ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

Climate Adaptation Framework
Regional Research Final Report

Project Reference Number: CAF2015-RR-19-NSY-Monprapussorn

Integrated analysis of climate, land-use and water for resilient urban megacities: A case study of Thailand and Vietnam

The following collaborators worked on this project:

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Project Overview

Project Duration	**:**	1 Year 6 Months
Funding Awarded	**:**	US$ 36,000 for Year 1; US$ 9,000 for Year 2
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Project Summary

This research focuses on the integration of land-use, climate and water resources for resilient urban cities purpose in different geographical area of Southeast Asia. Bangkok, and Hanoi, a capital city of Thailand and Vietnam, are included in the study. Future climate scenarios (AR5) of temperature and precipitation in 2050 will be created by using WorldClim downscaled data with 0.93 km resolution, looking for a baseline change in three cities. Land-use/land-cover change (LULC) will be further explored and modelled by simulating three future LULC scenarios; business as usual (BAU), rapid economy change (REC), and green growth scenarios (GGC) to ensure that all possible socioeconomic factors will be taken into consideration. Projected temperature, precipitation, LULC will be used as the input into Water Evaluation and Planning (WEAP) model in order to estimate how much of the precipitation that falls in the particular area ends up as run-offs into stream, and water budget based on demand and supply in 2050s. Proposed activities attempt to integrate different climate and LULC scenarios into water resources management by estimating future water demand to better conduct risk and vulnerability assessment in urban water context based on different socioeconomic and environment driving forces (thematic iii), while utilize climate, LULC, biophysical and socioeconomic data as input into urban water resources analysis (thematic vii) To get all related stakeholders involved in research, they will be contacted and informed at research preparation stage, each country will arrange workshop to communicate, consult and to brainstorm different ideas of current adaptive capacity and future adaptation plan in the water sector to identify suitable adaptation practice.
Keywords: Climate change; Land use, Urban Water

Project outputs and outcomes

Project outputs:

- Completion of Climate change projection In 2050 for Bangkok and Hanoi
- Completion of Land use change projection in 2050 for Bangkok and Hanoi
- Estimated water budget for Bangkok and Hanoi based on above studies in 2050

Project outcomes:

- Improved understanding of future climate change in Bangkok and Hanoi.
- Improved understanding of future trend of land use change in Bangkok and Hanoi.
- Useful for policy makers to better prepare for increasing urban resilience to climate, land use and water
- This research updated regional cooperation and disseminated the results of local research and field activity related to climate change adaptation and water resources management in Bangkok and Hanoi
- Adaptation Measures in term of Climate Change, LULC scenarios and urban water in Bangkok and Hanoi

Key facts/figures

- Temperature (minimum, maximum and average) and precipitation in 2050 have been projected to increase by 2050 in both Bangkok and Hanoi.
- Urban expansion tends to be increase in both Bangkok and Hanoi while shrinking of agriculture and other land uses were evidence in two cities.
- Increased water demand due to integral effects of urban expansion and climate change.
- Urban policy makers need to plan for mainstreaming mitigation and adaptation policy into practice to increase urban resilience from above changes.

Potential for further work

This project could be a good start for better understanding of integrated effects of climate and land use change on urban water resources. Results of this project can be used as a baseline data for further researches such as assessment of future urban heat island effect and how land use change plays a significant role in those effects. Moreover, increasing urban socio-ecological resilience to climate change would be a vital research by focusing on co-benefit between nature conservation and socio-ecological resilience through effective mitigation and adaptation strategy.

Publications

- A manuscript (Contents of the draft is “An assessment of Climate Change impact on the Land use in 2050 of Hanoi”) was slated for publication in the Scientific Journal of Climate Change (IMHEN).

- One manuscript is in a process of preparing to publish in international journal. The results of this study will be presented at International Conference on Geography and Geoinformatics for Sustainable Development (ICGGS) which will be held between19-20 July 2018 in Bangkok.

Awards and honours

Results of the project can be used as policy guidance both in short-term and long-term plan to increase urban resilient to climate change and water related extreme events in Bangkok and Hanoi

Pull quote

- This project is not only benefit to SWU researcher, but also benefit for society in term of revealing important information about future climate, land use and water resources changes and government and society could benefit from these data by implementing suitable mitigation and adaptation plan both short term and long term (Assoc.Prof.Cholvit Jearajit, Srinakharinwirot University)
- Anthropogenic change plays an important role in global and local change. It could make impact of climate change worsen and increase society more vulnerable. Integrated both effect could provide more holistic approach. (Sathaporn Monprapussorn, Srinakharinwirot University)
- This project can capable of examining how local government perspectives on disaster management are linked to climate change and land use planning (Le Phuong Ha, Division of Remote Sensing and GIS, Vietnam Institute of Meteorology, Hydrology and Climate Change)

Acknowledgments

This research was supported by Asia Pacific Network for Global Change Research (APN). We thank our international colleague Le Phuong Ha from Division of Remote Sensing and GIS, Vietnam Institute of Meteorology, Hydrology and Environment for sharing valuable insight and expertise during the course of this research. We thank Miss Montana Khamsanit, research assistant for hard working in collecting and preparing spatial data for Bangkok. We would also like to give a sincere gratitude to Faculty of Social Sciences, Srinakharinwirot and my colleagues from other Thai -Universities to support and give valuable comments to strengthen this research. We also thank to several government officers who provide data and information needed for this study.

1. Introduction

Water is now a very critical and important resource for human well-being in Southeast Asia. Access to clean water in sufficient quantities is traditionally one of the important issues in developing countries. Urban area currently faces a challenge to providing clean water and sanitation due to rapid growth of urban sprawl and makes water issue goes beyond security issue. Impact of climate change on water resource has been evidenced through sea level rise and intensification of changing hydrological cycle, which will entail more frequent and intense precipitation as well as longer dry spell periods e.g. flood and drought. Although many stakeholders have focused on threat from climate change to urban water problem and attempt to water resilient to climate change, it is crucial not to lose sight of the anthropogenic impact on water resources. The effects of human interventions are very difficult to separate from the effects of climate change and need to be integrated into analysis of urban water in a holistic way. A clearest example is the conversion of agriculture land to urban area that causes alteration of urban water balance. It is, therefore, important that human activities can exacerbate negative impacts of climate change by increasing vulnerability of urban water system along with climate change.

Cities concentrate population, infrastructure, economic activities and wealth, and will therefore be disproportionately affected by the climate change. Cities located in coastal areas and/or on the banks of rivers are particularly vulnerable to sea level rise and flooding. Urban population growth is expected to be taken place at a very rapid scale and links to low quality of life and poverty issues, increasing the size of vulnerable populations in cities and placing additional pressure on decreasing supplies of water resources (Pageler, 2009).

Bangkok is the capital city of Thailand. Bangkok occupies 1,568.7 square kilometres and locates in the Chao Phraya river delta's central plain. The city has also the most populated city in the country with over 8 million (12.6 percent of country's population). The rapid growth of Bangkok in the past lacked systematic urban planning and regulation. It resulted in overpopulation exceeding city capacity that has brought an exceeding demand of infrastructures, public utilities and services, which leading to deterioration of urban environment, urban services and urban quality of life. The location of Bangkok Metropolitan Area (BMA) is located in the delta plain of Chao Phraya river estuary which has made the city and the surroundings vulnerable to flood and many city and suburbs areas are as low as mean sea level. Impact of climate change on country level in particular, is realized by government and community. National strategy on climate change (A.D. 2008-2012) is the first short term climate change policy in Thailand that will be updated every 5 years. Thai government has also issued "Thailand Climate Change master Plan 2012-2050" which is considered as a long term climate change policy. In Bangkok people are aware of higher temperatures, change in rainfall pattern both frequency and intensity, especially the occurrence of urban flood after having a heavy rainfalls. In 2011, Bangkok faced a severe flooding during a monsoon in suburb areas and outskirt of Bangkok, especially in the western parts. Even the inner city has been protected from flooding, but the damage to economic and community well-being caused a serious disruption to businesses, manufacturing supply chain and urban livelihood. Bangkok is expected to continue to experience flooding after heavy rainfall due to water drainage management system caused by high volume of garbage in drainage system as shown in Figure 1

Hanoi, the capital city of Vietnam, is located in the Red river delta with an area of 921 square kilometres and population of 7.7 million (as of 2015). Hanoi contains three basic kinds of terrain, which are the delta area, the midland area and mountainous zone. In general, the terrain is gradually lower from the north to the south and from the west to the east, with the average height ranging from 5 to 20 meters above the sea level. Hanoi features a warm humid subtropical climate with plentiful precipitation. The city experiences the typical climate of northern Vietnam, with 4 distinct seasons; summer (May-August), fall (September-October), winter (November-January) and spring (February-April). Hanoi is one of the cities with rapid urbanization and population growth. Therefore, climate change's response and adaptation have been identified one of the important tasks which need to have a roadmap and plan for implementation. International cooperation has gradually shown the role of the city of Hanoi in the world in climate change response and helped the city to seek external support such as training human resources, technology transfer and technical advice, especially financial support and investment capital.

Figure 1 Periodically flash flood occurrence in Bangkok

The objectives of the project aim at the followings;
1. To explore climate and land use change projection in three cities (Bangkok, Vientiane and Hanoi) by 2050
2. To analyse and compare water budget in three cities and propose adaptation plan

This project attempts to integrate different land use change scenarios to estimate future water budget to better conduct risk and vulnerability assessment in urban water based on different socioeconomic and environment driving forces (thematic iii), while utilizing climate, land use those include both biophysical and socioeconomic drivers for water resources analysis (thematic vii) To get all related stakeholders involved in research, they will be contacted and informed at research preparation stage, each country will communicate analysis result to key stakeholders and consult them to get different perspectives of effective adaptation practices. Results can be useful in term of urban water budget analysis, including planning for mitigation and adaptation in urban water in three cities. Key information could be extracted from an international workshop to compare results of each city to provide some valuable insights for urban planning and policy related to water resources in response to change in climate and land use.

2. Methodology

Methodology comprises of 5 main parts in three cities as the followings;

2.1 Extraction of key information from secondary data

There will be an arrangement of informal communication between project leader and collaborators through social media and email in order to discuss about preparing research processes. Project leader and collaborators are responsible to search, collect and handle both primary and secondary data related to climate, land use and hydrological data, including the purchase of digital information such as GIS and satellite data.

2.2 Downscaling of climate data.

Projection of future climate in 2050 will be extracted by using Global climate model (GCM) data of HadGEM2-ES at RCP 4.5 , which is produced by WorldClim with 30 seconds spatial resolution (0.86 square kilometres at the equator) in Bangkok, Vientiane and Hanoi. Climate projection from GCM is downscaled and calibrated (bias corrected). The great advantage of downscaling is the suitability of climate projection method when dealing with small scale study area such as provincial level. Mean temperature, maximum temperature, minimum temperature and precipitation are four variables of concerns and will be projected for 2050 (average for 2041-2060) and compare to baseline observation data during 1960-1990.

2.3 Land use modelling.

Socioeconomic change will be represented by land use modelling. CLUMondo is used to model land use change in 2050. Three main components are prepared as an input for CLUMondo; land use conversion, logistic regression coefficient of driving factors and land use demand. CLUMondo will attempt to allocate and optimize land and display results in map comparison. Three future LULC scenarios will be analysed base on business as usual (BAU), rapid economy change (REC), and green growth scenarios (GGC). All necessary data such as land use and driving forces in each proponent country will be collected and prepared in ASCII format to project land use in 2050.

2.4 Water budget estimation

Water budget estimation is projected by using climate and land use change data to evaluate water situation in Bangkok. Water evaluation and planning system (WEAP) is an adaptable water resource planning model that is scalable depending on the complexity of the system under investigation and can simulate water allocation policy. WEAP is a water demand and supply accounting model (water balance accounting), which provides capabilities for comparing water supplies and demands as well as for forecasting demands. The Advantage of WEAP is the reliance of the development of scenarios and allows import of GIS layers into analysis with basic GIS operation like overlay. There will be three input parameters from each city into WEAP; water supply and demand, water and wastewater infrastructure and climate (temperature and precipitation), hydrology and water resources (runoff and storage efficiency, annual recharge, natural replenishment annual volume of rainfall and annual groundwater withdrawal) are estimated in order to calculate water budget in a future. Integrated analysis of climate, LUCC and water system to assess urban water demand and supply will be conducted to vulnerability assessment of water availability in three cities both water as resources (estimated by demand greater than supplies) and water as risk (estimated by high runoff rate and less storage capacity for the example of flash flood possibility)

3. Results & Discussion

Results will be separately reported by each city.

3.1 Extraction of key information from secondary data

3.1.1 Bangkok

Bangkok is flat and low-lying area with an average elevation of 1.5 metres above sea levels. The history of land use in Bangkok is originally agricultural based which was gradually drained and irrigated for agriculture by canal construction from 16th to 19th century. However, land use in Bangkok is heavily changed by the last three decades from agriculture to urban and residential areas. The city has grown from center along the Chao Phraya river into a sprawing metropolis surrounded by suburban property development extending north and south into neighboring provinces such as Nonthaburi, Samut Prakarn and Pathum Thani provinces where are realized as suburbs of Bangkok with defining by growing cities and high population. Agriculture area still remains in eastern and western fringes. Bangkok metropolitan (BMA)'s city planning department is responsible for planning and shaping future development. BMA is also in charge of creating Bangkok master plan e.g. the mass transit master plan in Bangkok Metropolitan Region, Bangkok master plan on climate change 2013-2023.

Bangkok is a huge economic center of Thailand as the centralized of economic development and investment. Bangkok contributes about 29 percent of gross domestic product (GDP) in 2010. Bangkok land use was focused on the promotion of trade and economic growth while retained livelihood of people. The density of high rise building and population is higher in inner city centre than outskirt of the Bangkok. City policy and planning of Bangkok has encouraged the development of infrastructure and economic activities, resulting in the expansion of growth from downtown to suburb and neighbourhood provinces such as Pathum Thani, Samut Prakarn and Nakorn Pathom.

A change from other type of land use to urban has been evidence in the last three decades. Figure 2 illustrate land use change in Bangkok from 2006 to 2013. Map indicates the expansion of urban land from a city centre to suburb in east and west directions. Approximately 15 percent of total population in Thailand resides in the Bangkok Metropolitan Area. As climate change and extreme events e.g. flood, drought and sea level rise is expected to be more intense and more widespread in the future. Bangkok poses a serious threat from climate extremes due to its low-lying geographical area. Bangkok is also located in downstream of Chao Phraya river basin which the city regularly receives water from run-off from the upstream and sea water intrusion from the gulf of Thailand.

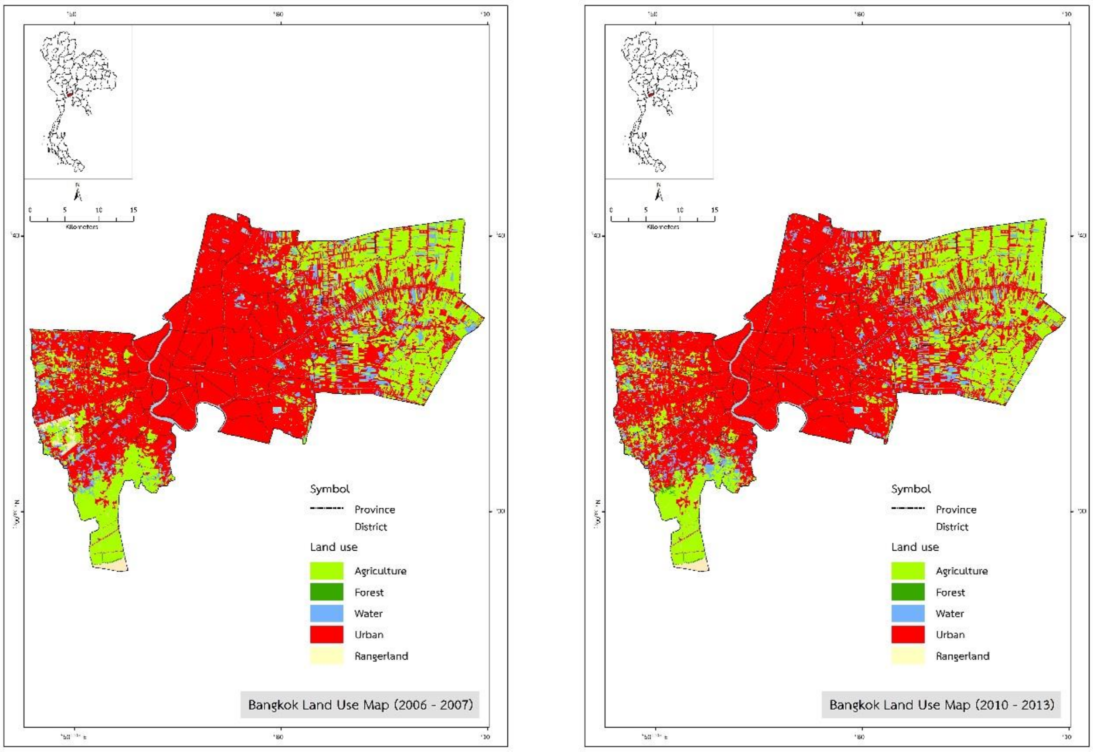


Figure 2 A comparison of five types of land use change in Bangkok for 2006 and 2013

Table 1 shows a change in five land use types between 2009 and 2013. Urban land is increased while agriculture land has been transformed to other types of land use. It should be noted that sea level rise has affected on Bangkok, especially in the coast area by eroding coastline in the lower west of Bangkok. Hence, the area has been changed to mangrove forest.

Table 1 Change in land area of five land use types between 2009 and 2013

Land use type	2009 area (km2)	2013 area (km2)
Agriculture	417.031	407.022
Forest	0.866	2.622
Miscellaneous	99.412	104.820
Urban	1002.318	1005.807
Water	48.373	47.728
Total	**1568.001**	**1568.001**

Bangkok is a city located in the downstream area of Chao Phraya river basin. Chao Phraya River begins at the confluence of two major rivers in the North namely; Ping and Nan rivers at Nakhon Sawan province. A river flows from the central Thailand to Bangkok and the Gulf of Thailand. The Chao Phraya watershed is the largest watershed in Thailand covering draining area of 159,000 square kilometres or approximately 35 percent of the country's land. About 40 percent of country's population live in Chao Phraya basin and generate approximately 60 percent of country's Gross domestic products (GDP). The upper part of the basin experiences a long period of warm weather because of residing in tropical latitude. In the southern part of the basin, temperatures are generally mild throughout the year because basin area is close to the Gulf of Thailand. The Chao Phraya river consists of 8 sub-basins: Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Tha Chin and Chao Phraya main stream. Groundwater storage is estimated to be about 14,000 million m^3/year. If considering only Chao Phraya river basin itself, there are only 2 sub-basin; Chao Phraya plain area and Bung Boraphet as shown in Figure 3. Thai government has focused on managing groundwater in sustainable manner and has prevented groundwater abstraction in Bangkok metropolitan area and some neighbourhood provinces.

In term of natural disaster, floods are usually occurred in the basin contributing to huge losses both in economic and people's livelihood. Rapid urbanization and decline in flood retention areas are 2 common causes of flooding. The Thai government attempted to control floods through the construction of multi-purpose reservoirs, dikes and other flood control infrastructures. The severe flooding in 2011 has inundated large parts of the capital city of Bangkok, Ayutthaya and over 20,000 km2 of agriculture land, causing over 800 deaths and gigantic loss in socio-economic. Most of the past floods occur in monsoon season. Drought is another weather related extreme event come along with dry season, leading to salt water intrusion and water shortage. Precipitation and water collected by dam play an important role to resist seawater flow into the land. In a situation of drought period, a lack of water allows saltwater creeps upstream and makes situation worse by destroying agricultural land and domestic consumption.

3.1.2 Hanoi

Vietnam is located in the South-East Asia between 8 and 22 N and 102 and 110 E and covers an area of 331.212 km² (Figs. 1). Vietnam has an area of 331.212 km², including about 327.480 km² land and over 4,200 km² sea inland, with more than 2,800 islands, reefs, large and small, near and far shore, including the Truong Sa and Hoang Sa islands that Vietnam male claimed that internal waters, territorial sea, exclusive economic zone and continental shelf of Vietnam Government identified nearly three times the land area of over 1 million km². Vietnam terrain varied by region as the wild -west, north-east, Highlands there are hills and mountains full of forests, while flat land covered by less than 20 percentages. Mountains account for the 40 percentages, 40 percentages hills, and cover approximately 75 percentages. The plains as the Red River Delta, Mekong Delta and the coast as coastal North Central and South Central.

In Vietnam, the current water demand standard in often built based on international references, not on specific studies. Therefore, the objective of this research was to investigate the real water use in such a big city as Hanoi, especially in residential areas to serve as one of bases for setting up water demand standard for Vietnam urban areas.

Hanoi is located in the Northwest of the center of the Red river Delta with coordinates from 20053' to 21023' North latitude and 105044' to 106002' East longitude. Hanoi is contiguous with Thai Nguyen, Vinh Phuc to the North, Hoa Binh, Ha Nam to the South, Bac Giang, Bac Ninh, Hung Yen to the East and Hoa Binh, Phu Tho to the West. Hanoi is situated in the right bank of the river Da and both sides of the Red river. However, larger area of city concentrates in the right bank of Red river. After the expansion of administrative boundaries in August 2008, Hanoi area is 3,324.92 km2, including 12 districts, 1 provincial town and 17 rural districts and becomes the largest cities of the natural area and ranks 2nd in urban area after Ho Chi Minh city.

Hanoi, a large urban, has the most rapid urbanization of Vietnam with urban area was occupied 30 – 32 percent in 2010 and will reach 55 – 65 percent in 2030 (Ngo Thang Loi. 2010). Rapid urbanization process in a short time had made the bigchange, especially the land use/land cover characteristics of city. The inconsistent conversion of land use/land cover of Hanoi has led to the change in land surface temperature. Associating with air pollution, water degradation, solid waste pollution, it makes a crucial challenge for sustainable development of Hanoi city. The characteristics of Hanoi are as the following;

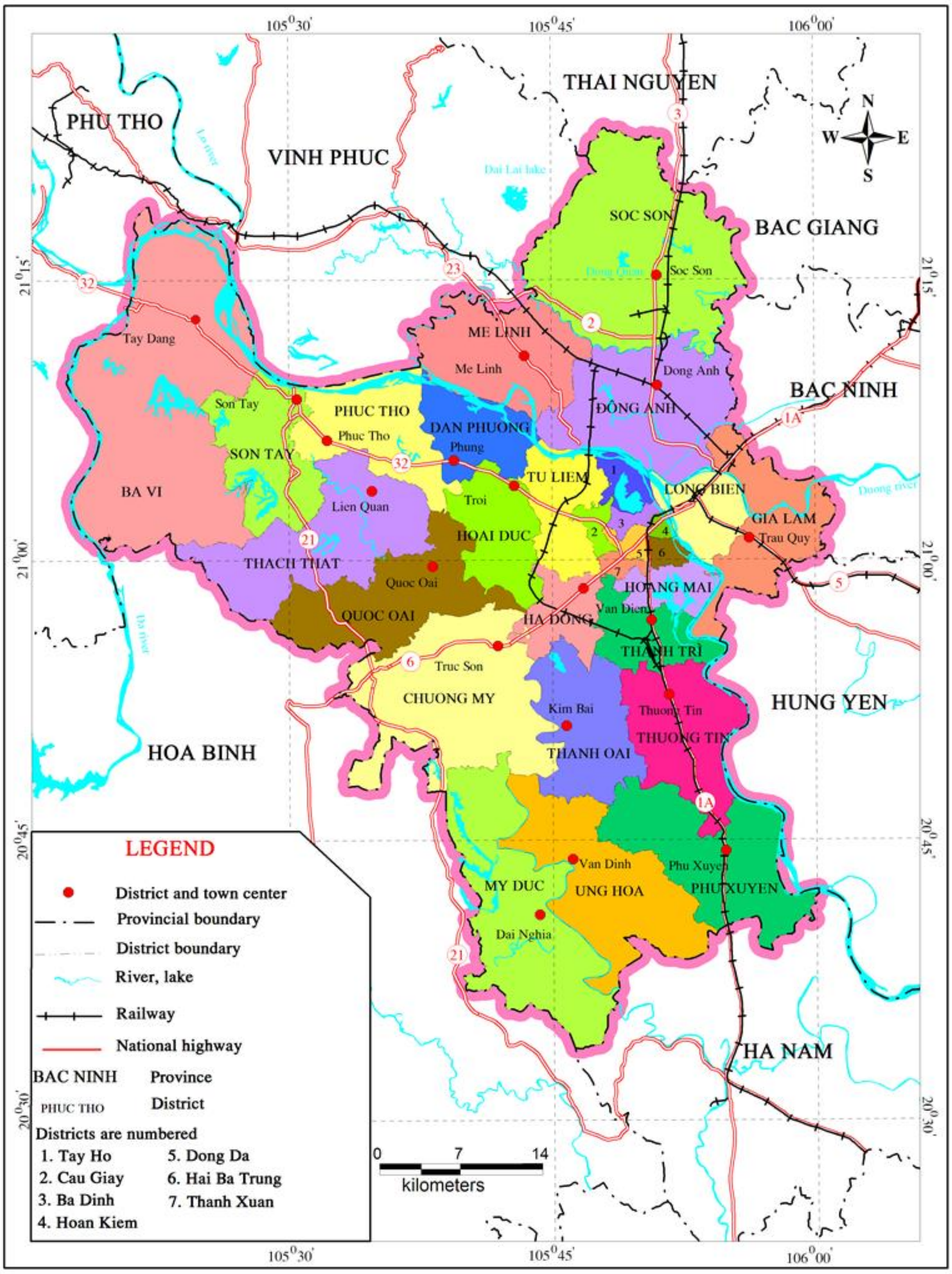


Figure 3 Administrative map of Hanoi in 2013

- Geographic location: Hanoi is located in the center of the Red river delta and bounded by Thai Nguyen prov., Vinh Phuc prov. to the North, by Hoa Binh prov. and Phu Tho prov. to the West, by Ha Nam and Hoa Binh to the South, by Bac Ninh prov., Bac Giang prov. and Hung Yen prov. to the East.

- Area: 3,324.92 km^2

- Topographic features: The major feature of Hanoi with large, high alluvial grounds and benches is plain leveled by rivers.

- Administrative units: Hanoi is divided into 10 inner districts: Ba Dinh, Hoan Kiem, Hai Ba Trung, Dong Da, Tay Ho, Thanh Xuan, Cau Giay, Long Bien, Hoang Mai and Ha Dong and 18 suburban districts: Dong Anh, Gia Lam, Soc Son, Thanh Tri, Tu Liem, Ba Vi, Dan Phuong, Hoai Duc, Phuc Tho, Thach That, Quoc Oai, Chuong My, Thuong Tin, Phuc Xuyen, Ung Hoa, My Duc and Me Linh.

- Population: 6,656,900 people

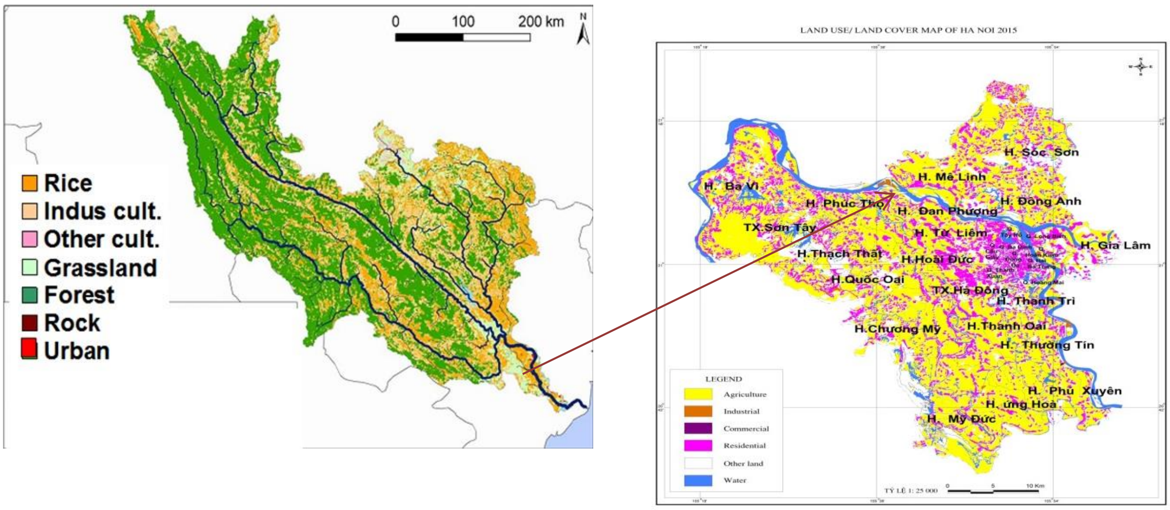
Land use in Hanoi is very diverse from one upstream sub-basin to another as well as between the upstream sub-basins and the delta area. Industrial crops dominate (58%) in the Lo basin, forests and bare land (74%) in the Da river basin, and paddy rice fields (66%) in the delta area. The Thao river basin is characterized by a larger diversity of land use including forest, paddy rice fields, and industrial crops (85%). The classification result shows that active agriculture occupies the largest area of land use/land cover type and widely distributes throughout the city, concentrating in the agricultural zone regions such as: Me Linh, Dan Phuong, Hoai Duc, etc,. Forest accounts for small area, mainly distributed in the West and Southwest of Hanoi: Ba Vi, Chuong Mi, My Duc and part of Northwest of Soc Son district. Whereas, residential concentrates on the center and the West of city, a small area is scattered in suburban districts. Water is located in rivers, natural lakes and wetlands in the South of the city (Ung Hoa, Phu Xuyen, My Duc districts). Land use/land cover change within the year is mainly reflected in the changes between active and inactive agricultural land and the change of water area. This is derived from agricultural activities of farmers. Water area increases when they pump water in the field to prepare for farming works and decreases when they cultivate or harvested crops. The change of forest or residential area is not clearly represented during the year.

The land use 2015 map of Hanoi shows that active agriculture occupies the largest area of land use/land cover type and widely distributes throughout the city when comparing to land use for 2010 and 2013. The residential area concentrates on central and western parts of the city, a small area is scattered in suburban districts. Water is located in rivers, natural lakes and wetlands in the South of the city. Land use change from 2010 to 2015 is shown in Table 2 and land use map for 2015 in Hanoi is shown in Figure 4

Table 2 Area of land use/land cover types of Hanoi city

No	Type of Land use/ land cover	2010		2013		2015	
		Area (Ha)	Proportion	Area (Ha)	Proportion	Area (Ha)	Proportion
1	Industrial	26619.74	8.01	30990.06	9.32	28699.17	8.63
2	Water	77577.59	23.34	31590.6	9.5	68129.45	20.49
3	Residential	27147.08	8.17	27684.15	8.33	46140.86	13.88
4	Commercial	7640.9	2.3	7744.06	2.33	20115.88	6.05
5	Agriculture	169823.52	51.08	195399.57	58.78	147160.55	44.26
6	Other land	23622.78	7.11	39024.81	11.73	22193.1	6.68

(Source: Calculation from maps)



(a) (b)

Figure 4 Land use map 2015 of the Red river and Thai Binh river basin (a) and Land use map 2015 of Hanoi (b)

Over time, forest and bare soil have changed not much in terms of the area as well as the distribution meanwhile other land use/land cover types have strong changed, especially residential, industrial and commercial areas. In 2010, residential, industrial and commercial concentrated in a small area in the city center and scattered in the suburban districts center. To 2015, urban has changed remarkably in which expands from residential zone and develops in surrounding areas near the city center and accounted for 20 percent of total city area. Residential, industrial and commercial lands were converted from agriculture and forest land. Hanoi residential areas have developed and expanded to Northeast, West and Southwest of city.

3.2 Downscaling of climate data

3.2.1 Bangkok

The projection of mean monthly temperature, mean monthly temperature, mean monthly minimum temperature and mean annual precipitation for Bangkok in 2050 is illustrated in Figure 5 and Figure 6. A comparison of climate parameters between 1960-1990 and 2050 is shown in Table 3

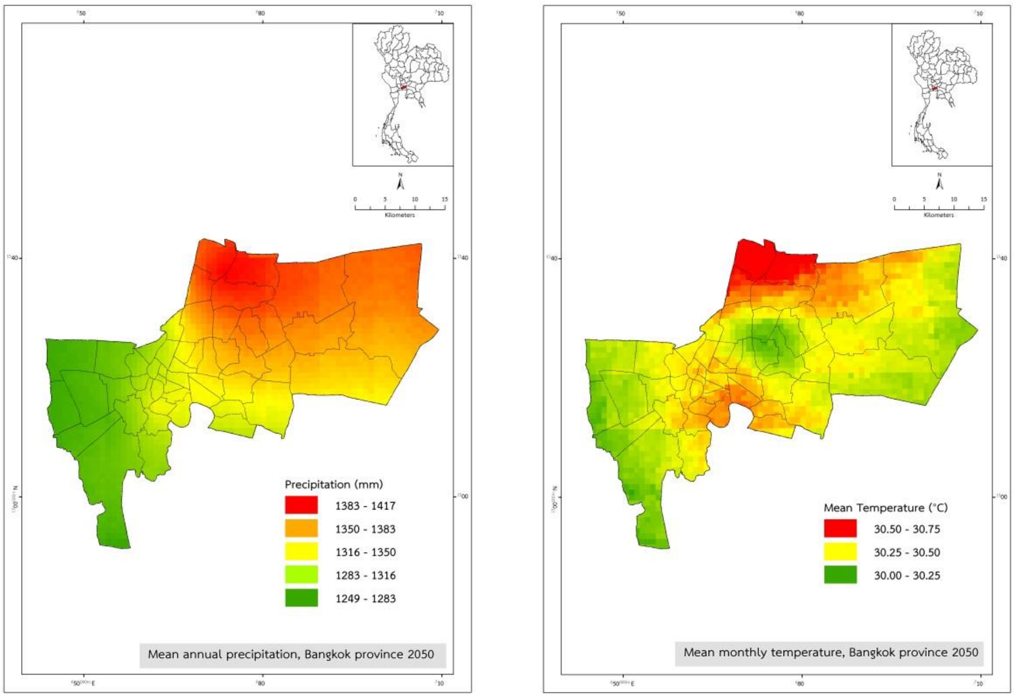
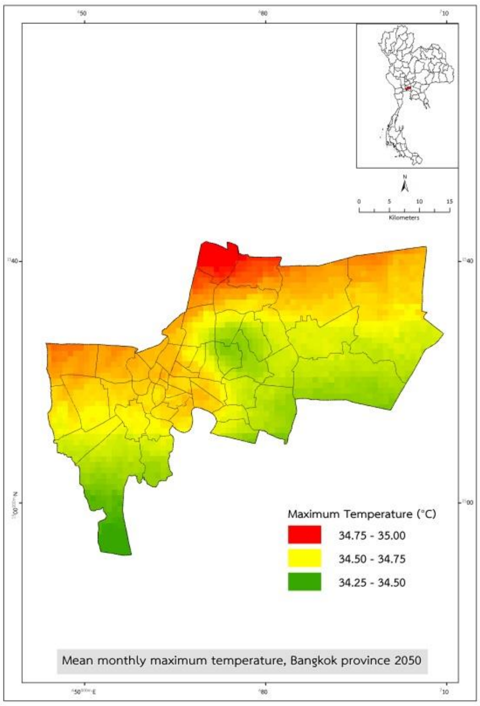


Figure 5 Annual precipitation and mean monthly temperature in Bangkok by 2050



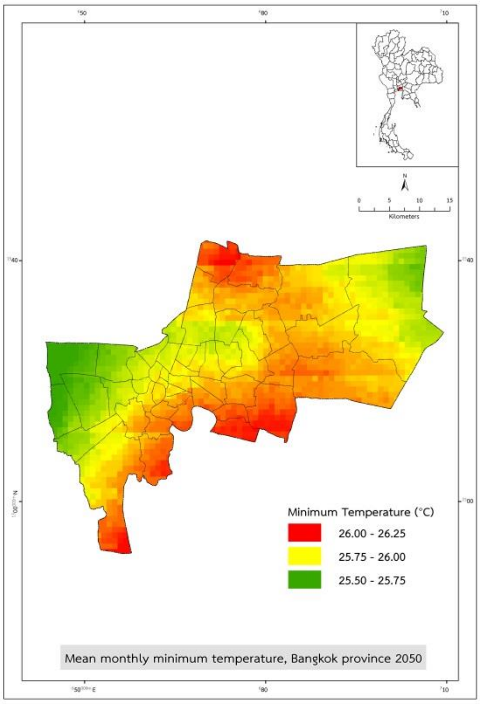


Figure 6 Mean monthly maximum and minimum temperature in Bangkok by 2050

Table 3 A comparison of temperature and precipitation in Bangkok between 1960-1990 and 2050

Climate parameters	1960-1990	2050
Annual precipitation (mm)	1445	1337
Mean monthly temperature (°C)	28.0	30.3
Mean monthly maximum temperature (°C)	32.4	34.6
Mean monthly minimum temperature (°C)	23.6	26.0

The average monthly temperature in Bangkok will be increase by about 2.3 °C in 2050 in comparison to 1960-1990. Both mean monthly maximum and minimum temperature tend to be increased by about 2.2 °C and 2.4 °C in 2050 in comparing with 1960-1990. However, precipitation is projected to be decreased by about 108 mm in 2050 when compares to 1960-1990. Temperature increases In Bangkok are expected to be within the range of 2.0 °C to 2.4 °C by 2050 or average for 2041-2060.

3.2.2 Hanoi

Hanoi's climate is humid subtropical with four distinct seasons (spring, summer, autumn and winter), there is also central characteristics of a tropical monsoon climate. From the observation data, daily minimum and maximum temperature and daily precipitation for 03 stations were kindly provided by the Vietnam Hydro Meteorological Data Center (HMDC). The data quality control was conducted based on 3 principles: (1) comparing each value with its climatologic value for each station; (2) comparing the physical consistence between 2 or more variables; and (3) a spatial test for each value with that of adjacent stations. All suitable data were utilized in the calculation of percentiles and the detection of extreme climatic events.

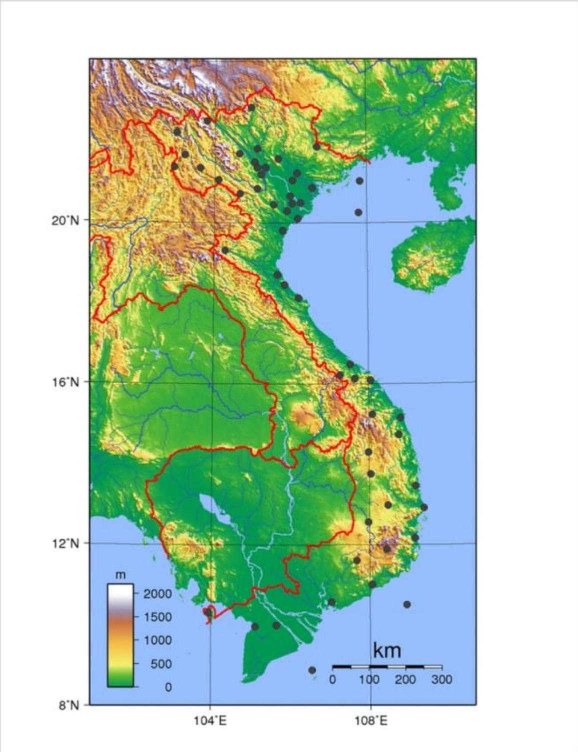


Figure 7 Meteorological stations with daily time series of temperature minimum, maximum and precipitation monitoring for the period 1981–2005 in Vietnam

GCMs climate data for 2050s at http://www.worldclim.org/CMIP5 and clip it by Vietnam boundary (shape-file). The global average surface temperature has increased, especially since about 1950. The updated 100-year trend (1906–2005) of 0.74°C ± 0.18°C is larger than the 100-year warming trend at the time of the TAR (1901–2000) of 0.6°C ± 0.2°C due to additional warm years. The total temperature increase from 1850-1899 to 2001-2005 is 0.76°C ± 0.19°C. The rate of warming averaged over the last 50 years (0.13°C ± 0.03°C per decade) is nearly twice that for the last 100 years. (IPCC-2007).Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (IPCC-2013). Follow the global warming trend; the results in this study also have an increase trend in temperature over Vietnam.

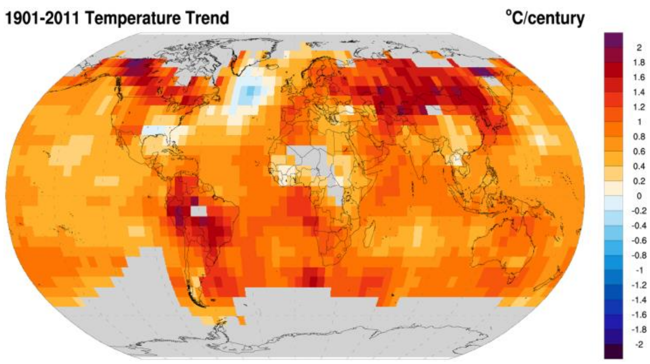


Figure 8 The global temperature trend over the period 1901 to 2011

(Source: http://en.wikipedia.org/wiki/Instrumental_temperature_record)

Over the period from 1981 to 2005, the daily maximum temperature and the daily minimum temperature had trend to increase in all regions of the country. The daily maximum temperature of country average increased 0.025°C. When considering future climate projection for Vietnam and Hanoi, monthly distribution pattern of GCMs climate data for 2050s is as the following;

(a) Precipitation;

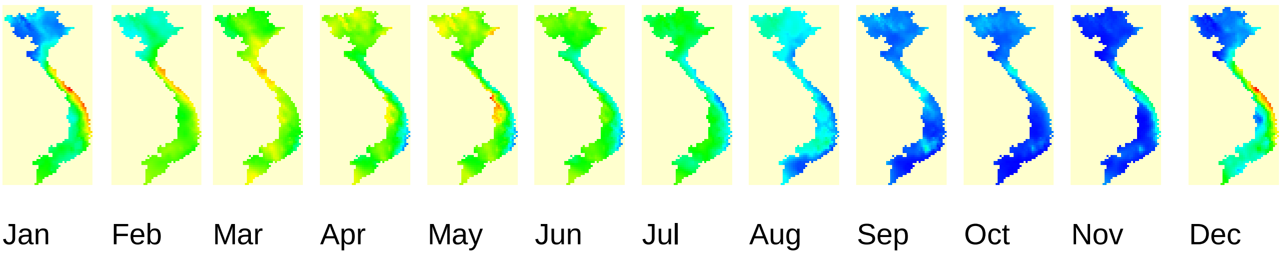


Figure 9 Pattern distribution of monthly country averaged over period 2050 by WorldClim-HadGEM3- RCP 4.5

(b) Maximum Temperature;

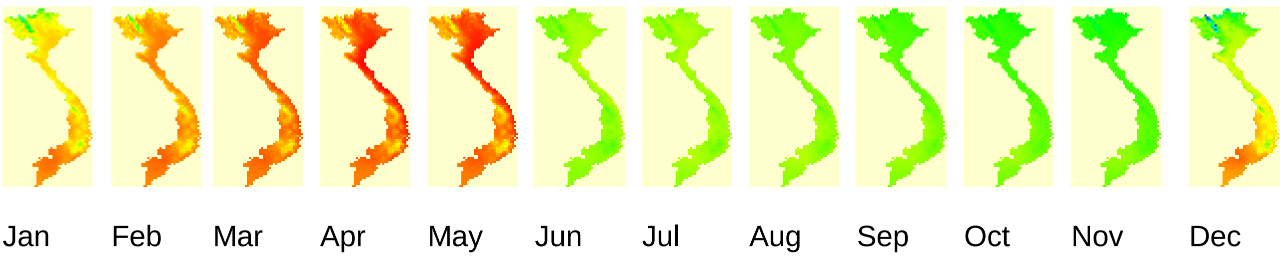


Figure 10 Pattern distribution of monthly country averaged over period 2050 by WorldClim-HadGEM3- RCP 4.5

(c) Minimum Temperature

Pattern distribution of monthly country averaged over period 2050 by WorldClim-HadGEM3- RCP 4.5

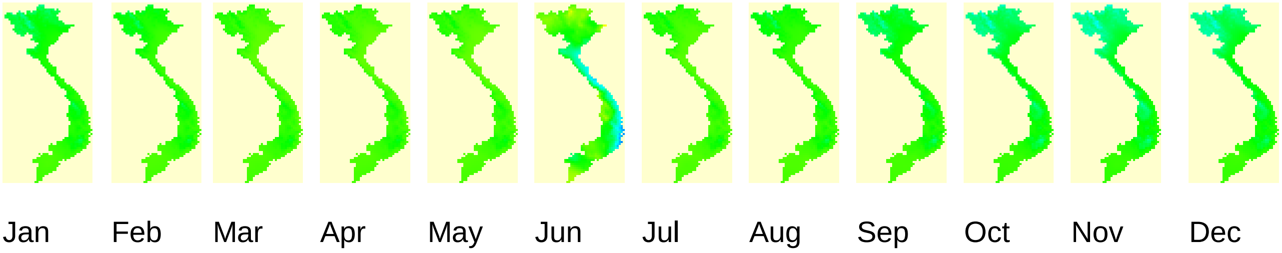


Figure 11 Pattern distribution of monthly country averaged over period 2050 by WorldClim-HadGEM3- RCP 4.5

Climate change scenarios take into account the change of climate variables in the middle of 21st century such as temperature (Maximum Temperature (^{o}C), Minimum Temperature (^{o}C) rainfall (monthly rainfall). About the precipitation change in the future, the model data is predicted not increase too much. However, precipitation on the whole country is inhomogeneous distribution; it concentrates in the coastal plain region of the North, coast of Central and the South of Vietnam. In the regions, the daily precipitation could increase to 12-14mm. Warmer temperatures could increase the probability of drought. Greater evaporation, particularly during summer and fall, could exacerbate drought conditions and increase the risk of wildfires. Meanwhile, the extra water vapor in the atmosphere will fall again as extra rain, which can cause flooding in other places. In this study, extreme climate events are predicted by 10 extreme climate indices that were calculated for the historical period.

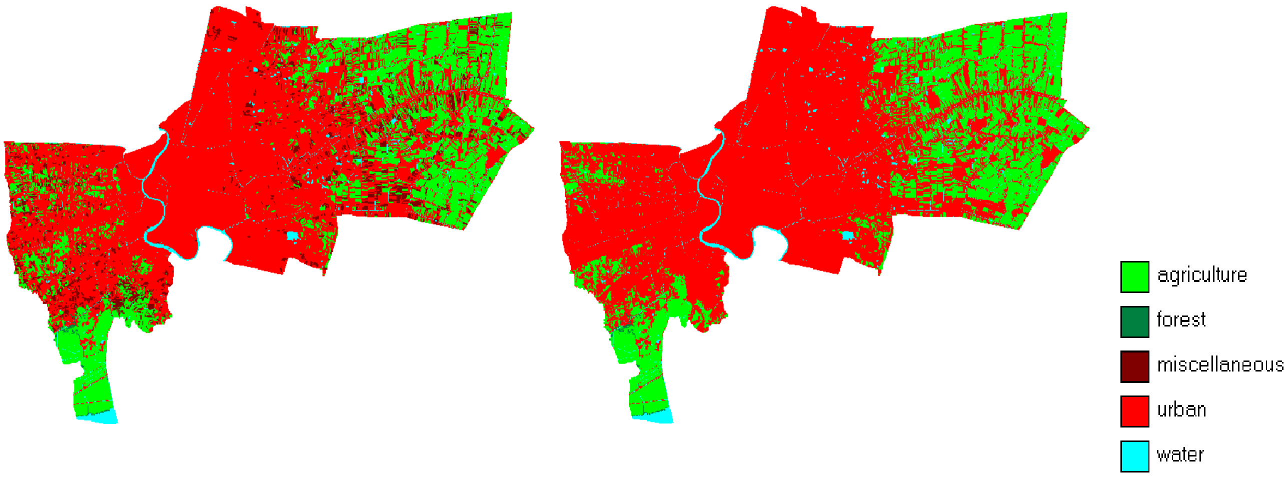
3.3 Land use modelling

3.3.1 Bangkok

Land use in Bangkok for 2050 is projected by using land use allocation method based on scenarios method. CluMondo software has been selected to be used in this study by considering performance for allocating land area depending on different demand, feasibility for conversion and land use resistance. Land use projection in 2050 will be divided into 3 scenarios as stated in topic 2.3 and will be compared to land use in 2010 which is identified as a starting year for modelling. Type of land use is classified by 5 categories; agriculture, forest, urban, water and miscellaneous.

The land use projection for Business as usual scenario (BAU) has been created by considering the physical and socioeconomic driving forces; distance to road, distance to rail, distance to stream, distance to mass transit and population density). A relationship between land use and driving forces is interpreted through logistic regression. The conversion resistance is one of the specific settings to determine the temporal dynamics of the simulation (Verburg et al., 2015). Land use type with high capital investment cannot be easily converted to other uses such as urban and stream. Therefore, dimensionless factors have been assigned to each type of land use, ranging from 0 (easily conversion) to 1 (irreversible change).

The productive capacity of one cell of a land use type for a specific land use service is defined by matrix table. The increase in urban area has been defined as land use services. Conversion from one land use type to another land use type needs to be considered by the model where 0 equals “no conversion allowed” and 1 equals “conversion allowance”. Two scenarios of land use; business as usual (BAU) and green growth (GG) is constructed by reviewing of related literatures and informal talking to local administrators. BAU tends to be driven by higher demand for urban expansion when comparing to GG scenarios. Figure 12 reveals a comparison between land use map in 2013 and the projected land use in 2050 under BAU scenario.



2013 2050

Figure 12 A comparison between 2013 land use and 2050 projected land use under BAU scenario

In contrast with BAU, GG scenario encourages a conservation of existing urban forest by minimizing urban expansion. Land use demand in 2050 for urban area in GG scenario is less than those in BAU scenarios. A comparison between 2013 land use and 2050 projected land use for GG scenario is shown in Figure 13

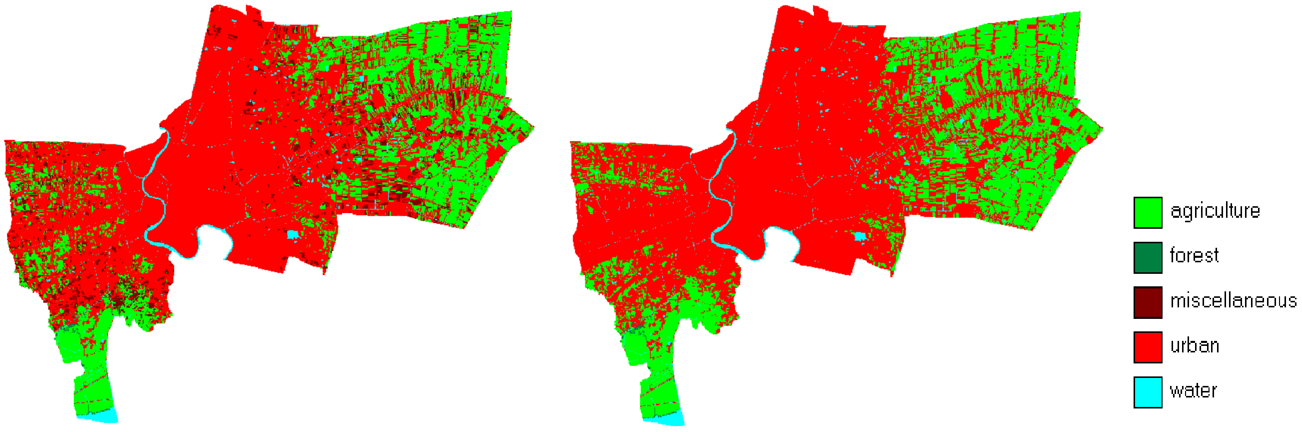


Figure 13 A comparison between 2013 land use and 2050 projected land use under GG scenario

3.3.2 Hanoi

Land use in Hanoi for 2050 is projected by using land use allocation method based on scenarios method. CLUMondo software has been selected to be used in this study by considering performance for allocating land area depending on different demand, feasibility for conversion and land use resistance. CLUMondo is based on the land systems approach. Land systems are socio-ecological systems that reflect land use in a spatial unit in terms of land cover composition, spatial configuration, and the management activities employed. The precise definition of land systems depends on the scale of analysis, the purpose of modelling, and the case study region. In contrast to land cover classifications the role of land use intensity and livestock systems are explicitly addressed.

Land use projection in 2050 will be divided into 3 scenarios as stated in topic 2.3 and will be compared to land use in 2015 which is identified as a starting year for modelling. Type of land use is classified by 5 categories; agriculture, forest, urban, water and miscellaneous. The land use projection for Business as usual scenario (BAU) is a scenario for future patterns of activity which assumes that there will be no significant change in people's attitudes and priorities, or no major changes in technology, economics, or policies, so that normal circumstances can be expected to continue unchanged. A comparison between 2015 land use and 2050 projected land use for GG scenario is shown in Figure 14

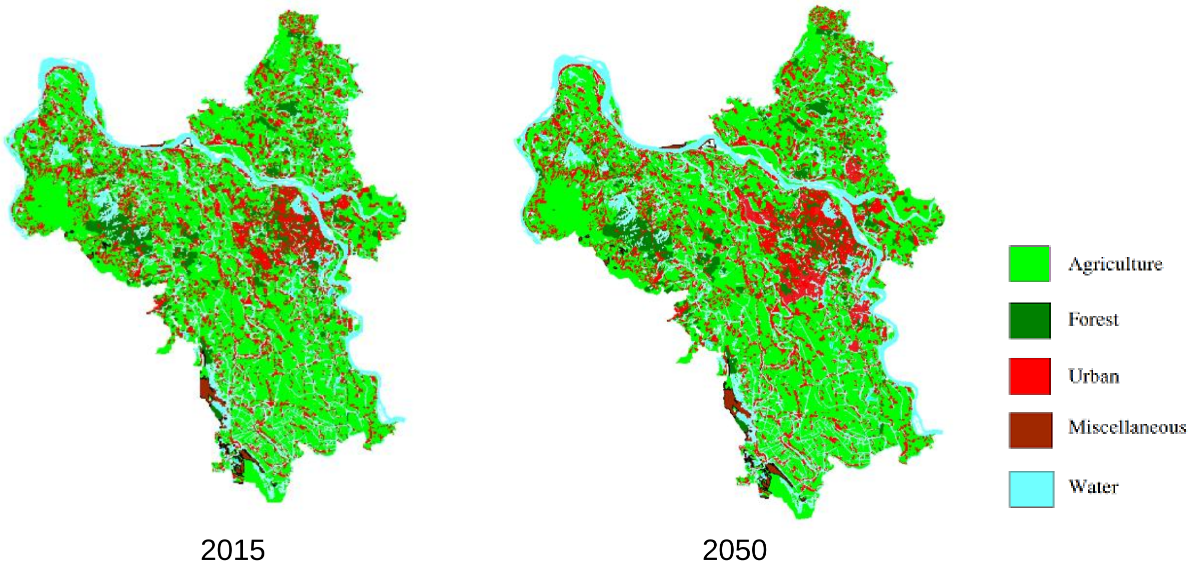


Figure 14 A comparison between 2015 land use and 2050 projected land use for BaU scenarios

Most of agricultural land is converted for use urban land. Miscellaneous is also converted to urban (with small percentage). Land use type with high capital investment cannot be easily converted to other uses such as urban or industrial estate.

The land projected land use under GG scenario means fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. A comparison between 2015 land use and 2050 projected land use for GG scenario is shown in Figure 15

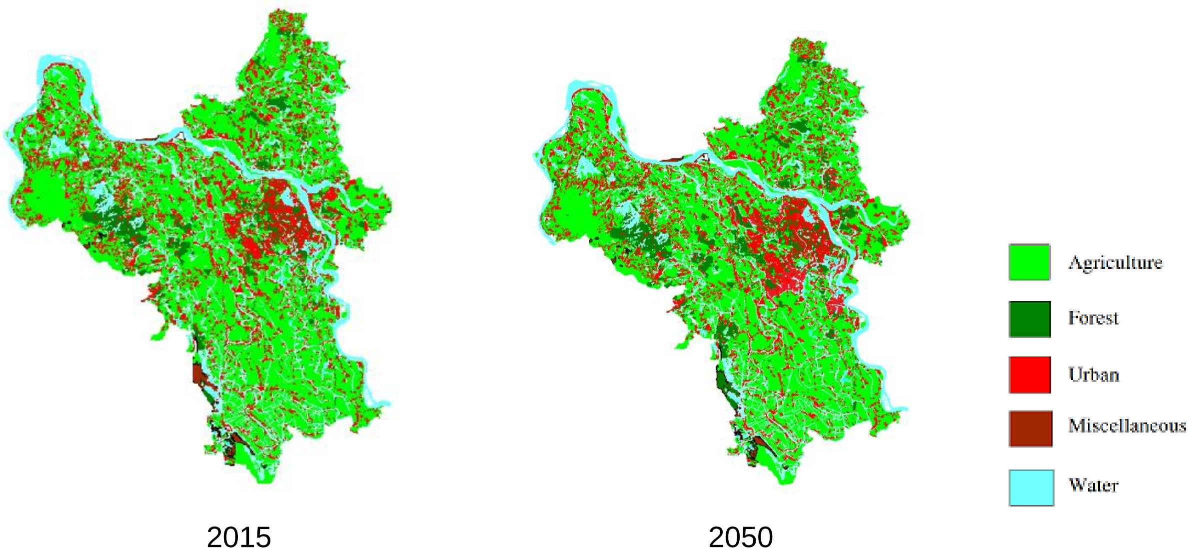


Figure 15 A comparison between 2015 land use and 2050 projected land use under GG scenarios

In 2050 projected land use under GG scenarios, both of urban and forest cover is increasing. In contrast with BAU, GG scenario encourages a conservation of existing urban forest by minimizing urban expansion. Land use demand in 2050 for urban area in GG scenario is less than those in BAU scenarios.

3.4 Urban water system assessment

3.4.1 Water demand for Hanoi in 2050

According to calculations, the water balance system for the current situation is as follows: Basing on the demand for water mainly the people's life and economic fields, the project simulates the water balance calculation scheme for the study area. Rescue with the main subjects are: water demand for living, agriculture, industry but not to mention the flow of the environment. The priority for water use needs of environmental and living water flows remains the highest, followed by industrial parks in the city's major centers, eventually demanding water for agriculture and other industrial parks. So the plan also comes up to look at those needs.

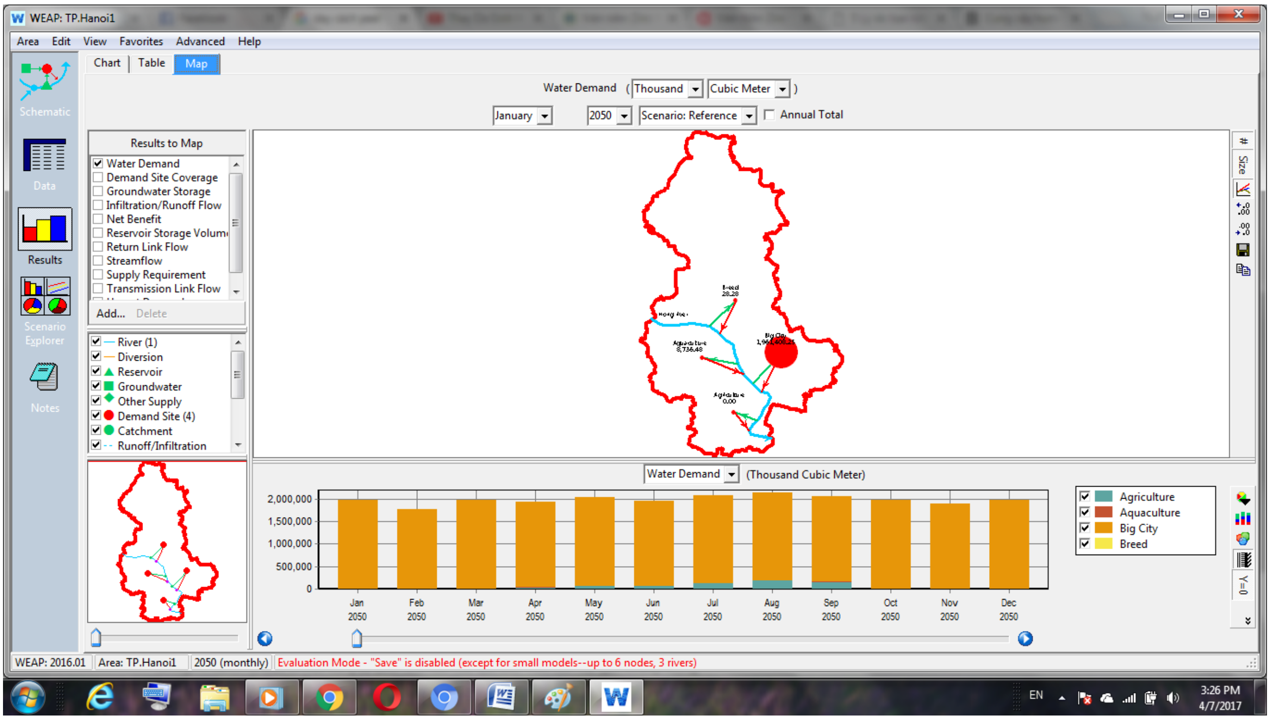


Figure 16 WEAP water balance model for Hanoi

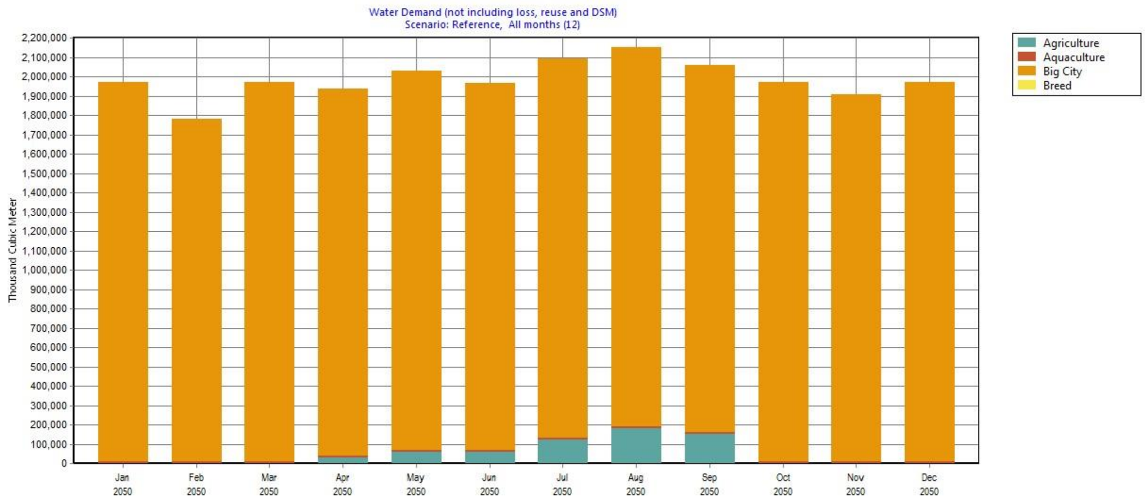


Figure 17 Total demand for water use for Hanoi

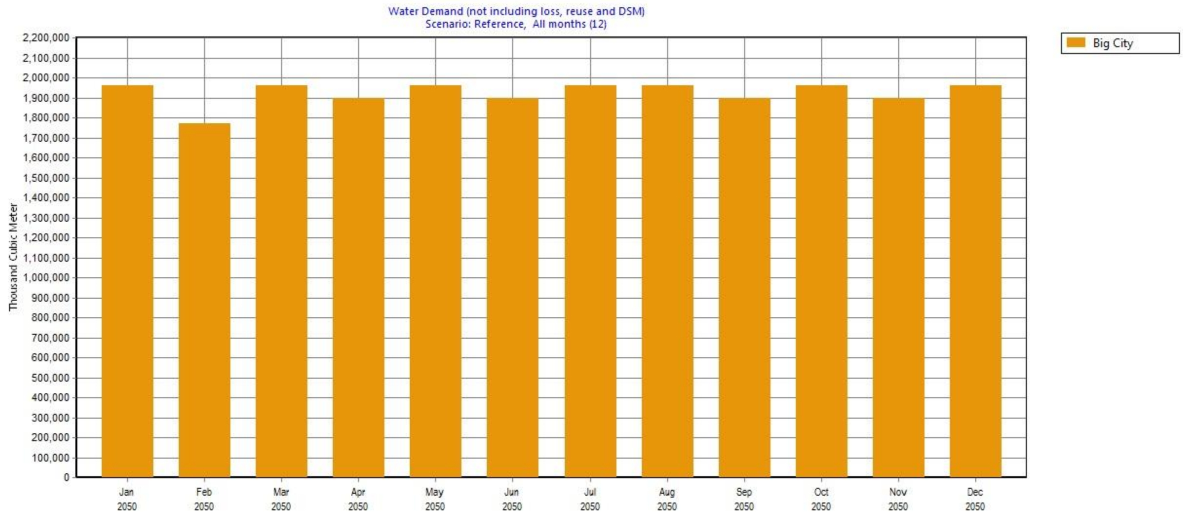


Figure 18 Demand for domestic water use for Hanoi

Based on the results obtained from the water balance calculations developed for the study area in the 2050 scenario, the watershed still faces many difficulties in distributing and supplying water in the future. As a relatively large basin, the population is large and is mainly active in the agricultural sector, so the demand for water for the users is quite high. Moreover, increasing living standards also increase the demand for water. At the same time, more and more industrial zones and hydropower projects in the basin increase, leading to increased water requirements. In addition, water resources in the basin are unevenly distributed over space and time, which will be a major difficulty in the distribution and use of water.

3.4.2 Water demand for Bangkok in 2050

Water demand in Bangkok has been assessed for domestic supply. Highest priority of current water use in Bangkok is dedicated to domestic supply. Total water consumption per capita of Bangkok is 340.2 litres/day and percentage of population those can access safe water is about 99 percent. More than 14 million people live in the Bangkok metropolitan area. The city gets most of its drinking water from the Chao Phraya river, which runs through the center of the city into the Gulf of Thailand a few miles downstream. During a drought, seawater can flow upstream, turning the river brackish. Low reservoirs are certainly not a new problem for Thailand, which has long proposed improving its water system to prevent catastrophic flooding and to preserve more water for the dry times. But it’s getting worse and climate change threatens to exacerbate the issues.

According to results, the water balance system for the current situation is as follows: Basing on the demand for water mainly come from domestic uses and small medium size enterprise (SME) in Bangkok, the project simulates the water balance calculation scheme for the study area. Rescue with the main subjects are: water demand for domestic supply, agriculture, industry but not to mention the flow of the environment. The priority for water use for domestic supply remains the highest, followed by agriculture. So the plan also comes up to look at those needs for further urban planning and management under climate and land use change.

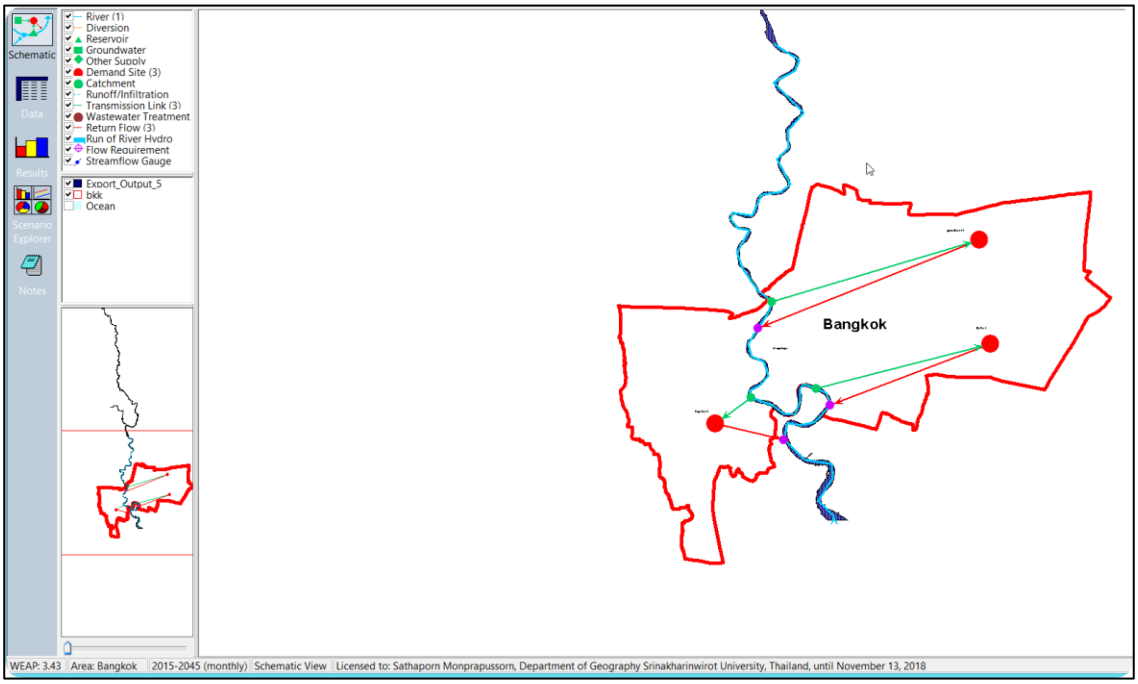


Figure 19 Area of study of Bangkok and Chao Phraya River

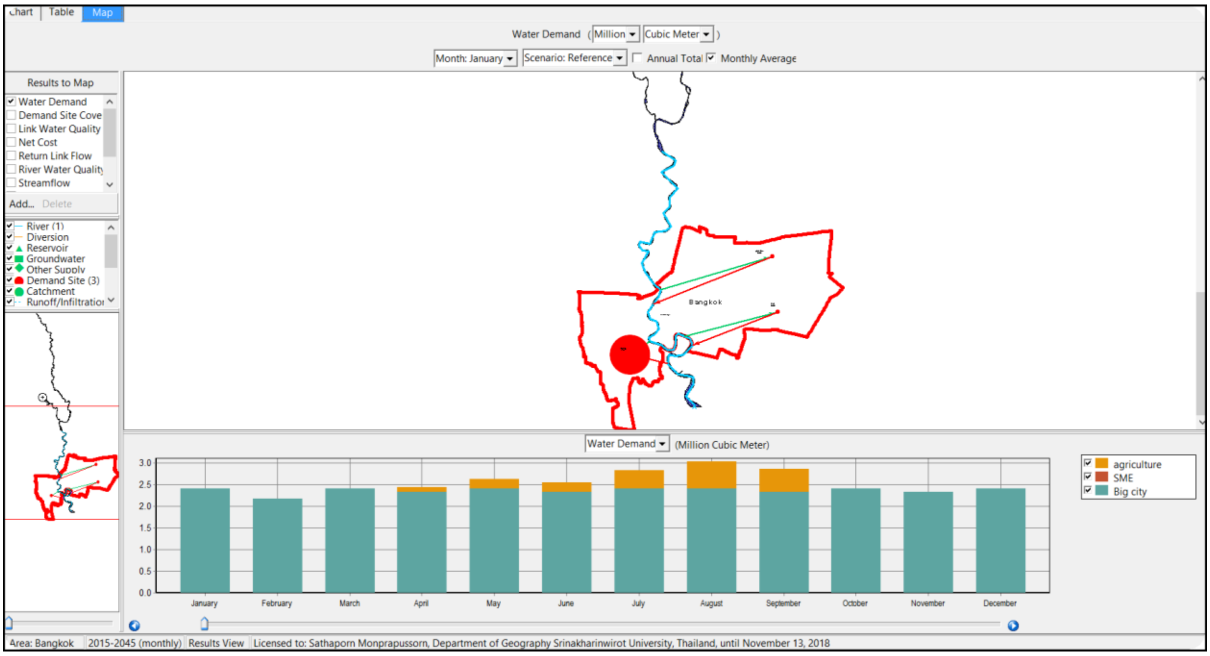


Figure 20 Total demand for water use for Bangkok

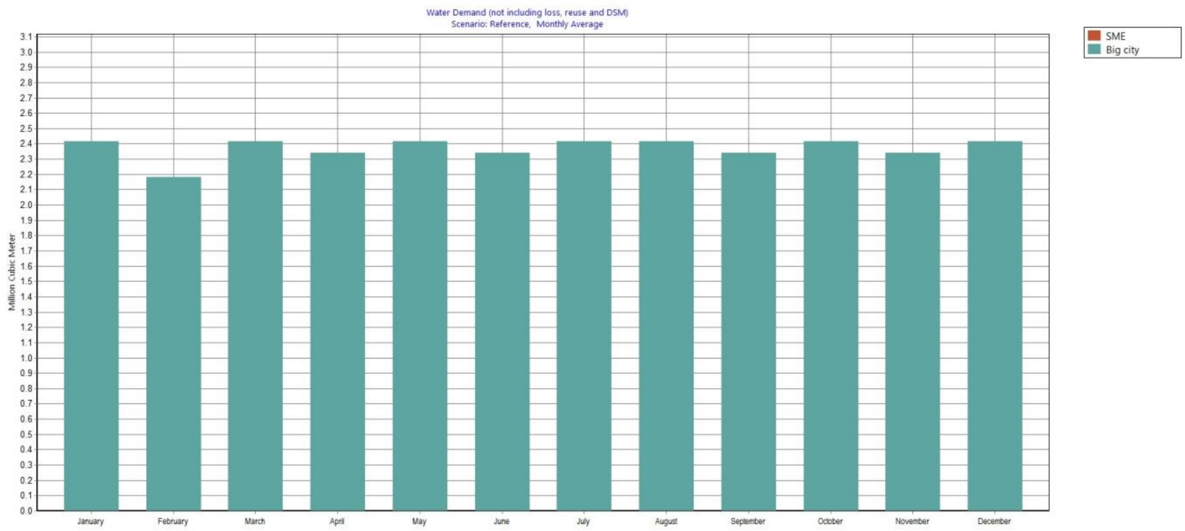


Figure 21 Demand for domestic water use for Bangkok

Based on the results shown in Figure 19, future water demand for Bangkok will increase according to the increase in population. However, the rate of population growth in a future is expected to be lower than the past due to fewer birth rates. From land use modelling results in topic 3.3, agriculture land tends to be decreased by transforming to urban area. Bangkok probably faces with water related extreme events both in frequency and intensity i.e. floods, drought and storm which can cause water shortage for domestic supply. The construction of the 110km diversion channel running in parallel with the planned 3rd Outer Ring Road which diverting water from the area south of the Chao Phraya River dam can play a significant role in alleviate floods problem in Chao Phraya river basin, including Bangkok. Area of construction includes the lower basin of Chao Phraya (Ayutthaya province to the Gulf of Thailand) which can protect the key economic zone and industrial estates of Bangkok and surrounding provinces. The lesson learnt from 2011 flood and climate change lead to the enactment of Section 44 on the Water resources Act to systematically create a database of the country's water flows, and find out ways to strengthen water resources management. Industry expansion in Bangkok, especially small and medium size enterprises (SMEs) may lead to higher water demand. City governor of Bangkok do needs to concern about securing sufficient water supplies for Bangkok population by closely coordinating with other provinces in Chao Phraya river basin to ensure effective water management in the basin.

3.5 Adaptation

3.5.1 Bangkok

Bangkok is the largest metropolitan area in Thailand. There are many challenges to Bangkok both internal and external factors. Internal factors include population growth, labour migration, over consumption, economic growth & competitions and capitalization trends. While many external factors influence Bangkok in various aspects such as Technological change, globalization and climate change. These factors introduce a huge impact on the environment e.g. air pollution, solid waste, water pollution, lack of green space and flooding and coastal erosion. Sea level rise situation in 2050 is expected to be worse than existing situation. However, rate of population growth in Bangkok is decreasing when comparing to those in the past ten year, but tend to be increasing in neighbourhood province instead such as Pathum Thani, Nonthaburi. However, the city water planner must focus on how to build a resilient to future uncertainties in impact of climate and land use change on urban water supplies. Bangkok Metropolitan is currently taking actions with a view to preventing and mitigating flood problems in Bangkok. However, none of the measures have explicitly taken climate change into account in their analyses or the design of the interventions. Several measures such as flood management and drainage infrastructure improvement, natural buffers and early warning systems are applied to improve flood management system.

In case of the availability of water supply, well coordination among city planners and the committee of upper river basin such as Chao Phraya and Tha Chin river basins is very important to secure sufficient amount of water to domestic supply in Bangkok. Sea water intrusion from rising in sea level can lead to a contamination of drinking water sources and other consequences. Although agricultural land in Bangkok tends to be dramatically decreased by 2050, drought spell along with sea water intrusion might affect Bangkok in term of water quality and water availability. In contrast with water availability, Bangkok tends to be affected by extreme water-related weather events such as flood. There is a tendency of increasing in frequency of extreme weather that result in flood in Bangkok in the past 30 years, especially a great flood in 2011 which ruined Thailand's economy and livelihood of people living in Bangkok. After 2011, government have invested in mitigation efforts to protect recurrent of flood such as flood way and hard infrastructure. However, city planner should also plan for urban resilience to climate change and flood risk by supporting adaptation. Reducing urban runoff by increasing green spaces, parks and urban wetland can enable more rainfall to soak into underlying soil. Floating house is another adaptation alternative against impact from flood. It would be useful in a future if further work on vulnerability and flood risk will be analysed and assessed resulting in more concrete perspectives on urban adaptation.

3.5.2 Hanoi

Hanoi is one of the growing metropolises with the most rapid urbanization speed of Vietnam. This process has led to the decreasing of agricultural land and subsequently the increasing of residential and industrial, commercial land. Climate change alters precipitation levels. The impact of climate change is causing the flood season to increase and the flow of dry season decreases. Both projected climate change and land use/cover change have an impact on water resources. Therefore, adapt to the effects of climate change and land use/cover change on stream flow within a river basin has become a necessary experience in hydrology and water resource fields.

While water management and climate change adaptation plans will be essential to lessen the impacts, they cannot be expected to counter the effects of a warming climate. One reason is that the changes may simply outrun the potential for alternatives such as modifying withdrawals, increasing water use efficiency, increased water recycling, enhancing groundwater recharge, rainwater harvesting and inter-basin or inter-county transfers to make up for water deficits. The widespread nature of the risk of water shortages may also limit the effectiveness of local solutions—such as acquiring more water from a neighboring county or basin—since many other localities will be trying to get control of the same resource. Hanoi is engaging in the following adaptation activities: Actively improve the flood preparedness and prevention standards for sustainable development. Current flood prevention probability level is 0.8 percent, but the target is 0.4 percents, and then 0.2 percent in the future. Many infrastructure based solutions have been proposed for flood protection in Hanoi i.e.; strengthening the dike system to protect the right bank of the Red River (Asian Development Bank project); clear river bed and unlock river flows to ensure prompt flood discharge in the Red River; lowering the elevation of inner dikes, relocating houses and construction from the restricted barrier of floods; building upstream water reservoirs to control the flood pressures and strengthening flood discharge and construction (following design procedures) to protect Hanoi in flood emergencies. Issue detailed socio-economic policies for flood discharge and control processes to ensure social equity;

Hanoi's planners have to find a fair balance between economic growth and competitiveness of the city on the one hand, and the protection of its natural wealth and built environment on the other. This is a difficult but stimulating task.

4. Conclusions

Using WorldCLIM climate database to project climate in 2050 together with hydrological model (WEAP) combined with Geoinformatics technique reveal a significant challenge for improving cities resilient in water sector. The allocation method was also used to project land use change in 2050 to analyse the effect of climate and land use change on the water resource (focusing surface runoff). The key findings are summarized as follows:

Bangkok and Hanoi are among the growing metropolises with the most rapid urbanization speed in Southeast Asia. This process has led to the decreasing of agricultural land and subsequently the increasing of residential, industrial, and commercial land. It means that impervious surface is rapidly increasing in these cities from urban expansion, resulting in more vulnerable to flood both in frequency and intensity. Initial research has assessed the impact of climate change on future water use needs in the water resources assessment. Climate change alters precipitation levels, Impact of climate change is causing the flood season to increase and the flow of dry season decreases, making extreme water related weather events happen stronger than before.

The interaction between LULC and hydrological response is a complex phenomenon. In this study, WEAP model was used to roughly estimate impact of climate and land use change in both Chaophraya river basin (Bangkok area) and Nhue Day River watershed (Hanoi area). Distributed hydrological modelling can reveal the spatial distribution of hydrological parameters. The results reveal that climate change has close connections with the hydrological cycle. The hydrological cycle is located in the earth hydrosphere this is the area in around earth which holds all the water. The water is moved around the earths hydrosphere in a cycle. The hydrological cycle is moved in five different steps - evaporation, precipitation, condensation, runoff, collection and infiltration. Due to the impact of climate change, water resources are subjected to increased risk of drought due to increasing droughts in some areas, seasons, direct impacts on agriculture, rural and urban water supply, and Hydropower generation. Modified rainfall patterns can cause severe flooding in the rainy season and droughts in the dry season, increasing conflict in the exploitation and use of water resources.

In conclusion, the results presented that the increase of built up land and the urbanization has great effected on water resources in term of higher water demand, particularly in this study is surface runoff and the increase in flood risk. Urban sprawl is the main cause of land subsidence throughout Bangkok and Hanoi at present and can worsen some impacts from climate change i.e. urban flood and coastal inundation. When considering both climate and land use change in Bangkok and Hanoi in 2050, the increase in temperature is more prominent than precipitation. The coupled impact of rising temperature and urban sprawl may lead to urban heat island problem which urban planners and policy makers should consider its significant impacts and prepare the cities for changing climate. However, it is expected that frequency and intensity of weather extreme such as extreme storm and flood will have numerous impacts on urban lives and properties. Cities must prepare for adaptation strategies and should begin to integrate effective climate change mitigation and adaptation strategies into both short term and long term plan of cities development.

5. Future Directions

Further work related to this research can be done in many ways as the following;

- More comprehensive climate change simulation by using ensemble methods which extract climate parameters (temperature and precipitation) from many global climate models as an input for water resources assessment.
- For land use modelling, increase in number of land use classes would provide more insight to urban climate and water assessment. Urban and agriculture land use could be broken down into many sub-classes such as residential, commercial, rice, crop and perennial area.

- More details analysis of urban resilience study in term of exploring socioeconomic and socioecological perspectives, focusing on the interlinking climate change with water-food-ecosystem nexus.
- Capacity building of key stakeholders such as government officials, policy makers and other interested group related to climate change and its impact on urban water resilience, including potential mitigation and adaptation strategies
- Include sea level rise analysis and its impact on urban land use and water resources in both cities such as coastal inundation floods and ecosystem based adaptation

6. References

Asian development Bank (2009).The economics of climate change in Southeast Asia: A regional review.

Berke, P., Cooper, J., Aminto, M., Grabich, S., Horney, J., 2015. Adaptive planning for disaster recovery and resiliency: an evaluation of 87 local recovery plans in eight states. J. Am. Plann. Assoc. 80 (4), 310–323.

BMA. 2013. Implementation plan for preventing and solving the problem of floods in Bangkok in 2013 under the responsibility of the Department of Drainage and Sewerage (in Thai). Department of Drainage and Sewerage.

BMA. undated. Local Government Profile. http://www.unisdr.org/campaign/resilientcities/cities/view/28; accessed on 5 April 2014.

Brown, A., Dayal, A., Del Rio, C.R., 2012. From practice to theory: emerging lessons from Asia for building urban climate change resilience. Environ. Urban. 24, 531–556 (2012).

Eitelberg, David A., van Vliet, Jasper, Verburg, Peter H., 2014. A review of global potentially available cropland estimates and their consequences for model-based assessments. Global Change Biology, 21, 1236-1248.

Lal, P.N., Mitchell, T., Aldunce, P., Auld, H., Mechler, R., Miyan, A., Romano, L.E., Zakaria, S., 2012. National systems for managing the risks from climate extremes and disasters. In: Field, C.B. et al. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 339–392.

Nordgren, J., Stults, M., Meerow, S. 2015. Supporting local climate change adaptation: Where we are and where we need to go, Environmental Science & Policy. 66, 344-352.

Storch, H., Downes, N.K., 2011. A scenario-based approach to assess Ho Chi Minh City's urban development strategies against the impact of climate change. Cities 28 (2011), 517–526.

Van Vliet, Jasper, Eitelberg, David A., Verburg, Peter H., 2017. A global analysis of land take in cropland areas and production displacement from urbanization. Global Environmental Change, 43, 107-115.

World Bank, 2012a. Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century.

World Bank, 2013b. Building Resilience: Integrating Climate and Disaster Risk into Development: The World Bank Group Experience.

7. Appendix

Funding sources outside the APN

In kind support for Thailand and Vietnam

1. Geographic information system licensed software (ArcGIS) (estimated expense of 6,000 USD)
2. Administrative support; office spaces, desktop computers and common materials (estimated expense of 4,000 USD)
3. Personnel support; time allocated for the projects, extra time works and allowances (estimated expense of 20,000 USD)

List of Young Scientists

Thailand

1. Miss Montana Khumsanit; During Jan 2016-2017, she worked as a research assistant of the project. She graduated from department of Geography, Faculty of Social Sciences, Srinakharinwirot University in 2014. Her research skills include Geographic Information System, Image processing and AutoCAD drawing. Her engagements in the project include spatial data cleaning and preparing as an input for climate change and land use modelling. The short message from her is as the following; "This research helps me to increase capacity so I can learn a new thing about how to get and extract international climate database via website, including basic concept of climate and land use change, including water resources assessment in urban area. Spatial data cleaning and preparation for model input are the main task for me in a project. This would be beneficial for me in a future as I have a plan to continue my graduate study in the field of environmental sciences and/or management, climate change and urban policy"

Glossary of Terms

Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.
Adaptive capacity	The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.
Climate change	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of

	its properties and that persists for an extended period, typically decades or longer.
Climate projection	A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions and concerning
Capacity building	In the context of climate change, capacity building is a process of developing the technical skills and institutional capability in developing countries and economies in transition to enable them to participate in all aspects of adaptation to, mitigation of, and research on climate change, and the implementation of the Kyoto Mechanisms, etc.
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.
Impact	Effects on natural and human systems. In this report, the term 'impacts' is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.
Land use	Management and modification of natural environment or wilderness into built environment.
Land use change	A change in the use or management of land by humans, which may lead to a change in land cover.
Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Runoff	That part of precipitation that does not evaporate and is not transpired, but flows through the ground or over the ground surface and returns to bodies of water.
Radiative forcing	Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in W m^{-2}) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.

Urbanization	The conversion of land from a natural state or managed natural state (such as agriculture) to cities; a process driven by net rural-to-urban migration through which an increasing percentage of the population in any nation or region come to live in settlements that are defined as “urban centres.”
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.