	- Conditioning spatial planning - Facilitating spatial planning

Table 1 Design tasks and related approaches as they appeared in the analysis of almost 50 Dutch spatial plans for the Netherlands. The analysis organised the plans using the layers model. Source: De Hoog, Sijmons, Verschuuren (1998b)

Figure 2. Layers-Approach, according to [De Hoog, Sijmons, and Verschuuren \(1998\)](#)

According to the Layers-Approach there are private domains (mainly occupation), public domains (networks), and the natural system (substratum). The public domain should mainly set priorities – in the western discourse – according to the dynamics of the different layers, and interact with the natural system the most. However, this clear order is subjected to a political shift from a centralized government to a market-based structure (a more or less similar process of decentralization is gradually happening in China) that allows for new forms of bottom-up governance styles. This shift has consequences for the order of the Layers-Approach because this means that the occupation layer gains more structural importance in an urban development while before this was designated to the network layer. The question is how the relationship between the occupation layer and the network layer can be the most effective and steered towards a more resilient way in future developments, especially also in relation to the substratum.

Two processes are especially hard to control in urban deltas in general: physical-territorial processes under influence of climate change, and societal processes. Currently in the European context there is a shift towards ‘building with nature’ to create more space for ‘bottom-up processes’ in the natural system (which is the bottom layer). It is important to create conditions for those systems or layer with the slowest dynamics (i.e. the

substratum), to prevent hazards such as flooding, and at the same time indicate how and where conditions for urban and economic development can be created. These dynamics are extremely important in policy-making and defining responsibilities. Since the Chinese practice is still lacking transparency (although this is improving gradually), a better understanding of these responsibilities will be extremely useful for understanding the status quo, possible risks, and actions to be taken.

The European planning context of top-down steering is gradually disappearing. Initiatives and steering comes more and more from local governments. Meanwhile the bottom layer (substratum) is also in a phase of transition in terms of governance, where the focus on water safety and water quality by strong government bodies has gradually expanded with the involvement of nature and environmental organizations in projects. Thus, both in the bottom layer as well as in the top layer, there are currently transitions in the European context where the traditional technocratic approach is gradually making place for a new, more organic approach.

In the Chinese context, there still is a very dominant steering from above, although the implementation by local governments usually is decisive, without much hindering by the central government, through lacking supervision and differing aims and ambitions. Therefore, the Layers-Approach needs some adjustments to be a handy tool in the Chinese context, to clarify and categorize the various levels of governance and the responsibilities and actions to be taken.

The Layers-Approach will be used for the case of Chongming, firstly by identifying the various factors that impact its spatial development. An overview will be given of the most significant space-altering initiatives that have been deployed on Chongming Island that influenced the rural-urban transition, especially since the year 2000 when the urbanization pressure accelerated ([Den Hartog, Harry, 2010](#)). The Layers-Approach will be followed to develop basic knowledge on the conflicts on every layer and the interrelations and interdependencies between the three distinguished layers. Bottlenecks in the usability of the Layers-Approach in the Chinese context will be identified and fixed where necessary.

Secondly, an overview will be given of the conflicting ambitions of the different policy levels: the national, the regional (Shanghai's direct-controlled municipality in the context of the wider Yangtze Delta) and the local level.

Finally, these initiatives and changes are categorized, with help of the Layers-Approach, to create a general overview of the direction the island is going. Based on this, some recommendations will be made to improve the spatial planning practice.

3. CASE OF CHONGMING ECO-ISLAND

Chongming Island, strategically located in the midst of the Yangtze River's estuary just north of Shanghai, is China's national appointed Eco-Island, a wished-for model for sustainable development. One of its main features is Dongtan Wetland Park; an international, strictly protected Ramsar Zone for migratory birds.

However, Chongming Island's contemporary dynamics are extremely high. The household registration system on this island was changed into 'urban' in January 2017. This means that all the registered residents on the island will receive an urban hukou household registration, and thus direct

access to urban facilities ([Den Hartog, H. , 2015](#)). Simultaneously the local government and developers have got more opportunities for urban development, although still with restrictions under the eco-island policy. This will add to the already existing urbanisation pressure on the island that started to accelerate in 2009 with a new bridge-tunnel combination that connects the island to the rest of Shanghai. Additionally, a rail-connection is currently in preparation.

Chongming is the world's largest alluvial island, although a large part was reclaimed with polders during the 1960s. Since the eighth century, it has gradually formed from several smaller islands and sandbanks in the estuary of the Yangtze River. The northern and north-western edges are reclaimed from the river with dikes. During the Cultural Revolution, the tranquil island was an exile for thousands of intellectuals who had to work on state farms. Since 1958 it has become part of the direct-controlled municipality of Shanghai, before it was made part of the Jiangsu province. Chongming District also contains two smaller islands.

Chongming District counts approximately 660,000 officially registered inhabitants living mainly a rural traditional lifestyle, in sharp contrast to the Central City of Shanghai. This number may differ from the actual number of people since many are registered here but living elsewhere, in particular, the younger generation is increasingly leaving the island behind to find opportunities in Shanghai or other cities. Meanwhile there are also unregistered migrant workers doing agricultural jobs or work on shipyards and related industries. The main island contains several shipyards and spread out industrial developments, as remains from the policies of the 1960s. There are four small towns with some industries for electrical equipment, pharmaceuticals, metallurgy alloys, card stock and steel, as well as weaving, and spinning cotton. The land is mainly used for agriculture (large state farms and smaller family farms), fishing farms (eel and Chinese mitten crab), cattle breeding, and since recently, extensive recreation. Nowadays most inhabitants work in the fields for low wages, and while younger generations move to Shanghai for career opportunities, their parents build oversized country houses filled with furniture waiting for them to return. Due to its remote location, backward image, and strict limitations on urban and industrial development caused by the Eco-Island policy (Chongming Island has been appointed by the Central Government in Beijing as an Eco-Island since 2001), the opportunities for economic development and employment are marginal. Currently the rate of population aging on Chongming is the highest in all of Shanghai (29.7% in 2013, according to Shanghai's Statistical Yearbook).

3.1 Transitions following the Layers-Approach

This paragraph explains how a variety of human and natural interventions have changed the spatial structure of the island. This is explained further in this section following the classification of the Layers-Approach.

3.1.1 Transitions and challenges on the substratum or bottom layer

The coastline of the Yangtze River Delta has shifted eastwards over the ages. Recent land reclamations are in line with this and aim to keep balance with the expected future urbanization and agricultural needs. Besides the large-scale state farms on reclaimed land along the island's coastline (there are seven of them on Chongming Island built in the 1950s during the period

of the 'Great Leap Forward' policy) several recent land-reclamations have been used as 'land use compensation strategies' to allow the city of Shanghai to build urban areas elsewhere while guaranteeing food security. However, land reclamations make the delta as a system also more vulnerable to flooding and affect the ecological system negatively by losing wetlands ([Ke, 2014](#); [Wang, 2012](#)).

3.1.2 Transitions and challenges on the network layer

On 31 October 2009, the first phase of the Shanghai-Chongming-Jiangsu Tunnel-Bridge project (six lanes and two rail lines) was opened, reducing a 45-minute ferry trip to a 20-minute car drive and making the island a target development site, as announced officially on the opening day. Shanghai is now within commuting distance. The intention to include one or more eco-cities into the initial eco-island plans was to ensure enough jobs in the long run and to prevent people from commuting, which is essential from a low-carbon point of view. Besides being a connection to the outside world, the bridge-tunnel combination is making property values rise quickly, causing high development pressure, although there are restrictions on building new housing and industries. Directly adjacent to the bridge the price per square meter of new real estate projects are at least four times higher compared to previous newly built projects elsewhere on the island. Simultaneously, almost all newly built residences are bought by the upper middle class living in the central city of Shanghai (the central city is defined as inside the outer ring road) as second houses or speculative objects and remain uninhabited (according to three local officials and five local real estate sellers that were interviewed by the author).

3.1.3 Transitions and challenges on the occupation layer

Due to the improved infrastructure, a huge number of people visit the island for daytrips and weekend tourism, especially the wetlands, thus putting pressure on the ecological values there. Additionally, real estate values are booming. In mainly four locations, relatively large recreational real estate developments are taking place aimed at Shanghai's new upper-middle class who can afford a second home on the island for leisure and speculative investment. Chongming Island provides an attractive escape from the pollution and congestion of Shanghai, thus urban influence is likely to increase here.

To realise the ambition of making Chongming into a 'National Green Eco-Island' several economic compensation strategies have been put forward and rural tourism has become a new source of income. The number of visitors is still relatively low, because of the 'uncomfortable' lifestyle that contrasts a lot with the lifestyle of the new middle class in Shanghai and other neighbouring cities. According to the previous master plan for Chongming (2004; see Figure 3, below) one of the ideas to attract people to the island was to get Shanghai Disney there. Some entrepreneurs even launched the absurd idea to build a copy of Michael Jackson's Neverland Ranch and a zone for gambling. Although the Shanghai municipality fortunately has halted these initiatives, two golf courses and a resort with large expensive villas have been constructed, adjacent to the location of the planned eco-city. Another golf course is in preparation and there are also plans for horse racing tracks (for gambling) in consideration now.

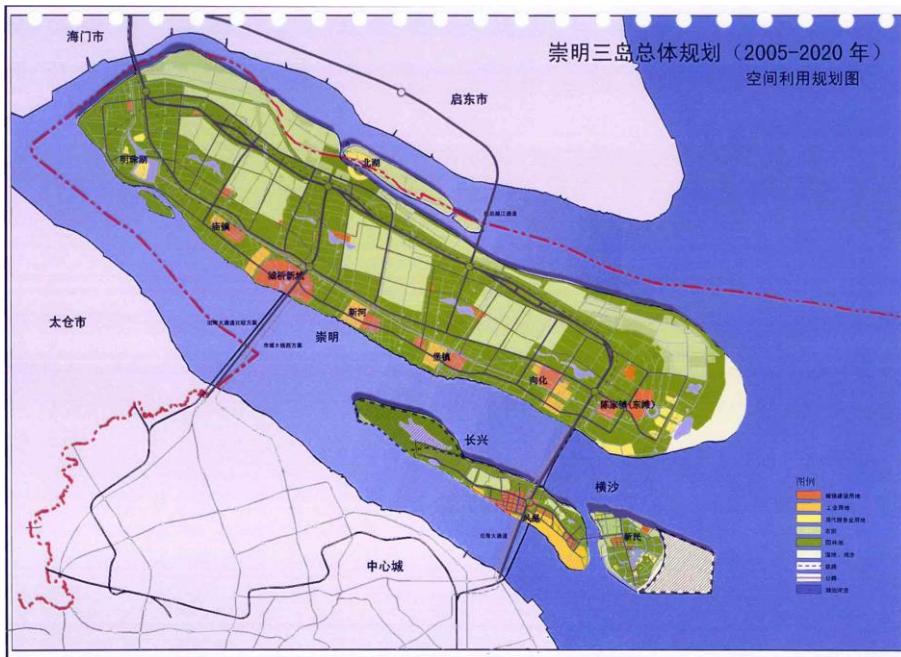


Figure 3. Chongming Master Plan 2005-2020

Recently more than 360 hectares of the former Dongping woodland has been transformed into Dongping National Forest Park for tourism. Simultaneously a part of the Dongtan wetlands (bordering the Ramsar zone with bird reserve) became an important tourist attraction, and on the former site of the Dongtan Eco-City, luxurious senior housing complexes are under development. These are without noticeable eco-features that differ from conventional housing, adding additional pressure on the local ecological and landscape values, especially since this car-based and quasi-Mediterranean architectural style built development is decorated with exotic flora – thus ignoring the local resources and eco-systems.

3.2 Conflicting policy ambitions

In China there are three de jure administrative levels, although de facto, the system is more complicated. Simplified the main three levels are: provincial level (Shanghai's Direct-controlled municipality is equal to a province), county and district level (Chongming used to be a county and became a district in 2017), and township level (Chongming island comprises of 19 towns and townships, of which two are situated in the Jiangsu Province). The difference between county and district is that a county has mainly a rural status and a district an urban status, with inherently different restrictions and regulations, such as the hukou household registration system that regulates access to services (Den Hartog, H., 2015).

China's governance system is currently organised in a strict top-down hierarchy. However, initiatives and decisions on a local level – especially by local governments, but also by the countless small and medium enterprises – are usually more decisive for achieving final results with far reaching consequences. Furthermore, there are huge discrepancies between top-down planning ambitions and daily life practices. Additionally, the economic and cultural gaps between urban and rural residents (as a result of the hukou household registration system) hinders the adaptation of local planning practices in rural areas such as on Chongming Island.

As opposed to most other countries, in China it is not possible to own land. China's land use system has mainly two types of ownership: state-owned urban land, and farmer collective-owned rural land. Although there are restrictions, rural land can be developed ([Huang et al., 2017](#)). Changing the formal land use from agricultural production to urban and industrial development is a critical process, especially in developing economies ([Yuan, 2004](#)). Developers can buy land-use rights, usually for 70 years in the case of residential land use and for 50 years in the case of industrial or commercial land use. Land use is strictly regulated and controlled, especially regarding agricultural use. However, as a result of economic reforms private investors can obtain land use rights from the government and even retransfer these rights to a third party. Consequently, land use leasing creates incentives for local governments to sell land use rights to generate income that can be used to finance urban, industrial and infrastructural projects ([He, Huang, & Wang, 2012](#)).

Since China was economically underdeveloped in comparison with western countries until late last century, currently the Chinese planning policies in general are in essence based on GDP-oriented motivations, aimed to catch-up economically. As a result, care for the environment and quality of life often is of secondary importance. China's latest Five-Year Plan however, indicates a demand for "People-oriented urbanisation", for which new planning approaches are needed. On a local level this meets many conflicts with local ambitions and practices, usually not looking beyond the political border, in combination with short-term goals, GDP-oriented motivations, a tabula rasa approach, and a lack of thorough market research combined with the urge to catch-up economically. This will be evident for the case of Chongming Island in the following section.

In 2001 Chongming Island was appointed as China's National 'Green Eco-Island' and pilot for sustainable development. However, so far this has resulted in several conflicts and misinterpretations ([Li, 2012](#)).

3.2.1 National policy ambitions

In 2001 Chongming Island was earmarked as China's national model for sustainability, energy efficiency and environmental awareness, and it became a national experimental zone for eco-civilisation. During the years more than 40 local and international firms and organizations have been invited to participate in various studies and design competitions for the whole island as well as for special cases such as Dongtan Eco-City and other proposed new towns on the island. In 2004 the American firm Skidmore, Owings & Merrill's winning urban and agricultural master plan for the whole island presented a combination of advanced agriculture as the island's major economic engine plus several compact transit-rich cities for a total of almost one million people along the southern shoreline. From the results a general structure plan emerged, made by SIIC (Shanghai Industrial Investment Holdings CO.,Ltd.), a government-funded real estate developer, in close cooperation with the Shanghai Municipal City Planning Administration.

In 2003 McKinsey & Company and Arup from the UK were invited to produce a development strategy for the case Dongtan Eco-City, a zero-carbon development for 500,000 people, which would become a pilot project within the context of the wider master plan for the whole island. On 9 November 2005 Hu Jintao and the former Prime Minister of the United Kingdom Tony Blair signed an agreement on trade, science, technology and education. This included the implementation of the plans for Dongtan Eco-

City as a joint project between SIIC and Arup. The intentions of this international cooperation were to make the 86 km² (including wetlands, buffer and recreation) Dongtan Eco-City the first self-sustaining city environment on earth by minimizing CO₂ emissions and maintaining social and economic sustainability, according to the previous master plan (2004). Arup was asked to design a dynamic post-industrial model city with respect for its natural surroundings and a minimum of economic constraints. The project should make it clear that China is willing and able to achieve sustainable solutions in the context of rapid urbanization. After the much-debated Kyoto agreement, the first substantial sustainable city would not be achieved by a Western developed country but by China, following these ambitions.

However, due to a political problem with (amongst others) Shanghai's responsible Communist Party Secretary in 2006 and additionally exploitation problems, the Dongtan Eco-City project came to a dramatic halt. Since recently the construction activities on the site started again, but without the original eco-ambitions though. And with strictly limited numbers of square meters yearly to be developed, due to restrictive policies for this sensitive location near the Dongtang wetlands. The new main target group for the current residential developments is wealthy aging people, all from Shanghai, according to SIIC. Two golf courses have been developed previously, near the former eco-city site, and on the site itself luxurious villas and apartments are under construction, also without any additional eco-features, surrounded by green decoration, mainly imported exotic plants that cannot grow in a natural way without intensive care by gardeners. The term 'eco-island' has been abused for 'green washing' here.

3.2.2 Regional policy ambitions

Chongming is the last remaining mainly rural and open part within Shanghai's direct-controlled municipality. Regionally the island can be seen as a green lung in the context of the densely populated Yangtze River Delta Region.

However, Shanghai's government has been looking at overall priorities in terms of development options around Shanghai since late last century. The island used to be one of the main rice bowls of the region, but this function seems to have become less important now. Chongming Island as a whole presents clearly a major opportunity for development. In the late 1990s, before the development of Lujiazui, there were already serious ideas to make 'a second Hong Kong' on the south-eastern tip of the island, a Special Economic Zone according to professors who have been involved as advisors for the eco-island concept development. Mainly due to the remote location and the still missing bridge, finally it became favourable to choose Lujiazui as a CBD and other parts of Pudong as Special Economic Zones, but not Chongming. This was in the late 1990s just before the Eco-Island policy was introduced.

This Eco-Island policy aims to safeguard the island from massive urban development to preserve especially the natural, but also agricultural qualities of the island. However, the recent conversion of the island into an urban district (since January 2017), and the earlier construction of the bridge-tunnel combination and the scheduled rail connection, make it very clear that regional ambitions still go further than keeping the island rural and green.

3.2.3 Local policy ambitions

Since the population is aging rapidly, due to lack of attraction and employment opportunities for younger generations, the local ambition is to generate income with real estate development projects and some additional (eco) tourism, aimed at the new middle class of the central city in Shanghai.

In the Master Plan for Chongming Island (2001) a series of new towns and (light) industrial zones have been scheduled along the south coast to support the local economy by creating jobs and facilities for the island's inhabitants. Since the start of the eco-island policy these new urban cores, which are mainly extensions of already existing settlements, have developed gradually, according to plan. Meanwhile however, on a smaller scale many sprawling developments have taken place in the rural areas where farmers have built countless new houses for themselves and for their offspring – similar to elsewhere around Shanghai and in the wider Yangtze River Delta Region. It seems that the restrictions on land use and construction activities have only partly been efficient so far, although since recently there is more strict supervision on limiting the building of new rural housing.

The township Haiyong, which is located at the northern tip of the island and belongs to the Jiangsu province, is illustrative of what can go wrong if there is no supervision. As a result of the natural sedimentation process over the years, the old natural border, on which the municipal border is based, has shifted to the north. As a result, almost 50 square kilometres of the 1,271 square kilometre large Chongming Island belongs to the Jiangsu Province, which is not covered by the National 'Green Eco-Island' policy. This part belongs to the township of Haiyong, which is under the jurisdiction of the City of Nantong on the other side of the river, who have greedily used this opportunity to develop a new town here for 100,000 inhabitants, named 'Long Island'. The development started with reclaiming land on top of former wetlands and tidal flats in 2013, which is relatively easier than converting agricultural land use into urban land use. In 2015 housing construction had already started, mainly villas and 40-floor-skyscrapers, which are technically full of risks such as subsidence and flooding. The worst problem is perhaps the ecological damage. More than five square kilometres of former wetlands have been erased here in favour of profitable real estate. More than 95% of the buyers of this real estate are families from Shanghai, who use these houses purely as speculative investment opportunities and possible weekend retreats, thus are not for their main living.

This so-called 'Long Island' project was initiated by the municipality of Nantong and Greenland, a large real estate developer from Shanghai. Warned by news coverage on CCTV late last year the central government in Beijing brought a halt to this project. Currently, a core team of specialists from Jiangsu province and Shanghai's Direct-controlled Municipality are trying to reach a consensus on how to proceed with this project. The first idea is to massively reintroduce greening here by planting trees. Some of the already built skyscrapers might also be destroyed as a symbolic act.



Figure 4. Sales centre for real estate on former wetlands (Photo by author, 2017)



Figure 5. Remnants of wetlands, waiting for urban development. On the horizon high-rises in the Haiyong township in Jiangsu Province, constructed since 2014 on former wetland and tidal flats. (Photo by author, 2017)

There obviously is no strict supervision on the implementation of the master plan and Eco-Island policy regarding land use limitations, at least not in the part that belongs to Nantong. Furthermore, the local government, both on the district level and township level, seem to have slightly different interpretations about the translation of the eco-island ambitions into practice. A big share of the implemented greenery along main infrastructure routes,

e.g. in Dongtan and Haiyong, is imported exotic and decorative greenery, and without much ecological value.



Figure 6. Wetlands north of Haiyong township in 2004 (Source: Google Earth, 11 February 2017)



Figure 7. Same location as Figure 6, Haiyong township with land reclamation and real estate development (Source: Google Earth, 11 February 2017)

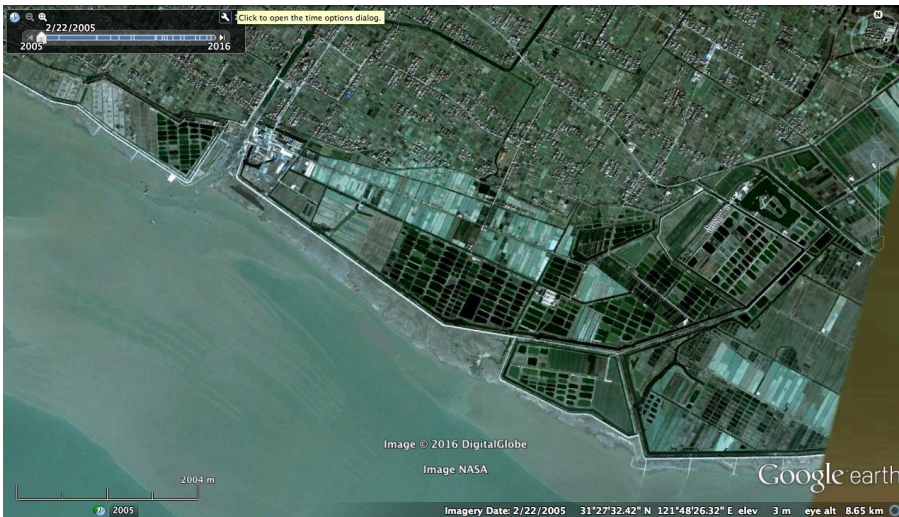


Figure 8. Dongtan in 2005 with fish farms and rice paddies (Source: Google Earth, 11 February 2017)



Figure 9. Same location as Figure 8, Dongtan in 2016 with golf courses and villas (Source: Google Earth, 11 February 2017)

4. DISCUSSION

China's rapid changing economy and society are not reflected in a change in spatial planning: the city is still regarded as 'a machine for living' without a direct relationship toward its natural, historical culture nor societal context.

Planning practises in China are mainly based on a tabula rasa approach, resulting in serious disturbances and conflicts between the different layers following the Layers-Approach. The bottom layer, the substratum, is often ignored.

In the Western discourse, however, the Layers-Approach promotes the bottom layer, the substratum, as the leading one in setting governance priorities. The middle layer, the infrastructural or network layer, functions as steering, to serve the occupation layer, although this is changing. In the case

of China, the Layers-Approach can be seen as a guidance tool to set priorities again for the substratum as foundation, to respect ecological values and to learn how to build with nature. However, the practice in China, as illustrated for the case of Chongming, is very different from this theory. The urge to catch-up economically gives the occupation layer absolute top-priority. Meanwhile the network layer is still serving, though usually totally ignoring the substratum.

Planners and policymakers in China have neglected the rural areas around Shanghai during the last two decades, while all attention went to urbanization, and followed the ambition to change Shanghai's Central City into a service-oriented prosperous international metropolis. One of the side effects of this is a serious polluted rural water system and the disappearance of many traditional water based rural communities.

The international expectations about the definition and implementation of an eco-island also do not match in the case of Chongming, since there are different priorities and aims, especially on a local level. The development of China's rural areas, in this case the rural fringes of Shanghai, are obviously in a different development phase with very different social and economic priorities. There is a pressing urge to catch up economically. Furthermore, there seems to be a discrepancy between top down planning ambitions, local practices and daily life.

Moreover, the eco-island policy on Chongming is not strictly controlled and implemented all over the island. The eco-label locally has been explained as 'green decoration' to market real estate and improve a feeling of comfort for the new middle class. Chongming Island is in a phase of beginning gentrification where the new (upper-) middle class is taking over while ignoring the local socio-cultural and spatial qualities. The trend is that main parts of the island become a backdrop for the city, which can be beneficial for the island economically, but conflicts strongly with the eco-island promises.

The main challenge is to find a balance between economic growth and protection of the environment and spatial qualities. Currently the increasing focus on eco-tourism and elderly communities (some consist of more than a thousand units, even with high-rises) forms a threat for local spatial qualities and, in some cases, also for ecological qualities.

A new spatial planning approach requires a search for a new balance between, on one side, the physical-spatial system of the urban delta and the needed interventions, and on the other side an adjusted practical governance system, in which the challenge is to find the best way of matching bottom-up and top-down processes. In the Chinese context, the top-down approach is still omnipresent, but in reality initiatives and decisions on a local level, by local governments and developers, sometimes even by (influential) local residents, are far more critical factors.

Since recently China's spatial planning and design climate has been in transition, gradually opening up, and shifting toward more small scale and locally oriented developments. Another glimpse of hope is that on a small scale there are more and more promising local initiatives, often with the help of citizens from elsewhere who are willing to 'adopt' rural lands – for example eco-farmers, who also play a role in disseminating knowledge on things such as organic farming to local farmers, community-supported agriculture or even facilities for eco-tourism.

To steer the spatial development into a more resilient direction, an integral approach is essential. This needs to go beyond the Layers-Approach and should also include socio-economic and social-cultural factors.

Residents and other stakeholders on Chongming Island, and also in many other rural cases, are facing different priorities and needs. Daily realities also need to be considered in the spatial planning and other development policies, otherwise it will be hard to steer spatial development in a sustainable way. The increasing economic and cultural gap between local residents and newcomers on the island leads to fundamental conflicts, with dramatic spatial, ecological and socio-economic consequences. Knowledge dissemination and capacity building under local stakeholders is crucial. Simultaneously, better guidance and supervision are essential, preferably by a team of independent experts. The Layers-Approach can become a handy tool in this to distinguish priorities and responsibilities by policy choices. Consequently, the relationship between the occupation layer and the network layer can become more effective and be steered towards a more resilient approach in future developments, especially also in relation to the substratum. Re-appreciating and working with existing natural values, landscape and water systems, could become a new pathway, consequently mitigating the vulnerable balance between nature and society and making the delta as a system more resilient.

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CONFLICTS OF INTERESTS

The author declares no conflict of interest.

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3D Insolation Colour Rendering for Photovoltaic Potential: Evaluation on Equatorial Residential Building Envelope

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Abstract: Photovoltaic (PV) installation potential on residential building envelope in equatorial region was analysed by 3D insolation colour rendering employing BIM Revit solar analysis tool. Monthly global solar radiation calculation was employed to investigate solar potential in study case area. Actual energy consumption of residential sector was used as a base to predict energy demand for next 10 years. Predicted energy demand was then used to calculate the area needed for photovoltaic installation to balance future energy demand. The energy consumption by residential building was divided into five different installed electrical power capacities namely 450 Watt, 900 Watt, 1300 Watt, 2200 Watt and 3500-6600 Watt. Study results suggest that the potential location of photovoltaic panel installation on detached houses is on the roof, East, and West walls. Abundant solar energy in equatorial region was proved by high potential of PV energy generation 7 – 9 kW/m² for amorphous silicon, 17 – 18 kW/m² for polycrystalline silicon, and 19 – 23 kW/m² for monocrystalline silicon. The roof element alone can provide sufficient electrical energy generated by installed photovoltaic panels for the next 10 years. The area needed to supply 450W – 6600W installed power capacity were 13 – 75 m² for monocrystalline silicon, 23 – 120 m² for polycrystalline silicon, and 50 – 259 m² for amorphous silicon. To conclude, implementation of photovoltaic installations on residential buildings have a huge potential to secure not only recent energy consumption, but also future energy demand.

1. INTRODUCTION

Renewable energies have gained popularity and have been widespread on residential buildings for the past few decades due to depletion of energy resources and global warming issues. Most common renewable energy generation method used in residential buildings was photovoltaic panel (Yoza et al., 2014). Some reasons have led to this phenomena such as: it did not create noise, releases no pollution (Lukač et al., 2014; Mondal & Islam, 2011), and is easy to integrate with existing building (Vieira, Moura, & de Almeida, 2017). In generating energy, several factors influence photovoltaic

productivity namely: photovoltaic panel (tilt angle, type and area) and climatic elements (irradiation, ambient temperature, and wind speed) (Othman & Rushdi, 2014; Lang, Ammann, & Girod, 2016).

When photovoltaic panels are installed on the building envelope, its productivity will connect to the building’s design features, like the building orientation, building geometry, and roof geometry. Influence of adjacent construction and vegetation also must be included in consideration for it can create shaded areas thus decreasing photovoltaic productivity. This study introduced a 3D insolation colour rendering method to visualise the amount of photovoltaic energy generation and potential shaded area on building envelope which will be helpful in evaluating photovoltaic potential.

Photovoltaic potential is often assessed by technological or economical evaluation (Fath et al., 2015; Lang, Ammann, & Girod, 2016; Mondal & Islam, 2011; El-Shimy, 2009; Seng, Lalchand, & Lin, 2008). The potential has been evaluated by photovoltaic energy generation based on total annual solar radiation (Hofierka & Kaňuk, 2009; Lukač et al., 2014), surfaces for calculation predictions have mostly been limited only to roof implementation, and results generally displayed as numbers or diagrams (Matrawy, Mahrous, & Youssef, 2015).

This study addresses photovoltaic potential by capacity of total building surface area in providing sufficient electricity energy for future energy demand. This potential evaluation was drawn from optimal placement of photovoltaic installation within the building envelope which is best presented by insolation coloured 3D modelling (Figure 1). Future energy demand in this study was projected based on ten years of actual energy consumption by residential sectors. Instead of annual solar radiation data, this study used monthly global horizontal irradiation data to calculate photovoltaic energy generation, thus it can be compared with monthly energy demand.

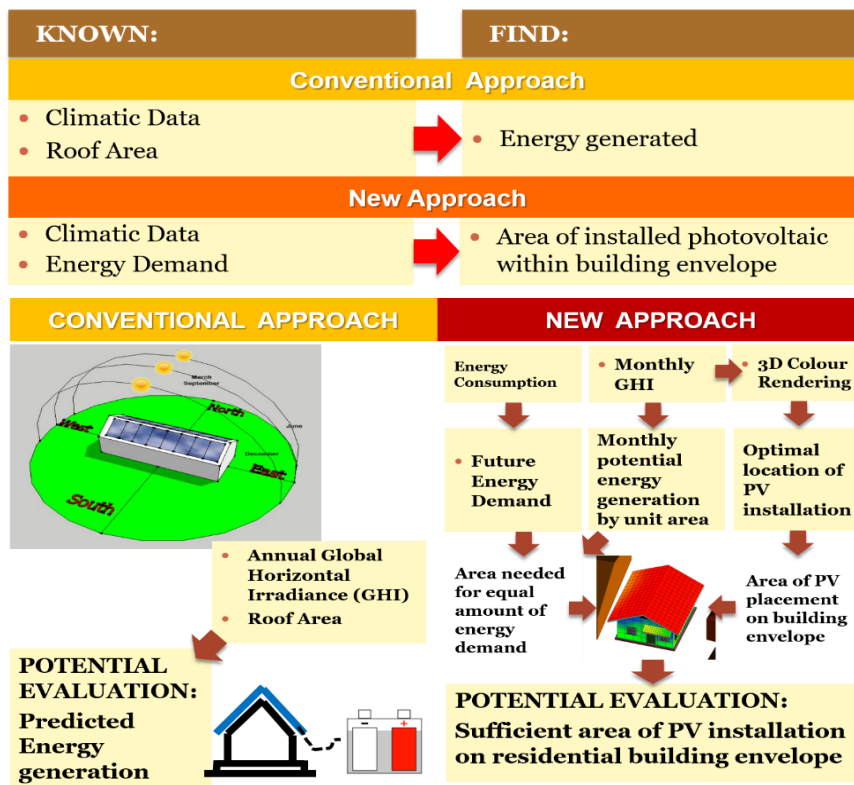


Figure 1. Proposed Approach of Photovoltaic Potential Evaluation

In photovoltaic potential studies, certain methods and tools have been utilized including calculation software such as HOMIE ([Lang, Ammann, & Girod, 2016](#)), Open-source solar radiation tools and 3D city models implemented in GIS ([Hofierka & Kaňuk, 2009](#)), and HOMER ([Mondal & Islam, 2011](#); [Adaramola, 2014](#)). These software calculate for a large-scale area thus resulting in a large deviation on calculations when implemented on an individual building. Several software can be employed in building scale such as Radiance, EnergyPlus, and TRNSYS software ([Vuong, Kamel, & Fung, 2015](#); [Fath et al., 2015](#); [Shan et al., 2014](#)). However, the simulations performed by these software are based on several simplifications of building form. Hence, detailed form of building are often not included in calculations.

Photovoltaic simulation performed on BIM Revit software includes detailed calculation on building form and adjacent construction. BIM Revit software is a three-dimensional building design tool which is widely used by architects and building engineers. It has comprehensive information on 3D models and can perform realistic colour rendering. The software has released analysis tools that can help to analyse solar potential in building design. Analysis tools ensure that building design is optimized for maximum performance ([Gupta et al., 2014](#)). Required information of a given building ([Ham & Golparvar-Fard, 2015](#)) can be directly obtained from the Revit model, thus minimizing the time to construct solar models. Previous studies have verified the accuracy of the BIM Revit energy analysis for building installed photovoltaic in electricity production simulations ([Kuo et al., 2016](#)). Hence, it is the suitable choice to be employed in this study.

Hypothetical residential buildings were constructed on BIM Revit software based on three existing buildings in Palu City, Indonesia. Palu is the capital of Central Sulawesi Province. The city with the third most severe electricity crisis in Indonesia. For decades, this city has experienced rotating electricity blackouts about 5 to 8 hours a day. This condition is in contrast with its potential in harvesting solar energy.

Situated in the equatorial belt, daily horizontal irradiance in Palu City has a great potential for solar energy generation which ranges from 5.32 kWh/m² to 6.51 kWh/m². Residential buildings are the largest sectors in electricity consumption in this city (State Electricity Enterprises and Ministry of Energy and Mineral Resources, 2015). Therefore, installation of photovoltaic panels on residential building envelopes can serve as domestic energy generation, hence, it can help the city to suppress electricity shortages.

This study aims to evaluate the potential of photovoltaic installations in equatorial regions based on the available surface area of residential building envelopes to satisfy future energy demand. Optimal photovoltaic location within the building envelope and the size of available area for photovoltaic installation to meet future energy demand, are the focus in this paper. Efforts were then made in this study to visualize the optimal placement of photovoltaic panels and the potential of shaded area on building surfaces for analysis purposes.

A study which investigates the area of optimal photovoltaic placement on the building envelope, especially in the equatorial region, is still considered outstanding. Hence, it is expected that the results of this study can contribute to the body of knowledge by presenting building parameter considerations for optimal photovoltaic installation in the equatorial region that accounts for both self-shading of the building geometry and shading from adjacent structures. The proposed method is applicable for practical photovoltaic potential evaluation and visualization at the scale of individual or clusters of buildings. The method will be useful for planners and building designers to evaluate

photovoltaic potential installation not only at the design stage for new buildings, but also for existing buildings as well.

2. METHOD

2.1 Solar Potential Analysis

Solar potential in this study is defined as the potential suitability of a given surface for photovoltaic installation (Lukač et al., 2014) evaluated from the total daily estimated irradiance throughout a month. Solar irradiance data was converted from recorded sunshine duration data by local weather stations over a period of 5 years from 2011 to 2015. The average value of solar irradiance from each month of the year was used for the evaluation.

Conversion of sunshine duration to horizontal global irradiation was calculated by the following equation (Markus & Morris, 1980; Koenigsberger et al., 1974; Szokolay, 1987):

$$D_h = D_{oh} \times (0.29 \cos Lat + 0.52 (n/N)) \quad (1)$$

Where D_h refers to horizontal global irradiation (Wh/m²), D_{oh} refers to horizontal global irradiation at the upper limit of the atmosphere at the same location (Wh/m²), Lat denotes geographical latitude, n denotes sunshine duration, and N denotes possible sunshine hours a day. D_{oh} Can be derived from the following equation (Brock, 1981; Szokolay, 1987):

$$D_{oh} = G_{on} \times (24/\pi) \times \cos Lat \times \cos Dec \times \sin SSH + (SSH \times \pi/180) \times \sin Lat \times \sin Dec \quad (2)$$

Where:

G_{on} refers to adjustment for the time of year, the extra-terrestrial normal irradiance. The solar constant (G_s) is **1353 W/m²**, and the number of the days after 1st January (the Julian Day) as NDY (Table 1).

$$G_{on} = G_s \times [1 + 0.033 \times \cos(360/365 \times NDY)] \quad (3)$$

$$DEC \text{ refers to solar declination} = 23.45 \times \sin [(360/365) \times (284 + NDY)] \quad (4)$$

$$SSH \text{ denotes sunset hour angle} = \arccos (-\tan Lat \times \tan Dec) \quad (5)$$

Table 1. Recommended average day for each month and values of Julian day by month (Duffie & Beckman, 2013)*

Month	Date	Julian Day (NDY)	Declination (°)
January	17	17	-20.9
February	16	47	-13.0
March	16	75	-2.4
April	15	105	9.4
May	15	135	18.8
June	11	162	23.1
July	17	198	21.2
August	16	228	13.5
September	15	258	2.2
October	15	288	-9.6
November	14	318	-18.9

December	10	334	-23.0
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* The average day which has the extra-terrestrial radiation closest to the average day for the month.

2.2 Photovoltaic Location Analysis

Potential shaded areas on a building envelope can be easily determined by visualizing the estimated solar energy density in three-dimensional (3D) colour rendering rather than by displaying it through mathematical calculation. The insolation received by the building envelope will be associated with surface colour where red represents the highest and blue refers the lowest insolation value. A bright-red colour indicated that the area of the envelope was less shaded while the dark-blue colour showed severely shaded areas. From this coloured envelope, the optimal placement for photovoltaic installation can be determined immediately.

BIM Revit software was used to construct 3D Models and to visualize incident solar radiation (insolation) that falls on the building envelope by employing the built in solar analysis tool. Location of photovoltaic panels was determined using monthly cumulative insolation received by the building envelope (walls and roof). Climate data including solar radiation data used in BIM Revit software was accessed through a cloud server called the Autodesk Climate Server that compiles data from both physical weather stations (at airports) and from meteorological simulations.

The incident solar radiation calculation in BIM Revit is computed as:

$$\text{Incident solar radiation} = (I_b \times F_{\text{shading}} \times \cos(\Theta)) + (I_d \times F_{\text{sky}}) + I_r \quad (6)$$

Where: I_b refers to direct beam radiation, measured perpendicular to the sun, I_d refers to diffuse sky radiation, measured on a horizontal plane, I_r refers to radiation reflected from the ground, F_{shading} is the shading factor (1 if a point is not shaded, 0 if a point is shaded, a percentage if measured on a surface), F_{sky} denotes the visible sky factor (a percentage based on the shading mask), and Θ denotes the angle of incidence between the sun and the surface being analysed.

The simulation was conducted in three selected months; March, June, and December. These months represent the nearest and the farthest sun position towards the earth sky.

2.3 Area of Photovoltaic Placement Analysis

A guide to the basic available solar energy usually estimated by total annual solar radiation on a tilted surface is used so that the output is maximised. Energy generation from photovoltaic installation is often calculated from the following expression ([Lang, Ammann, & Girod, 2016](#); [Mandalaki, Papantoniou, & Tsoutsos, 2014](#)):

$$P_{PV} = G \cdot \eta \cdot PR \cdot \beta \cdot A \quad (7)$$

Where, G refers to horizontal irradiance (Wh/m²), η denotes module efficiency, PR denotes performance ratio of the complete system before temperature effect, β refers to correction factor compared to a horizontal panel, and A refers to total panel area.

Electrical energy generation from photovoltaics is calculated for three types of solar technology in this study, monocrystalline, polycrystalline and amorphous silicon (Table 2). While several researchers estimated the photovoltaic potential of power generation based on total annual solar

radiation ([Lang, Ammann, & Girod, 2016](#); [Mondal & Islam, 2011](#)), this study uses a monthly calculation in order to investigate PV power generation within different months.

The potential of energy output from photovoltaics can be calculated per unit area (m^2) with area (A) equal to 1, so the expression will be:

$$P_{PV \text{ per unit area}} = G \cdot \eta \cdot PR \cdot \beta \quad (8)$$

The area needed for photovoltaic placement on the building envelope to fulfil energy demand by the residential building can be drawn by dividing actual energy consumption with potential energy generation per unit area.

$$A_{PV} = E_c / P_{PV \text{ per unit area}} \quad (9)$$

Where, A_{PV} refers to the needed area for fulfilling energy demand, E_c denotes actual energy consumption, and $P_{PV \text{ per unit area}}$ indicates generated electrical power by installed photovoltaic per unit area.

Table 2. PV Technology Efficiency used in Calculation

PV Technology	Efficiency	Power deviation	Performance Ratio
Monocrystalline silicon	15%	$\pm 3\%$	0.933
polycrystalline silicon	12%	$\pm 3\%$	0.941
Amorphous silicon (thin film cells)	5%	$\pm 5\%$	1.046

Adapted from ([Lukač et al., 2014](#); [Jelle, Breivik, & Røkenes, 2012](#)).

2.4 Case Study: Palu City, Indonesia

Palu is located in the centre of Sulawesi Island which is one of the biggest islands in Indonesia. It is astronomically situated between $0.36^\circ\text{S} - 0.56^\circ\text{S}$ latitude and $119.45^\circ\text{E} - 121.01^\circ\text{E}$ longitude, with $0 - 700$ m height above sea level (Figure 2). The climatic conditions in this area are categorized as tropical warm and humid climate. The city covers a total land area about 395.06 km^2 and is inhabited by 342,754 people.

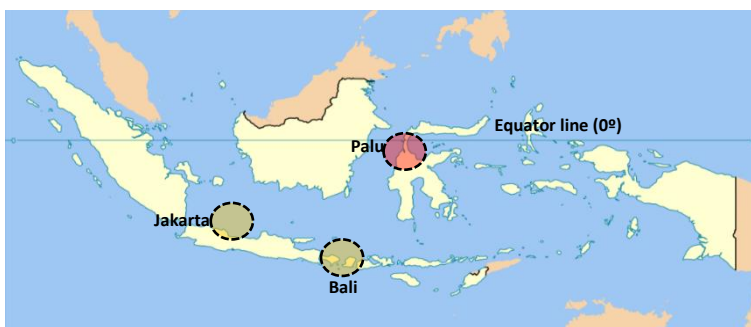


Figure 2. Palu location in Indonesia archipelago







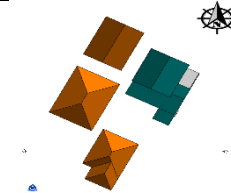
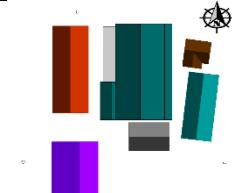
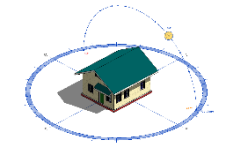
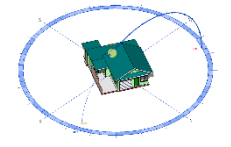
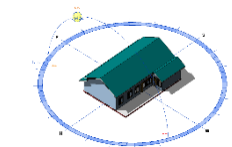
Population growth in Palu has risen from 313 in 2009 to 356 people in 2013. At the same time, electrical energy consumption also rose from 297.59 GWh to 512.67 GWh. Accordingly, population rate had increased about 3% while the energy consumption rate increased sharply, reaching 15% within these periods. As for many areas in Indonesia, the residential sector is the largest sector of electricity consumption in Palu. It was recorded in 2014 that the residential sector used 65% of total electrical energy generation, and this

kept increasing each year. In 2005 residential buildings used 150.23 GWh of electrical energy and in 2014 it had doubled up to 382.34 GWh.

2.5 Solar Model

A solar model was constructed using Revit 2016 software. This model is used to determine and visualize the optimal location of photovoltaic installation within the building envelope. The constructed models are only based on three existing residential buildings in Palu City, which represent three different installed electrical energy generation systems, namely: 450, 900 and 1300 Watt systems (Table 3). No 2200W or 3500-6600W houses agrees to be objects of the study due to privacy reasons. Location data of the solar models and their obstruction from adjacent buildings based on the real existing location of the sample houses is as shown in Table 3.

Table 3. Sample Houses as Solar Models

Sample House	450 W Sample House	900 W Sample House	1300 W Sample House
Location  : Sample  : Adjacent building	 0°53'28.1"S 119°51'57.9"E	 0°53'08.1"S 119°52'08.5"E	 0°53'29.8"S 119°51'55.9"E
Site plan			
Perspective and Orientation (long axis from North)	 10°	 25°	 0°
Area (m ²)			
Floor	49.03	80.87	210.34
Roof	81.07	126.57	294.57
Wall (North)	23.78	27.21	56.15
Wall (South)	22.17	23.79	51.36
Wall (East)	21.30	37.34	45.26
Wall (West)	21.89	31.62	50.03
Installed Power Capacity (W)	450	900	1300

3. RESULT AND DISCUSSION

3.1 Solar Potential

The first step of analysis began with investigating solar potential for electrical energy generation. It was analyzed using global horizontal irradiation and average sunshine duration in different months. Total horizontal irradiation in Palu ranged from 168 – 202 kWh/m² per month with sunshine duration of 6 – 8 hours per day. The highest irradiation and the longest duration of sunshine happened in October, while the lowest level of irradiation and the shortest duration was in January (Figure 3). This condition was relatively varied by sunshine duration and cloud cover, which is clear in the lower rainfall period (October – December) and becomes cloudy in the rainy season (January – March). In spite of the sky condition, variation of solar potential in the study case area is evenly distributed throughout the months.

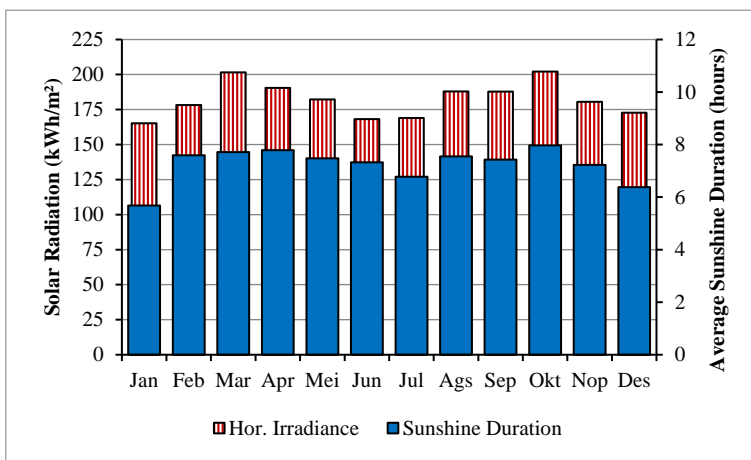


Figure 3. Horizontal (Hor.) Global Irradiance in Case Study Location

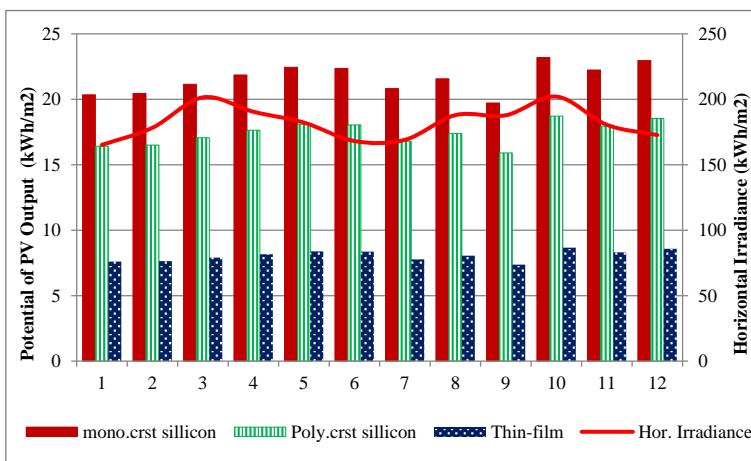


Figure 4. Potential of Photovoltaic Energy Generation by Different PV Technology

The potential generated energy per unit area by photovoltaic installation with different levels of efficiency can be seen in Figure 4. Power output expected from monocrystalline, polycrystalline and amorphous silicon ranges between 20 – 23 kWh/m², 16 – 19 kWh/m², and 7 – 9 kWh/m² respectively. Thus, there is a promising potential for electrical energy supply from PV panels to fulfill self-energy demand for residential buildings.

3.2 Residential Energy Consumption

The average electrical energy consumption data from 836 households was used and it varied from 264 – 328 kWh. The highest consumption was 2,280 kWh, and the lowest was 50 kWh (Figure 5) depending on the number of occupants, number and type of appliances, consumer behaviour and building area. The energy consumption from residential sectors was divided into five categories of installed electrical power capacity namely: 450W, 900W, 1300W, 2200W and 3500-6600W. The energy consumption data was gathered from State Electricity Enterprises data in 2015 and included 294 houses for 450V houses, 335 houses for 900W, 130 houses for 1300W, 59 data for 2200W and 18 houses for 3500-6600W.

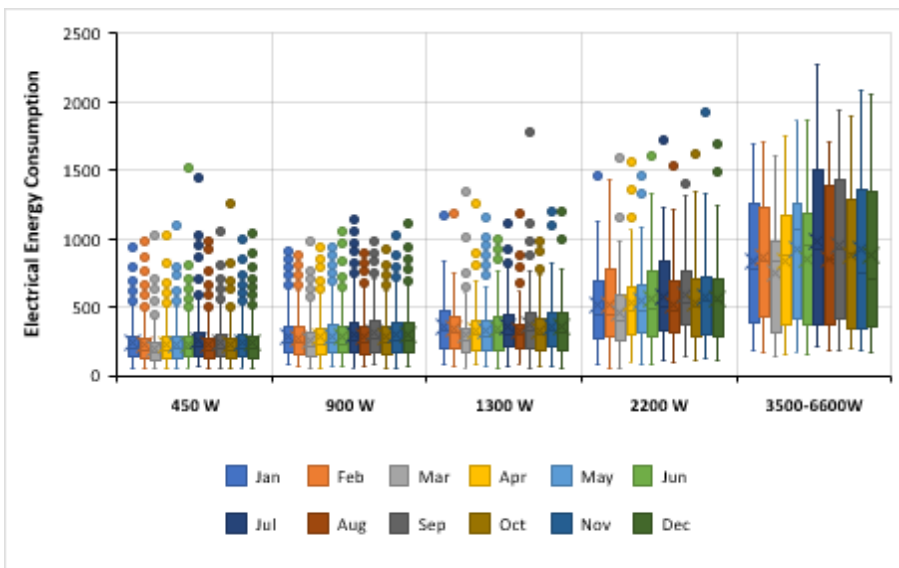


Figure 5. Residential Energy Consumption by Installed Power Capacity in 2015

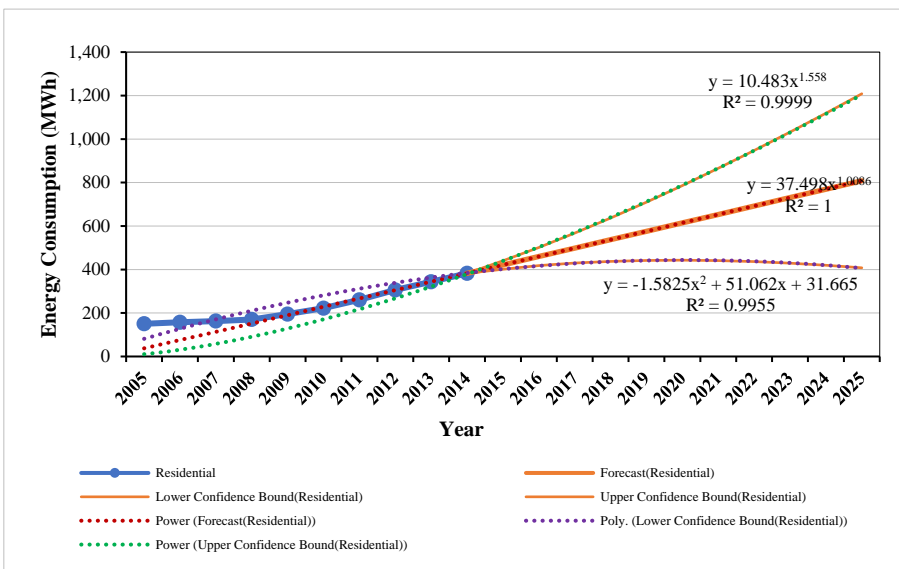


Figure 6. Predicted Residential Energy Demand in 2025 in Palu

This installed electricity generation capacity was generally representing the economic situation and the size of the detached house as well as the type of electrical appliances used in the house. But all these indicators came out of

discussion, except for the size of the building. The size of the building in this study refers to the surface area of the building envelope. This was used to evaluate the capacity of different types of power installed on a house to support their self-energy demand.

Ten years of average electrical energy consumption by residential sectors was used for projecting future energy demand in 2025 (Figure 6). From the projected energy consumption, it can be known that the energy demand in 2025 will be double the actual consumption in 2015. Accordingly, the monthly energy consumption data was multiplied by two to get the future monthly energy demand. The predicted value was used to calculate the area needed for a PV installation to supply sufficient electrical energy for the residential buildings self-energy demand for the next ten years.

3.3 Location of Photovoltaic Panel

Optimal location of photovoltaics was analysed by rendered colour visualization of superimposed insolation on the building envelope. As to be expected, the simulation result shows that three models receive the highest amount of solar energy on the roof, which always exceeds 100kWh/m^2 . This is due to their location in the equatorial region, thus the angle of the solar azimuth is near vertical for most months. Installing photovoltaics on the roof will provide a huge amount of electrical energy supply to the buildings.

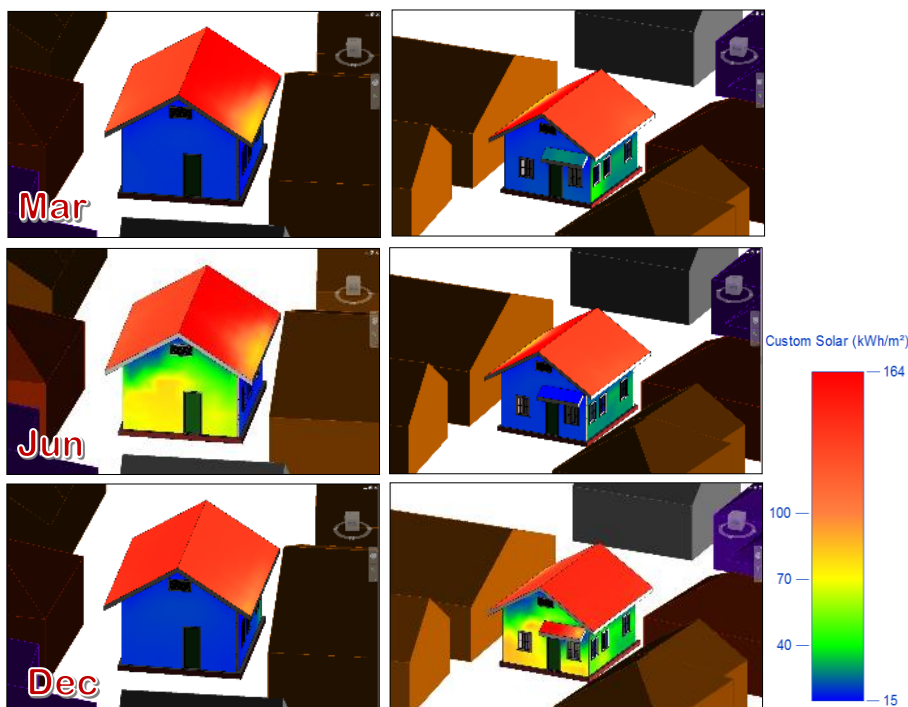


Figure 7. Solar irradiance falls onto building envelope of 450W building sample

The result of the 450W house model insolation coloured rendering can be seen in Figure 7. The figure shows that the insolation reached a maximum 164kWh/m^2 , shown by the bright-red colour of the associated roof surfaces. On the contrary, heavily shaded walls resulted in the minimum insolation of 15kWh/m^2 which is represented by the dark-blue colour. The usable insolation for photovoltaic installation in this study was determined to be from 50kWh/m^2 and higher.

The 450W model can receive a promising amount of solar radiation on its ESE facing wall throughout the year, displayed by a light green to yellow colour range (50-70kWh/m²). SSW facing walls will receive a higher amount of solar radiation in December, displayed by the yellow to light-orange colour range which is between 70-90kWh/m², while for the remaining months it only receives between 20 and 40 kWh/m², displayed by the dark-green to green colour range (Figure 7). In contrast, NNE walls will receive higher insolation in June, rendered as yellow to orange in colour, representing an insolation value of 70 – 100kWh/m², while the other months will receive a low insolation range 15 - 20kWh/m². The lowest insolation received by NWN walls was due to being heavily obstructed by adjacent buildings, hence all the months are presented in blue colour.

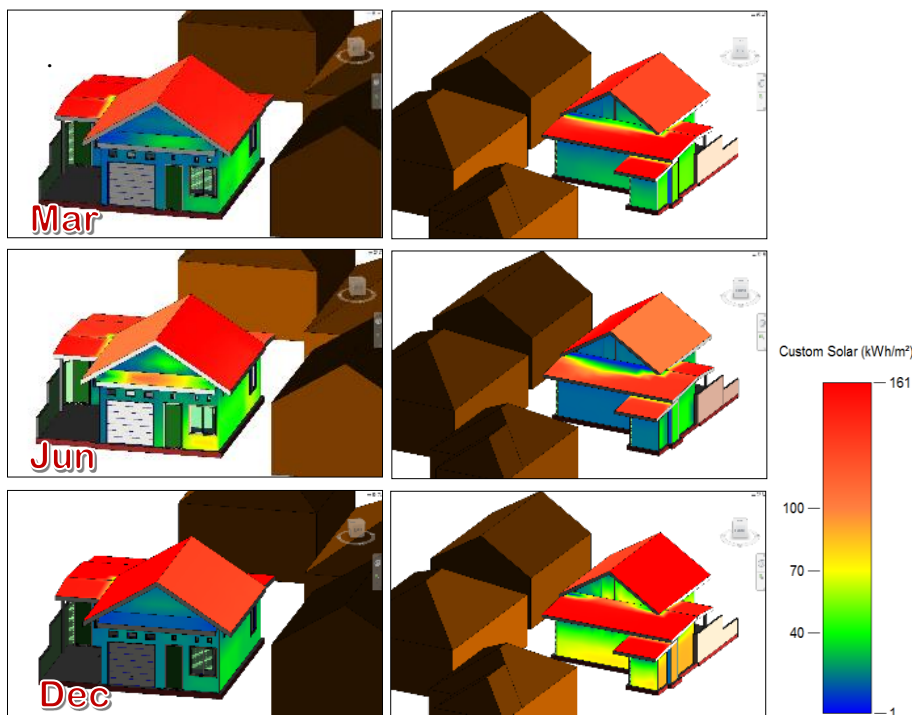


Figure 8. Solar radiation falls into building envelope of 900W building sample

Coloured rendering result for the 900W house model is showed in Figure 8. The bar scale of rendered colours displays the minimum insolation received by this model as 1 kWh/m² presented by the dark-blue colour, while the maximum value was 161 kWh/m², the bright-red colour, which was achieved by roof surfaces. The model receives the highest amount of solar energy from SE facing walls especially in December. The amounts range from 80 to 100 kWh/m² in December and 50 – 65 kWh/m² for the remaining months. This is due to its orientation which is 25° from North, thus it receives higher radiation from the east circumsolar in the morning and south inclined circumsolar in December. Additionally, without any obstruction from adjacent construction, SE walls can gain more insolation than other walls of differing orientations.

The NW facing wall also received a promising potential in gaining electrical energy. The range of rendered insolation colours shown for this wall represent values of 40 – 65 kWh/m². The NW walls received less insolation than SE walls because the available obstruction comes from near buildings. On the other side, the NE facing wall receives unstable solar radiation. In June, most parts of it received a higher amount (60 – 75 kWh/m²) and the last part only received 20 kWh/m².

In the case of the 1300W model, three walls did not receive uniform amounts of solar radiation (Figure 9). This condition is due to its long axis facing exactly through North – South in orientation. Hence, solar radiation can only be received by North walls in June, and the South wall in December. This condition is worsened by the adjacent building which is too close to the model. Better performance conditions are found for the East walls, where the amount of solar radiation varied from 50 kWh/m² to 70 kWh/m². Enough space between the model and adjacent buildings on the East side allows morning solar radiation to reach East wall surfaces.

From the result of 3D insolation colour rendering, it can be seen that different building orientations have no major influence on the amount of insolation received by the roof element. Therefore, building orientation is not a critical factor for roof mounting of photovoltaics in the equatorial region. On the contrary, the adjacent buildings' height and distance indeed has significant influence, since adjacent structures can reduce the total amount of insolation received by the roof element by shading it. Shaded areas of roof also can be formed by its own construction. This study confirmed that the more complicated the roof form is, the less solar energy can be harvested due to self-shading of the roof element.

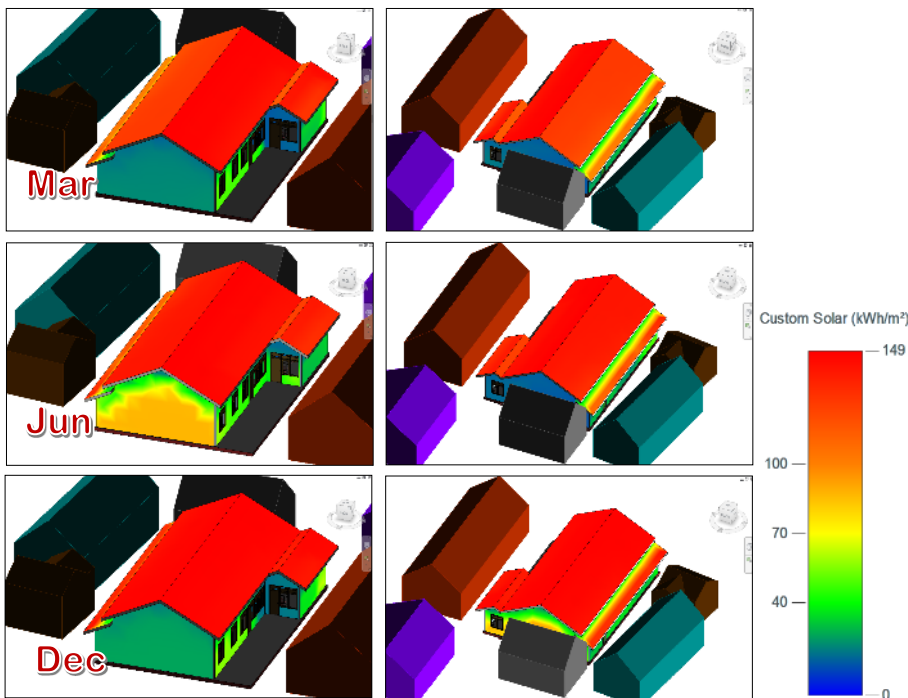


Figure 9. Solar radiation falls into building envelope of 1300W model

The optimal location of wall photovoltaic mounting is on the West and East walls. They not only provide a uniform solar energy distribution in different months, but also supply a higher amount of solar energy. Because these walls get the highest insolation, they also provide the highest potential for heat gain to the building interior. The higher the radiation amount falling onto the building envelope the more heat it produces, thus, potentially leading to overheating of interior environment. In the tropics, heat is a major problem for thermal comfort. Adding photovoltaic panels to both walls will add extra insulation to the walls.

3.4 Area of Photovoltaic Placement

Area of photovoltaic placement on the surfaces of the building envelope is mapped based on required size of photovoltaic installation area to support future energy demand. The result of the required area for each installed power capacity can be seen in Figures 10 –14. The highest value of required photovoltaic area across all months was selected for determining the area of photovoltaic placement on the building envelope.

To supply the average energy demand of the 450W model which ranges from 396 kWh to 512 kWh, the required area for photovoltaic placement using different technology was 66 m² for amorphous silicon, 31 m² for polycrystalline silicon, and 20 m² for monocrystalline silicon (Figure 10). The available roof area for this model is 81 m², hence the roof surfaces alone are more than enough to fulfil the energy demand. For optimal energy generation, the shaded area by the adjacent building can be avoided for the photovoltaic placement. Therefore, the net area used for photovoltaic installation will be less than 81 m² which is 74.73 m² (Figure 10). This net area for the 450W model is still enough to serve the energy demand.

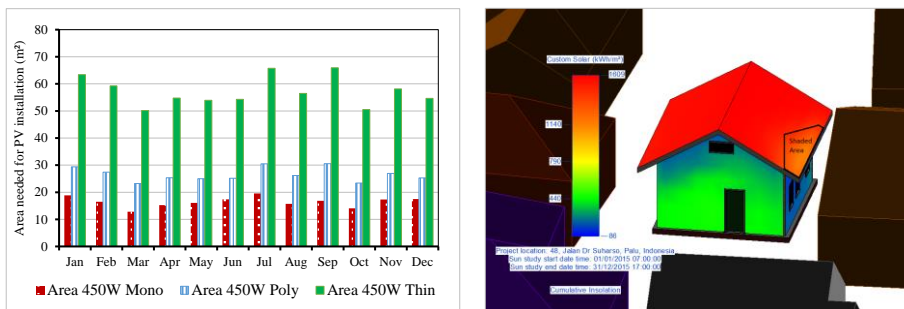


Figure 10. Required area for photovoltaic installation on 450W model (left) and annual insolation mapped on building envelope (right)

Available roof area on model 900W is 126.57 m², while the required area is 83 m², 38 m², and 21 m² for amorphous silicon, polycrystalline silicon, and monocrystalline silicon respectively (Figure 11). 8.24 m² of this model's roof surface area is shaded by its own form, making the net area available for photovoltaic installation 118.33 m². With the remain net surface area, this model still surpasses the required area to serve the average energy demand of 497 – 612 kWh.

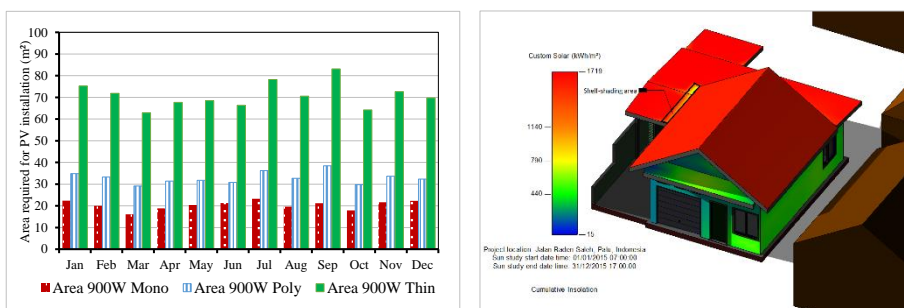


Figure 11. Required area for photovoltaic installation on 900W model (left) and annual insolation mapped on building envelope (right)

The average energy demand for the 1300W mode ranges from 603 – 728 kWh, thus the required area for photovoltaic mounting is 28 m², 46 m², and 99 m² for monocrystalline silicon, polycrystalline silicon, and amorphous silicon

respectively (Figure 12). The available roof area is 284.57 m², while the shaded area covers 49.74 m² of roof area. Hence, the remaining net roof surface area is 244.74 m², which can adequately generate energy to supply future energy demand.

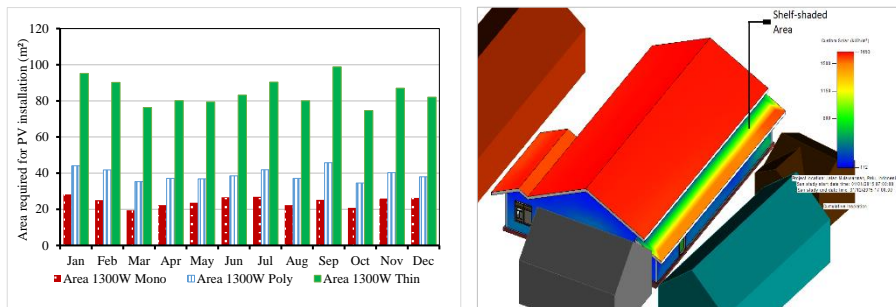


Figure 12. Required area for photovoltaic installation on 1300W model (left) and annual insolation mapped on building envelope (right)

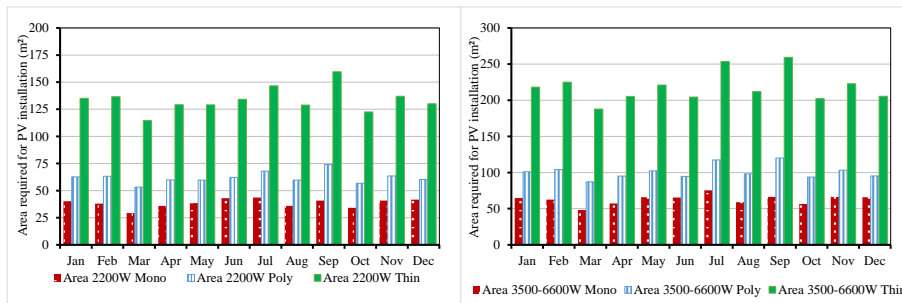


Figure 13. Required area for photovoltaic installation on 2200W and 3500-6600W electrical power installed capacity houses

The simulated model for 2200W and 3500-6600W installed power capacity was not constructed. The reason is because none of the house owners from these types agreed to be measured as a study sample due to privacy reasons. This type of house belongs to the high-end economic class people. Thus, the size of the houses is generally bigger than for the other types. The surface area of the houses is believed to meet the required area needed for photovoltaic installation. The required area for 2200W houses to supply an energy demand of 906 – 1176 kWh is 160 m², 74 m², and 44 m² for the three different photovoltaic technologies. While the required area for 3500-6600W houses to support an energy demand of 1485 – 1972 kWh is 75 m², 120 m², and 259 m² for monocrystalline silicon, polycrystalline silicon, and amorphous silicon respectively.

From the three models, it can be known that the available surface areas of the building envelope are more than enough to provide a sufficient amount of energy demand in the equatorial region. Available roof area alone from each model can suffice their own future energy demand. Therefore, photovoltaic mounting on residential building envelopes generally has excellent potential to supply the future energy demand.

4. LIMITATIONS

Our simulated models might be constrained by weather data which was accounted for by 5-yearly average values, and cannot account for short-term

weather variation. The building models also might not resemble all residential buildings in Palu City. In addition, this prediction only focuses on the available area from the building envelope surfaces for photovoltaic mounting, thus giving rise to several interesting points for future research. First, our study models only consider solar radiation gained by photovoltaic panels for energy output calculations, therefore temperature effect behaviours of the photovoltaic panels become an interesting future research topic, especially in tropical climates. Second, economic consideration should be included in assessments of prospective photovoltaic building installations. Finally, extending the study scope from single buildings to neighbourhoods and entire areas will become a future point of study.

5. CONCLUSION

In this paper, we evaluated the potential of photovoltaic installations on residential building envelopes in the equatorial region by constructing three buildings, representing three different categories of electricity generation in BIM Revit software. Our study proposes a practical method for photovoltaic potential evaluation employing 3D insolation colour rendering which can be easily implemented at the building design stage by building designers. The method included optimal area on the building envelope to provide sufficient electrical energy for future energy demand.

Evaluation results show that implementation of photovoltaics on residential building envelopes has enormous potential in the equatorial region. Roof surfaces of residential buildings can have photovoltaics attached, for the highest and relatively uniform amount of solar radiation falls onto this area throughout the year. Walls of the building oriented to East and West also have great potential to harvest electrical energy. Additional barriers to the effectiveness of wall-mounted photovoltaics are the surrounding obstruction, like buildings, though trees have enough space for solar radiation to penetrate to the walls.

To design new buildings with optimal PV power generation, a simple roof design and a building form that avoids self-shading potential is highly recommended. Larger wall areas may be oriented to East and West as additional areas for PV installation, however, thermal loading to a residence needs to be considered.

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Thermal Environment Simulation of an East-West Street in Taipei

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Abstract: In order to analyse the relationship between street geometry and thermal environment in a city, this study collected data using five thermal comfort measuring instruments and applied computational fluid dynamics (CFD) to determine the relationship between street thermal environment (thermal comfort) and street geometry factors. According to this study's results, street geometry, wind path, and waste heat of buildings all play very crucial roles with regard to effecting air temperature and thermal comfort conditions in the street. Meanwhile, the data from field work and CFD simulation confirmed that creating more wind paths and mitigating waste heat of buildings may be the best strategies for creating a comfortable thermal environment in the street.

1. INTRODUCTION

Taiwan is urbanizing more quickly every day. According to government statistics, about 17.33 million people (about 74%) of the total population (about 23.53 million) were living in metropolitan areas in Taiwan as of the end of 2016. As a result, Taiwan's urban thermal environment is deteriorating, and the urban heat island effect has recently shown that high urban metropolitan temperatures will significantly impact people's lives if future urban planning and design does not take timely measures. In the past, the research and application methods of the heat island effect and thermal environment were similar, including the use of fixed meteorological station data to study the heat island effect ([Magee, Curtis, & Wendler, 1999](#)), using mobile observation methods for urban heat island ([Sun, 2011](#); [Sun et al., 2009](#)), and the use of remote sensing as the main tool for measurement ([Yuan & Bauer, 2007](#)). However, those studies focused on urban temperature changes rather than human thermal comfort as their research focus.

Studies on the urban thermal environment have led to the emergence of street and community-scale research, such as a study that focused on the relationships between heat island and sky view factors in the cities of the Tama River basin, Japan ([Yamashita et al., 1986](#)), research that confirmed that vegetation is a kind of roof material cities can use to cool the

temperature ([Sun et al., 2012](#)), an analysis of building clusters and shading in urban canyons for a hot, dry climate ([Bourbia & Awbi, 2004](#)), research that claims that vegetation is an urban climate control strategy in the subtropical city of Gaborone, Botswana ([Jonsson, 2004](#)), an assessment of thermal stress in a street canyon in pedestrian areas with or without canopy shading ([Paolini et al., 2014](#)), a preliminary study on the local cool-island intensity of Taipei City parks ([Chang, Li, & Chang, 2007](#)), one research evaluating the cooling effects of greening for improving the outdoor thermal environment at an institutional campus in the summer ([Srivanit & Hokao, 2013](#)), and a discussion about characteristics of permeable pavement during hot summer weather and its impact on the thermal environment ([Asaeda & Ca, 2000](#)).

In addition to the thermal environment, more research has paid attention to human feelings closely related to thermal comfort; for example, such research has included a study of the thermal comfort of urban microclimate and the number of space users ([Nikolopoulou, Baker, & Steemers, 2001](#)), a thermal comfort analysis in outdoor and semi-outdoor locations in Sydney, Australia ([Nikolopoulou & Steemers, 2003](#)), a paper discussing urban thermal comfort for outdoor cities in different European countries ([Spagnolo & De Dear, 2003](#)), a study of urban comfort and psychosocial adaptation as a guide to urban spatial design ([Nikolopoulou & Lykoudis, 2006](#)), research focusing on the effects of shading on long-term outdoor thermal comfort ([Lin, Matzarakis, & Hwang, 2010](#)), a discussion of the seasonal effects of urban street shading on long-term outdoor thermal comfort ([Hwang, Lin, & Matzarakis, 2011](#)), a paper studying the impact of street environmental characteristics on the microclimate, such as building density, green coverage, and street aspect ratio ([Sun, 2011](#)), and a discussion of temperature decreases in an urban canyon due to green walls and green roofs in diverse climates ([Alexandri & Jones, 2008](#)).

In fact, more studies have become interested in the thermal environment. For example, one study compared different streets in Morocco to clarify the relationship between urban street environment and thermal environment ([Johansson, 2006](#)). Furthermore, research of low-rise urban street canyons in Israel ([Pearlmutter, Bitan, & Berliner, 1999](#)) shows that street hyperthermia is a common phenomenon in the desert climate at night. One study applied objectives to simulate the characteristic role of building aspect ratio and wind speed on air temperatures in various street canyon heating situations ([Memon, Leung, & Liu, 2010](#)), its results demonstrated that the air temperature difference between high and low aspect ratio street canyon was the highest at night. In addition, research has been done on temperature and human thermal comfort effects of street trees across three contrasting street canyon environments, focusing on the importance of greening as a potential method for passive cooling and for use in reducing ambient air temperatures ([Coutts et al., 2016](#)). Therefore, the results of this study have highlighted the importance of the street canyon aspect ratio and wind speed on urban heating.

To analyse the relationship between street geometry and thermal environment in cities, this study collected data using five thermal comfort measuring instruments and applied computational fluid dynamics (CFD) to determine the relationship between street thermal environment (thermal comfort) and street geometry factors.

2. METHODOLOGY

In this study, we have set up five fixed stations for microclimate and thermal comfort on an East-West Street in Taipei to collect data about street thermal environment temperature and humidity. Then, using CFD simulation data, we analysed the surrounding streets' environmental factors and thermal environment measurement data so that we could specifically propose an effective approach for reducing the urban street thermal phenomenon.

2.1 Fixed monitoring station (thermal comfort measurement)

"Thermal comfort" is a form of subjective evaluation of ambient temperature, environmental temperature impact, humidity, wind speed, average radiation temperature, human activity, clothing, and other factors. In general, in this study, the actual measurement data includes a variety of thermal comfort indicators for evaluation, which were ultimately analysed using urban street environmental factors in order to clarify the composition of urban streets and thermal comfort.

In this study, the main instrument for measuring thermal comfort was the instrument cluster (*Figure 1*), which measures temperature, humidity, wind speed, wind direction, solar radiation, black bulb temperature, and wet bulb temperature.

2.2 Study area

Taipei City (25° 03' N, 121° 30' E) is the biggest city located in northern Taiwan. Surrounded by mountains, the climate is characterized by hot and humid summers and cold winters. The annual average temperature is 22°C, and the annual rainfall is about 2,100 mm. We selected Taipei City for this study because its weather conditions and street characteristics are representative of most cities in Taiwan. In this study, a number of experimental procedures were performed in urban street canyons, which were oriented with their long axis in an E-W direction and were located in a typical residential neighbourhood near National Cheng-Chi University (*Figure 2*). We established five measurement sites (*Table 1*) with the intention of investigating thermal characteristics during March. The centre of the streets consisted of asphalt roads, and the building façades were made of concrete, generally covered with plaster or tiles.



Figure 1. Fixed monitoring station

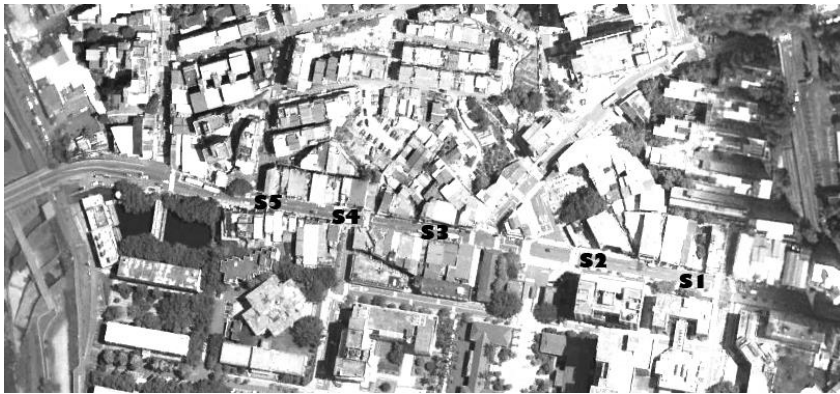







Figure 2. Fixed monitoring stations (S1 to S5 are the measurement sites)

2.3 Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is a discipline that has evolved rapidly since the 1960s and has matured significantly over the course of the past 50 years. CFD uses a numerical method to solve the governing equations of fluid mechanics using a computer in order to predict the flow field. This study applied the ANSYS 14.0 version of the FLUENT suite of software for urban street thermal environment simulation analysis, as well as thermal comfort data using the measured thermal environment data for comparison. Through the CFD simulation, the proposed scheme for improving the street environment and the potential benefits are expected to be verified.

Table 1. Measurement sites' condition and photo

Measurement sites' condition	Photo
<p>S1 (Site #1): The north side of the measured area is adjacent to a commercial building, and the south side is adjacent to a pedestrian walkway and tree-shaded street beside the university.</p>	
<p>S2 (Site #2): The north side of the measured area is adjacent to a commercial building, adjacent to the university's pedestrian trail but without a tree-shaded street.</p>	
<p>S3 (Site #3): North and south sides of the measured area are both adjacent to commercial buildings and have no tree-shaded street.</p>	
<p>S4 (Site #4): The north side of the measured area is adjacent to commercial buildings, and the south side is the university entrance without a tree-shaded street.</p>	
<p>S5 (Site #5): North and south sides of the measured area are both adjacent to commercial buildings without tree-shaded street, but very close to a river.</p>	

3. SIMULATION

3.1 Model setting

In this study, we performed computational fluid dynamics using the Fluid Flow (FLUENT) suite of software from ANSYS 14.0. When ANSYS 14.0 computational fluid dynamics is carried out in a "finite field", the relevant parameters are set in the reference range, and the simulation results more easily converge to a steady state. Therefore, the software operation process must first establish the 3D model of the reference field in the simulation area. However, due to the calculation function limit, the plane scale of the reference field model in this study is limited to 500 m * 500 m.

The study area is an east-west street about 450 m long with the highest building on either side being about 8 stories high (each story is about 3 meters high). To ensure accuracy, this study's simulation uses actual building dimensions. In order to maintain the effectiveness of the model calculation, the model constructed for this study simplifies the model of buildings with the same number of stories. A total of 41 building measurement units are used, and the height of individual arcades and buildings are set according to the current situation survey and building control map (*Figure 3*).

3.2 Mesh setting

CFD simulation is based on the "mesh" theory. When completing a street model, the "mesh setting" approach is crucial. It includes the shape, size, density, and smoothness of the mesh, as well as some other parameters. Meshing can be modelled in many ways in accordance with the actual situation ([Bakker & Oshinowo, 2004](#)). In general, the use of hexahedrons as mesh-splitting units can be achieved by using CFDs for simulations in a variety of instances (Mavriplis, 1997). For the most accurate simulation results, since the CPU performance and data may converge to a stable state, tetrahedron meshing is the most effective approach for this research.

In this study, the mesh is divided into tetrahedrons, the maximum length of the tetrahedral mesh is 5 meters, and the mesh is encrypted in the details of the buildings. The total number of model mesh is 670,183, the total number of mesh nodes is 133,109. To make the model more refined, we used the highest mesh smoothness of 100. Meanwhile, the local encryption part of the baseline field around the vertical boundaries' subdivision units is 1.25 m, and the building's unit is 1 m (*Figure 4*).

3.3 Condition setting

To determine the relationship between street thermal environment and comfort, we set up five fixed monitoring stations to collect data related to environmental factors and measured thermal comfort several times. In this study, the meteorological data obtained on March 23, 2013 were used as the background conditions for CFD simulation.

3.3.1 Wind conditions

In the present study, the wind direction data of the day were taken as the basis of the urban wind field. Said data show that the wind was moving to

the east. Since the real street environment is open, the outlet is set to the base field in the other direction, except for the ground and the east (*Figure 5*).

3.3.2 Anthropogenic heat

Buildings emit various forms of artificial heat, but this study does not aim to measure the artificial heat of buildings. Therefore, we only estimate the heat generated through the air conditioning. Assuming a residential unit of approximately 115.70 square meters, the total energy consumption of two rooms with one freezer per ton of refrigeration is approximately 16,000 BTU / hr = 4000 kcal / hr, which is approximately 4600 Joules per second, or 4600 W (watt). Under this assumption, the heat generation per square meter is about 40W (39.76W). Therefore, in this study, 40W was used as the heat value of the external wall of the first floor of the buildings, and the thickness of the wall was set to 0.5 m. We conducted both 80W and 120W input simulations in order to observe the influence of anthropogenic heat on street thermal environment.

3.3.3 Calculation mode

CFDs are categorized into three types based on the following modes of calculation: 1. Direct Numerical Simulation (DNS); 2. Large-Eddy Simulation (LES); and 3. Reynolds Averaged Navier-Stokes Simulation (RANS). In theory, the DNS method can correctly simulate the flow field, but all the eddy currents are required. The LES method can calculate the large eddy and small eddy, but cannot operate on a single small platform. Therefore, we used the RANS method to calculate the global mean value with the widely used k- ϵ turbulence model.

Because of its close to infinite eddy motion and nonlinear mathematics, turbulence motion is very complicated. As a result, in the related model establishment, a microcosmic model that considers vortex viscosity and Reynolds stress is established in three-dimensional space based on average property. The model can be divided according to the number of differential equations: zero, one equation, two equations, and multi-equation model. The k- ϵ turbulence model proposed by Launder and Spalding in 1972 is derived from a large number of experimental deductions of the typical two equations, which means that the model consists of two main variable equations (turbulent kinetic energy and energy consumption rate), with a wide application range of precision and reasonable characteristics.

In the CFD simulation, different parameter settings were established to clarify the correlation between street environment and thermal comfort. In this study, the initial temperature of the reference field was taken from the average temperatures collected at the four thermal comfort stations during the day, and the initial wind speed was measured by the thermal comfort station during four periods (*Table 2*).

In the second stage of the study, we used 40W, 80W, and 120W as the divergent heating value of the buildings. The initial atmospheric temperature was set at an average temperature of 26.286° C (299.436 K) measured at the five fixed stations between 10:00 and 21:00. Likewise, the initial wind speed was set at an average wind speed of 0.148 m /sec measured at the five fixed stations from 10:00 to 21:00.

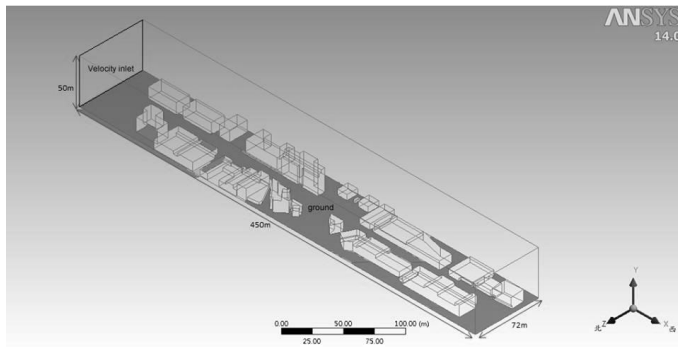


Figure 3. 3D model

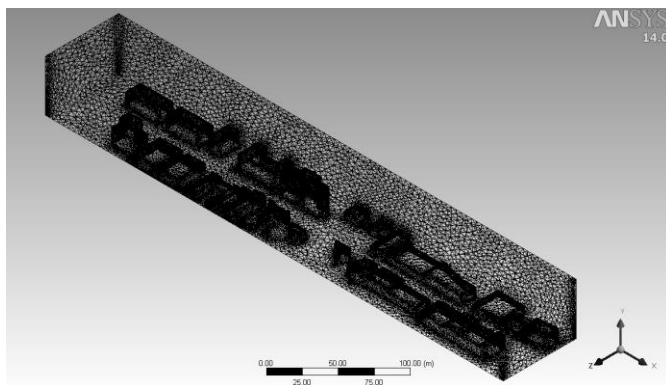


Figure 4. 3D model with mesh setting

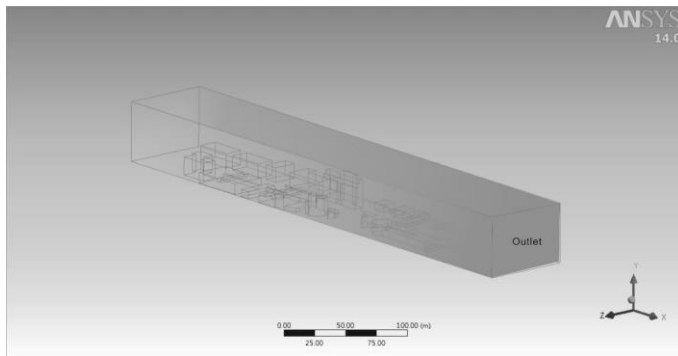


Figure 5. 3D model with outlet setting

Table 2. Setting data

Time	Average Temperature (°C)	Average Temperature (K)	Average Wind Speed (m/sec)
11:00-12:00	28.417	301.567	0.267
14:00-15:00	27.447	300.597	0.200
17:00-18:00	25.236	298.386	0.052
20:00-21:00	23.991	297.141	0.052

4. RESULTS AND DISCUSSION

4.1 Street thermal environment states at different time periods

In this research, we carried out CFD simulation of urban street thermal environment for four different time periods (*Figures 6, 7, 8, and 9*). The main variables come from background temperature and wind speed conditions. Furthermore, the street around the buildings' heat dissipation in the four simulated calculations was maintained at a fixed value.

The simulation results demonstrate that high temperatures are mainly concentrated on the west and southeast of the study area. The main reason for the west side of the study area is that it is located in the downwind region; after accumulating a large number of buildings' heat dissipation on both sides of the street, the region eventually appears to be at a higher temperature. On the other hand, the southeast side of the study area is because the large local area building heat dissipation and ventilation cooling conditions are poor. As a result, it also shows a high temperature situation. Furthermore, in the middle part of the study area, the buildings are relatively sparse (building heat dissipation is lower), and the ventilation cooling effect is better, thus resulting in a low temperature situation.

The simulation results at three different periods show that even though the background temperature at noon and in the afternoon is higher, the wind speed in the evening is clearly lower than that of the other two periods. Therefore, the simulated result of the evening indicates several regions with high temperature condition. In the CFD simulation, the background wind speed condition is a significant factor dominating the thermal environment simulation results.

4.2 Simulation of different building heat dissipation

The different building heat dissipation simulation results (*Figures 8, 10, and 11*) show that as building heat dissipation increases, the overall temperature of the study area also gradually increases, and the temperature difference range of the whole area increases accordingly.

When the building heat dissipation increased from 40W to 120W, the overall temperature difference in the study area increased by 6K, which indicates that although the temperature in the low temperature region only increased slightly, a high temperature area accumulated due to the heat, resulting in other areas with about a 6K temperature difference. This change will seriously deteriorate the urban street thermal environment and thermal comfort, and its impact should not be underestimated.



Figure 6. Simulation result of 40W building artificial heat at 11:00-12:00

The simulation results show that if a building can effectively control its building heat dissipation, it could potentially maintain the urban street thermal environment at a certain condition of thermal comfort.

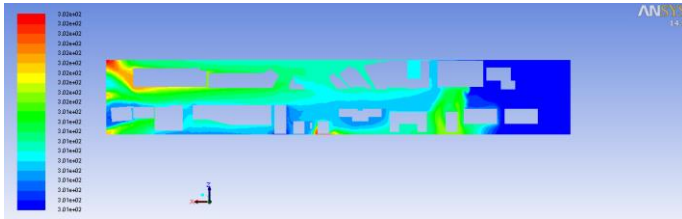


Figure 7. Simulation result of 40W building artificial heat at 14:00-15:00

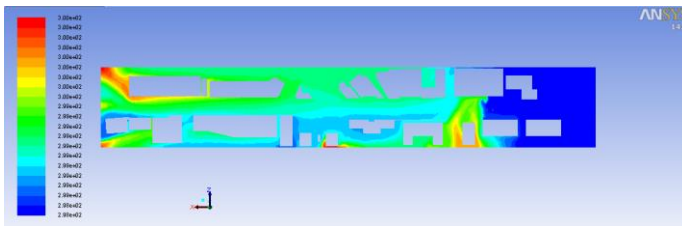


Figure 8. Simulation result of 40W building artificial heat at 17:00-18:00

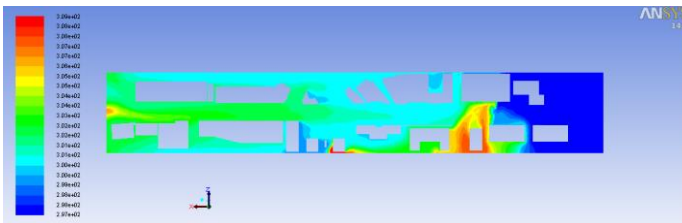


Figure 9. Simulation result of 40W building artificial heat at 20:00-21:00

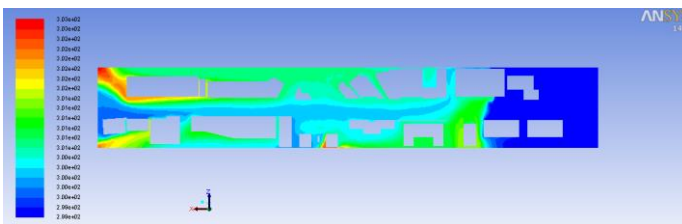


Figure 10. Simulation result of 80W building artificial heat at 17:00-18:00

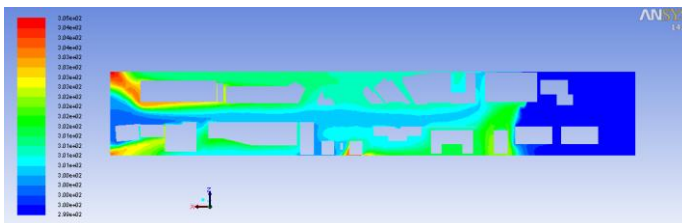


Figure 11. Simulation result of 120W building artificial heat at 17:00-18:00

5. CONCLUSION

In Taiwan, the majority of people live in cities, so urban street thermal environment and thermal comfort has a significant impact on quality of life. Air conditioning, energy consumption, and outdoor activities all make up an important part of this. To investigate the relationship between urban street environment and thermal comfort in Taipei City, this study established five measurement points to determine the change of microclimatic data and then used CFD to simulate the thermal environment of urban streets. The urban street environment and people's field of activity could improve thermal comfort. The specific conclusions and recommendations of this study are described as follows:

According to the results of the study, the high-temperature area of the study area occurred around the west end of the model and the southeast side of the buildings. Therefore, an appropriate reduction in building density and retention of building spacing will be conducive to the flow of the urban micro-climate of the wind and promote urban street cooling.

The simulation results show obvious differences in the following four time periods: 11:00-12:00, 14:00-15:00, 17:00-18:00, and 20:00-21:00. The trend is "the background temperature is lower, and the simulation results are cooler"; furthermore, the simulation result of 20:00-21:00 is the most significant. The background temperature is shown to still be the most important factor affecting CFD simulation results, so controlling the heat dissipation of urban buildings to avoid heat from escaping the building to the streets to maintain a high-temperature state can improve the urban street thermal environment comfort as a strategic direction for improvement.

The greatest contribution of this paper is the use of the micro-weather station in the urban street thermal comfort analysis. In addition, through the analysis of the surrounding buildings, greening, shadows and human activities, this study suggests proposals to improve the thermal comfort of the streets. Based on the results of this study, creating more wind paths and mitigating waste heat from buildings may be the best strategies for mitigating urban warming and creating a comfortable thermal environment.

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