Local Flood Risk and Responding Adaptation in Northern Bangkok Metropolitan Region: Case of Tha Khlong Municipality

Manatsavee Euanontat[1], Vilas Nitivattananon[1,*], Napassorn Sutthiprapa[1], Thanakom Wongboontham[1], and Shenghui Cui[2,3]

ARTICLE INFO

Article history:
Received: 23 March 2020
Revised: 9 August 2020
Accepted: 12 August 2020

Keywords:
Adaptation
Flood risk
Peri-urbanized metropolitan
Urban planning and management

ABSTRACT

The central plain of Thailand faces significant flood issues due to its geography, especially in the Peri-urbanized ecosystem of the rapidly expanding northern Bangkok Metropolitan Region (BMR). In addition, the extended part of the urban development often lacks environmental and socio-economic services, due to the complicated responsibilities of such areas. The objective of this study is to assess flood risk and responding adaptation at the local scale in BMR using Tha Khlong Municipality (in Pathum Thani province) as a case. The study applied mixed methods of analysis, incorporating in-depth interviews, focus group discussions, field observations, and document review. The findings indicate that some areas have occasional floods due to heavy storm waters. However, most of the time the floods were caused through reduced drainage capacities subject to different human-related activities together with incompatibility of responsibilities among several agencies – also at different levels generating some bottlenecks in the system. Current adaptation practices are mostly less proactive within each of the relevant agencies. There is the potential enhancement of synergies between adaptation measures and the risks requiring an integrated approach to be applied.

1. INTRODUCTION

In Asia, the expansion of urban mega-cities has expanded beyond the metropolitan borders and has resulted in the emergence of mega-urban regions. Urban development is haphazardly spilling over the existing agriculture sector surrounding cities [1]. The extended part of urban development often lacks the central government's environmental and socio-economic services, usually due to the complicated responsibilities of management area and land development owners would require internal infrastructure, and the conflicting governance management is starting to cause stormwater management difficulties. In addition, new roads and buildings resulting from the expansion of the city replace the agricultural area, which would generally serve as a hydrological feature [2]. New developments often replace natural wetlands where, as a rule, floodwaters are usually supplied with concrete. As a result, the water should also be diverted to the sewage system [3].

Most of the rapid urban growth in middle-low-income countries is struggling with urban flooding due to inadequate drainage and waste management [4]. There are several causes of floods, such as urban floods, including river floods, coastal floods, pluvial and groundwater floods, glacial floods, and dam breaks. Although one of the main drivers of urban flooding is the climatic condition (e.g. extreme precipitation and flow) and anthropogenic activities (e.g. spontaneous urban development) [5], localized stormwater floods could occur due to the impervious surface that produces high surface runoff due to insufficient drainage. In addition, the flood was considered to be a minor limited only to the impact on the affected communities [6]. Haque responded by pointing out that insufficient drainage and wastewater infrastructure systems are the product of inappropriate policies, sparse institutional arrangements, outdated mandates, and lack of funding [7]. This lack of stormwater management and flood control has forced both the private and public sectors to initiate their own flood adaptation and responding measures [8]. The Bangkok Metropolitan Region (BMR), consisting of the Bangkok Metropolitan Administration (or Bangkok City) and its five surrounding provinces, is affected by pluvial floods. It is frequently reported that there is a flood in the streets. Many claimed that the flood was caused by inadequate drainage. Insufficient drainage

[1] *Urban Innovation and Sustainability, Asian Institute of Technology (AIT), P.O. Box 4, Klong Luang, Pathum Thani 12120, Thailand.*
[2] *Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China*
[3] *Xiamen Key Lab of Urban Metabolism, Xiamen 361021, China.*
**Corresponding author:* Vilas Nitivattananon; Phone: 66-2-524- 5601; E-mail: vilasn@ait.asia.

can be caused by a lack of maintenance or infrastructure deficiency, which allows the flood to persistent.

The objective of this study is to assess flood risk and responding adaptation at local scale, focusing on causes, effects and responses in northern BMR's peri-urban areas, using Tha Khlong Municipality (TKM) as a case could be. The scope of the study includes frequent stormwater floods due to lack of holistic information and management. One ad-hoc adaptation may cause flood in another location including the impact of the flood. The lack of premise drainage maintenance or drainage incapacity may increase the flood occurrences in other areas. Therefore, autonomous flood management need to be reviewed.

2. LITERATURE REVIEW

2.1 Urbanization, stormwater flood and management

Stormwater floods triggered by extreme rainfall have increased. A study [8] on floods in China has shown that pluvial floods in China caused by extreme rainfall and clouds have erupted in 6 events over the last 10 years. The report [13] claimed that the cause of the floods was climate change, extensive and rapid urbanization, and unsustainable urban development combined with management failure (Fig. 1). In accordance with another study [2], pluvial floods have been correlated with rapid developments, increasing vulnerability to increasing flood hazards due to climate change. In addition to the development dominated by economic growth and lack of environmental aspects, the aquatic ecosystem has been replaced by impervious surfaces at a rate of 6.5 percent per year. This leads to a lack of water resilience and reduces the land capacity to absorb, store, infiltrate, and detain rainwater. On the other hand, soil pollution, frequency, and flood intensity increased. Urban drainage systems that have not maintained pace with developments have resulted in insufficient or poorly maintained drainage capacity.

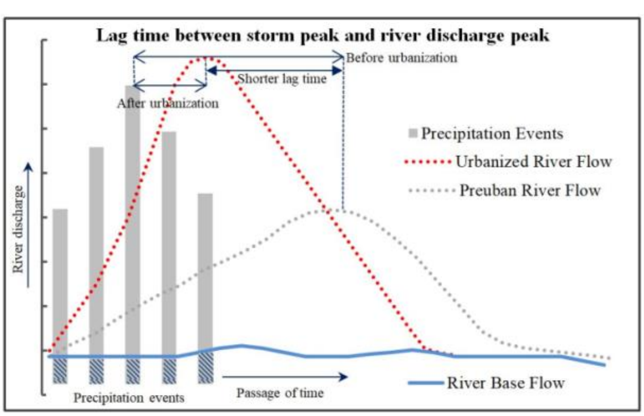


Fig. 1: Hydrological impact of urbanization on the flow of rivers through landscapes (adopted from [8] [10]).

In order to solve the issue, China is launching sponge city initiatives to address of problem of flood management. Sponge cities equipped with sponge-like capacity to absorb, store, infiltrate, purify, and release rainwater through the expected natural ecosystem and low impact of top-down management. The concept proves useful, although implementation can require the authority to advocate for enforcement and vision. In comparison, the concept has been aligned with sustainable urban drainage in terms of low impact growth in the United Kingdom and water-sensitive cities in Australia [9].

2.2 Hazard, Vulnerability and Risk

According to ADPC [11], risk is a combination of the interaction of hazard, exposure, and vulnerability where there is a hazard of an incident occurring. Vulnerability is a factor in the severity of the event, and exposure is what could be harmful when the event happens. If one of these variables had risen, the risk probability would also have increased. Essentially, spatial flood risk index maps have been developed using empirical spatial modelling that quantifies areas where flood hazards are expected to occur, the landscape morphological characteristics, demographic socio-economic criteria and the density of huge building complexes [12].

2.3 Alternative stormwater flood solution

Stormwater is an issue not only in a tropical country, but also in heavy downpour, and lack of drainage could cause stormwater to flood anywhere. In addition to the increasing urbanization of hard surfaces to replace softscape, surface water needs to be handled. A study [13] shows the principle and number of water-sensitive urban designs used to solve the stormwater crisis. The concepts are to reduce runoff by using natural features, source control, pre-treatment, retention, and infiltration [13] [14].

2.4 Stormwater flood management practices

In most countries, stormwater floods are applicable. If precipitation is greater than the drainage capability, a stormwater flood is more likely to occur. In Sweden, Augustenborge housing in Malmo, Sweden [15] has implemented a sustainable urban drainage system (SUDS) to mitigate the flood risk. The estate was developed in the 1950s, with as infrastructure of 50s. Drainage was not sufficient as the waste and groundwater were mixed and induced overload and reflux. In 1990, the project underwent regeneration where SUDS was implemented and an open stormwater system was applied to reduce stormwater loads.

In order to enhance drainage functionality and public space, numerous programs control water flow and applied water management techniques. As a result, the drainage was separated into three sections, and the numbers of water collections was used to improve the estate landscape. Any drainage was to be deposited in the local reservoir, while the minimum amount of runoff was drained into the public sewage when the site retention was overflowing. Fig.2

demonstrates the implementation of the SUDS that the design has been observed and noted in order to ensure its implementation. The drainage system was incorporated into the public space design and used as a soft scape feature and visually improve public space as shown in Fig. 3.

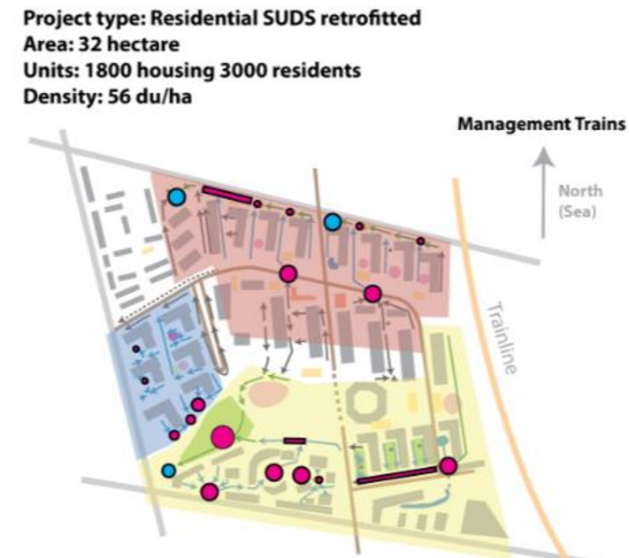


Fig. 2: SUDS implementation at Augustenburg, Malmo, Sweden [16].

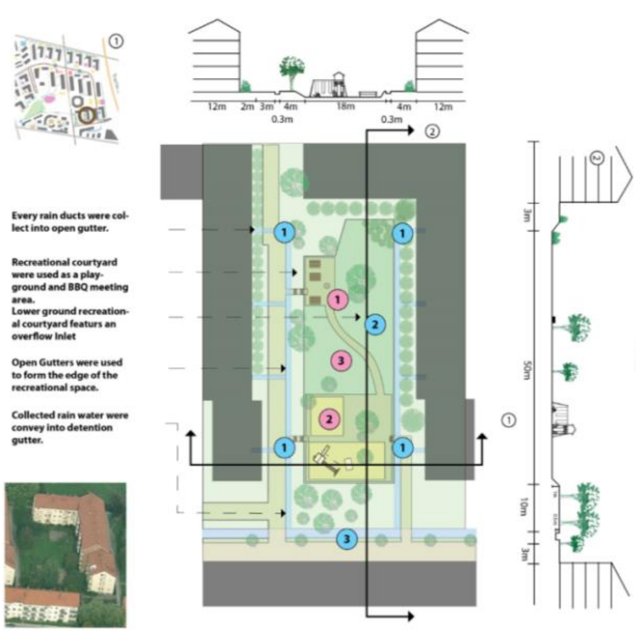


Fig. 3: Example of public space and drainage design [14]

3. METHODOLOGY

3.1 Overall approach and methodology

The study used mixed methods to collect data, with a combination of interviews, field observation, and literature review, to explore the cause and impact of localized flooding, to gain an understanding of the overall nature of the cause, and to find the alternative solution. The overall process involves a total three steps: review of literature and historical records of the study area, field data collection together with gathering of secondary data from stakeholders, and analysis of data incl. presentation of observations and findings.

3.2 Study area

The TKM, as shown in Fig. 4, is a peri-urban development affected by Bangkok's expansion and the industrial boom. It is a flood-prone agricultural area. However, hard surface development such as industrial and residential development has invaded wetland for agriculture, which in effect, has limited the capacity to control water naturally. TKM was reported to have had frequent floods in various areas. Km.44 Estate was selected on the basis of flood risk information [17] [18] and the characteristics of flood.

3.3 Data collection methods

Therefore, the research targets the actual frequent flooded area in the municipality from interviews with the involving authorities, news, records, and confirm with the local residents. Purpose sampling [19] was used to select respondents who are involved in flood management (e.g., villagers, neighbourhood committee members, village legal entity and municipal representative). The snowball method [20] was used to select flood-affected recipients for interviews. Relevant personnel were interviewed regarding flood occurrences, impacts, frequencies, and countermeasures. The question to the affected group included clarification of the flood area, intensity, duration, and the maintenance or counteraction of witnesses. Field observation was used to gather the primary data such as landscape characteristics and local social activities in order to observe human behaviours and basically flood adaptations.

Field observation images were taken as a support resource during site visits and interviews. In order to confirm the primary data collection, the documents and reports such as TKM and its development plan were reviewed. Then, the land use land cover (LULC) change was extracted by using Remote sensing approach as the random forest classification. This model was imported and analysed by using Landsat 5 and 8 satellite images in the Google Earth Engine platform (GEE). The next step in the analysis of secondary image data involves historical flood peak events observed using Google Earth, both aerial photographers and high resolution satellite imagery, and vulnerability and urban risk assessments were analysed by using Landsat 7 and 8 satellite images [21] as a moderate resolution in the Remote Sensing approach through GEE. The next process, vulnerability and risk evaluation of peri-urbanized ecosystem under multi-criteria pressure using secondary data was supported by the Department of Public Works and Town & Country Planning at Pathum Thani province and analysed using the weight overlay method in the Geographic Information System (GIS).

3.4 Data analysis methods

The data collected was processed using qualitative content and quantitative analysis, where the information reviewed was tabulated to finds its relationship in comparison to the literature in order to find the relevance and the recommendations [22]. In addition, the content analysis was also utilized. The data collected were compared and verified from various sources. The spatial pluvial flood risk index (R_F) was determined using multi-criteria overlay function. The pluvial flood hazard (H_F) as a high peak flood event in 2011 was modelled using both the elevation from ALOS PALSAR radiometric terrain Corrected with high resolution 12.5 m. through Alaska Satellite Facility (ASF) [23] and the Normalized Difference Water Index (NDWI) for estimating the relevant urban flood parameters from satellite images [21] as well as the calibration of hotspots obtained by field observation and interviewing. The exposure of population density (V_E) was extracted on the basis of the vulnerability of the building characteristics as high and type through GIS approaches for simulation and reclassification of exposure ratio.

The sensitivity of the economic sector (V_S) represented by waste gasses which generated from automobile industry to environmental pollution. Therefore, it was measured using the Normalized Difference Built-up Index (NDBI) using satellite images [21] to establish the sensitivity ratios in urban areas. In addition, the Normalized Difference Vegetation Index (NDVI) trough satellite images [21] was measured kind of the natural green surface or blue and green areas especially in order to simulate the ratio of adaptive capacity (A_G) to minimized risk of flood hazard. Consequently, pluvial flood risk (R_F) has been combined with vulnerability of exposure and sensitivity, hazard and adaptive capacity towards multiple layer overlay [12] in order to assess the risk of pluvial flooding in the research area as shown in formula (1).

$$R_F = V_E \cap V_S \cap H_F \cap A_G \tag{1}$$

4. RESULTS

4.1 BMR and Specific Characteristics of the Study Area

BMR is the government defined "political definition" of the urban region. The region covers 1,568.737 sq.km. Bangkok is located in Chao Phraya River delta, which the river runs through the heart of the city, the low-lying areas in the lower section of the river. Therefore, Bangkok is exposed to extensive riverine floods and subject to annual flooding. However, the expansion of Bangkok reduces the floodplain area where floods can naturally overflow [20]. Fig. 4 shows that Pathum Thani (incl. TKM) in the northern BMR.

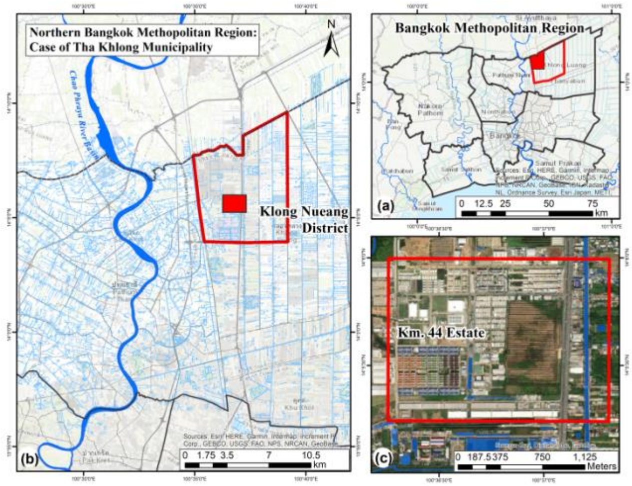


Fig. 4: Location of study area at Tha Khlong municiplaity in Pathum Thani province – northern BMR.

Pathum Thani's Flood risk

Pathum Thani province is a major part of the BMR expansion as shown in Fig.4 – (a). The province is classified as tropical savannah, which has less rainfall in winter than in summer. The average annual precipitation is 1,426 mm, which highest in September [24]. The urban development has been sprawled to the area for decades. Since the area is naturally a flood-prone area, most developments are at risk of flooding. However, the sprawl doesn't concern the land use. It naturally increases the vulnerability of the area itself as resulted in the 2011 flood loss [25]. Chantamas [25] had shown that Pathum Thani has the incline of 0-0.5%, which was the lowest among the criteria. The soil type is mixed with low permeability and more pervious ability. According to the Sieves Analysis, Prathum Thani especially around the Paholyothin Road appears to be the high flood risk area.

Tha Khlong Municipality

TKM is one of the three municipalities that comprise Klong Luang District in Pathum Thani Province as shown in Fig. 4 – (b). The area is located directly north of Bangkok and considered peri-urban of Bangkok. It is located in the east of Chao Phraya River, and has been traditionally the irrigated land. The area comprises of series of irrigation canal or "Klong," initiated by King Rama V in the late 19th century. As a result, it is divided by geometric pattern canals [26]. The large plot of agricultural land was replaced by other uses from 1952, such as divided plot, individual housing, apartment, townhouses, fish pond in place of the agricultural rice field, and orchard. Some of which became vacant and inaccessible [26].

In 1986, agricultural land was severely transformed, due to the growth of Thailand's economy, which contributed to industrial exploitation. Industrial uses mostly replace agricultural land in the north of Bangkok [27], especially in

Pathum Thani province. Further industrial development has led to residential and commercial development, replacing existing agricultural land [28]. TKM has a major northern road (i.e., Paholyothin) running north-south in the middle while Klong Luang – Chiang Rak Road runs in the south of the municipality. The western border of the municipality is the railroad track and canals that runs north – south along the track. However, Klong 1 and Klong 2 are the main water diversion of the municipality.

Land use map of TKM and vicinity

Result of TKM land use land cover analysis in 1999 to 2018 [21] with five-time intervals every five years without 2009 using random forest classification method is shown in Fig.5, with a significant increase in urbanization trends since 2004. The urbanization areas are almost along Paholyothin Road, especially in municipalities of Tha Khlong and Rangsit.

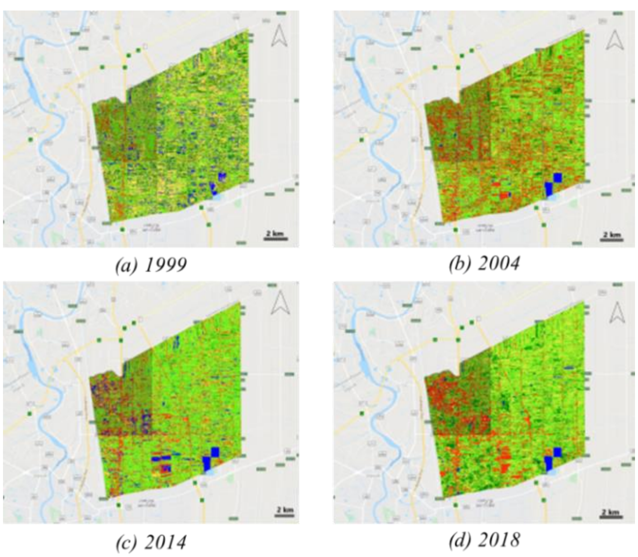


Fig. 5: Land use changes in Tha Khlong Municipality [21].

Km. 44 Estate

Km.44 Estate, as also shown in Fig. 4 – (c), is located on the west side of Paholyothin Road, was developed for industrial estate and did not connect to the adjacent Nava Nakhon Industrial Estate. Later development, the government supported Baan Ua-Athorn then Km.44 was developed, which increased the residential and wastewater tremendously. The estate has been reportedly flooded for over ten years.

Km.44 Estate was first built to accommodate an industrial use. Due to the road infrastructure is quite old, the drainage capacity is not sufficient for the developing land-use in the Estate. Especially, the estate drainage outlet is located only on Paholyothin Road. In addition, the estate was not transferred to the municipality. Therefore, public maintenance cannot be done, and the internal legal entity's maintenance is in doubt. The estate is flooded internally almost immediately after a heavy rain and often overflow onto the entrance at Paholyothin Road. The municipality had adapted to the installed water pump, which used to divert water to nearby water sources along Paholyothin Rd. Since the water could not be directly diverted to Klong 1 due to the different legal entity management and the community resistance.

The severity of the flood, according to Innnews [29] reported that Km.44 Estate had been frequently flooded for over ten years. The flood occurs at the footpath level at the main village junction for 5-600 meters. The flood level is as high as 30 cm in some area, which affects over 100 households in the project. The car and motorbike owners were affected by the flood level. However, there is no property damage reported. The problem has been persisted for more than ten years, especially when there's over 40 min heavy rains. Siriwat [30] reported that the municipality response to the project drainage at the south of Paholyothin Road in TKM by cleaning and increase its capacity.

4.2 Km.44 drainage conditions

From the survey, as also shown in Fig 6, Km.44 street where the frequent flood has been reported appear to be neglected and the drainages appear to be in lack of maintenance. There are underpass drainage and permanent flood pump which show the government effort to mitigate the flood from the estate. However, the main cause of the Km.44 flood remains and the pump has been deactivated from the community. The equipment management, reportedly, has to be authorized from the Department of Rural Roads. Hence, the equipment cannot be operated by local authority which has to use portable pump. The situation has been shown that the installation of the device was not enough to solve the problem.

Fig. 6: Photos taken from field survey, 2019.

4.3 Drivers/causes of floods in TKM

According to the interview with the Director of the Division of Public Works and the Officer of Sub-division of Disaster Prevention and Mitigation of TKM, climate change factors such as the increasing amount of rainfall, have an impact on TKM's floods and are difficult to drain enormous water, while the water level of canals such as Klong 1, is somewhat higher when it rains. Moreover, decreasing agriculture allocation and vacant land, which serve as a water retention area, are also reducing drainage capacity. As a consequence, surface water is directed to the drainage system, which often requires cooperation on the road (Interviewees 6 and 7, see the interview's logbook in APPENDIX A).

Causes of floods in Km.44 Estate

TKM successfully diverts stormwater to Klong 1. However, Km. 44 Estate's floods are caused by two factors responsible for by two ownerships. Km.44 Estate is an old industrial estate in which the drainage collects all adjacent residential development expansion into the same system without maintenance or increase in the drainage capacity. Especially, the estate is managed by a legal committee. The municipality cannot involve in the estate drainage unless being requested. The infrastructure was barely improved or maintained.

According to the survey, the drainage covers all the sidewalk. It functions as the wastewater collection for all of the premises within the estate. In the estate, the factories were the first priority in the area, however, due to the closed lot with the only two streets connecting to Paholyothin Road, the government housing, residential development project, and industrial estate expansion has been developed using the same infrastructure. Since all the drainage water in the estate as directed to the only two exits with limited capacity, the drainage water became overflow. In addition, there was no maintenance schedule, and based on the survey condition, the drainage was blocked, broken, or full of sediment stagnant inside the manhole.

In addition, waste water from households also becomes an issue since stormwater and wastewater are combined. The universal drainage design is 60 - 80 and 100 cm diameter at maximum. Therefore, the drainage could be overloaded if many the households drain their wastewater at the same time, especially when the stormwater or wastewater drainage is following a set of standard regardless of the drainage network. The size of the estate, as shown in Fig.7, reflects that the size of the estate is quite large for the drainage outlet. In case of heavy rain, the water run-off would overflow the drainage.

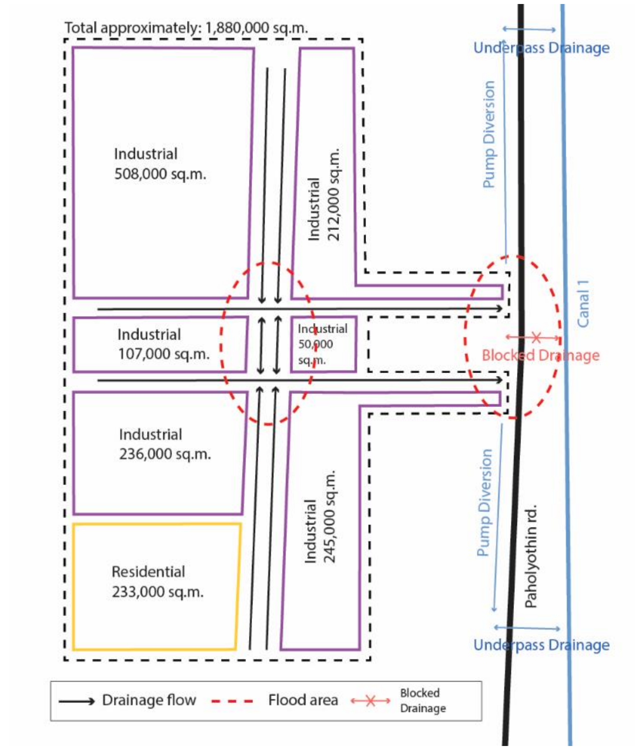


Fig. 7: Landuse, drainage and flood areas at Km. 44 Estate.

Problem of Paholyothin Road's drainage's and management

Paholyothin Road passes through TKM from north to south dividing the area into two and parallel to Klong 1. As a result of developments along main road, stormwater drain to the main road. Thus, the Klong 1 underpass is mostly necessary, which is the responsibility of the Nava Nakorn sub-district highway depot, Department of Highways (DOH). The underpass drainage to Klong 1 is significantly necessary. However, if the underpass drainage is blocked or over capacity, the stormwater will become stagnant. In the case of TKM, the underpass is blocked by the community between Paholyothin Road and Klong 1 as the bottleneck area.

4.4 Impacts and exposure of floods

Km.44 Estate's flood affected groups

Whenever the stormwater flows out of drainage system due to flooding, most of the floods occur in the streets following heavy rainfall and traffic is disrupted. Residents in the estate and the passing vehicles are most likely to be affected. Overflow can result in the interruption of transportation, but does not affect the property damage. The height of the floodwater was as high as the sidewalk but it did not hit the house or damage the property (Interviewees 1, 2, 4 and 5, see interview's logbook in the APPENDIX A).

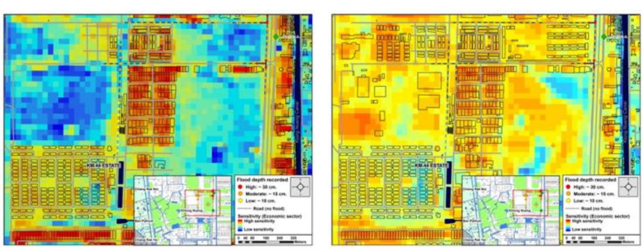
Km. 44 Estate and vicinity vulnerability and risk assessment

The exposure comparison between 2011 and 2020 has shown the transformation of natural and green areas in the western-northern and eastern-northern areas of the study area into the industrial and business areas respectively, and the exposure range is visualized on the basis of high building and building categories. Buildings in the Km.44 Estate are highly exposed due to the presence of 168 buildings, 7,560 units and approximately 15,120 persons, as shown in Fig. 8.

(a) 2011 *(b) 2020*

Fig. 8: Exposure maps in 2011 and 2020.

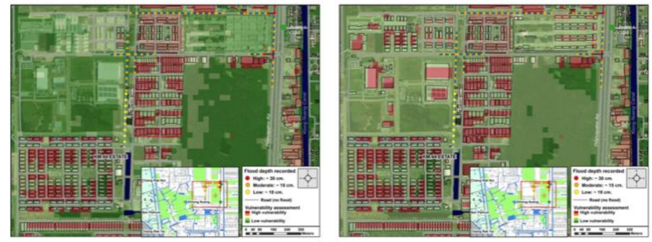
In 2011, industrial production was almost highly sensitive in the center and south of the study area, while it was in industrial zone. Subsequently, the high sensitivity area in 2020 is transformed into an increased industrial and commercial area in the north and west of the study areas, and natural green area in east as well as shown in Fig. 9.



(a) 2011 *(b) 2020*

Fig. 9: Sensitivity maps in 2011 and 2020.

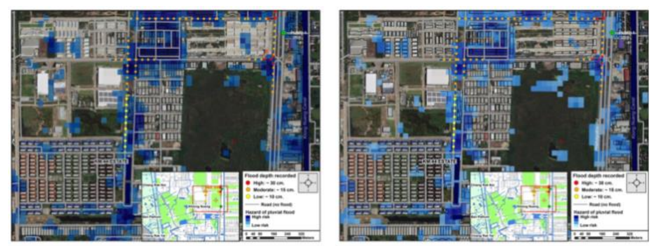
Almost residential and industrial zones are the most vulnerable to exposure and vulnerability in this study region (Fig.10) as these areas are linked to social life and the economic field. In addition, the high vulnerability identified in the eastern community as the nearby main road, Paholyothin Road and Klong 1, should perhaps concern social, economic and environmental impacts.



(a) 2011 *(b) 2020*

Fig. 10: Vulnerability map in 2011 and 2020.

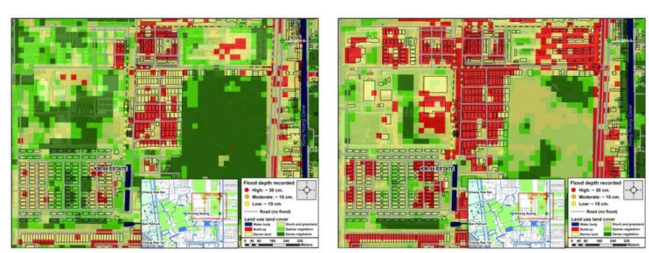
Pluvial flood hazards were found to be almost a road threat, especially in low elevation areas such as the northern part of this study both in 2011 and 2020, but in 2011 the hazard was higher than present caused by heavy storm and rain in 2011 (Fig.11). In addition, stormwater from Km.44 can be assumed to have been flooded on Paholyothin Road's drainage. As a consequence, it affects traffic on the major road when heavy rains occur. As a result, vehicles passing along road are affected as a whole.



(a) 2011 *(b) 2020*

Fig. 11: Pluvial flood hazard maps in 2011 and 2020

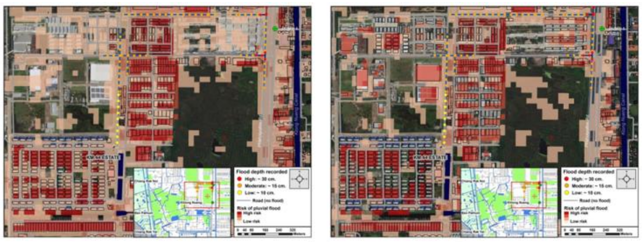
However, the relative difference in the estimation of adaptive capacity using NDVI data without a drainage system. The high ability to reduce the risk of pluvial flooding is linked to green and wetland areas such as the western and eastern areas. Analysis of these natural adaptive capacities has shown that these areas have been changed to bare land more from 2011 to 2020, as seen in Fig. 12.



(a) 2011 *(b) 2020*

Fig. 12: Adaptive capacity maps in 2011 and 2020.

Finally, the potential risk of pluvial floods in this study area is increasing due to vulnerability of exposure and sensitivity increased, while the adaptive capacity factor is decreased. As a result, pluvial flood risk trend is the largest increase in residential, industrial, low elevation, built-up and bare land areas, such as west and east of study area as shown in Fig. 13.



(a) 2011 *(b) 2020*

Fig. 13: Pluvial flood risk maps in 2011 and 2020.

4.5 Response or adaptation to floods

In response to the flood, the residents of Km.44 cope with the stormwater by walking through the flooded area, hiring a motorcycle or waiting until the flood to reduce. The municipality copes with the fraction management by initiating flood management in their responsible area. They install the water pump alongside Paholyothin Road to push the flooded water through the road canal to the adjacent canal and underpass, since the direct underpass drainage was blocked and required response from other authorities.

Adaptation, resilience and metropolitan governance

Km.44 Estate has been coping with the frequent flood. The flood is affecting transportation and halting the business in the area. However, the business resume after the flood subsided from the area within 3-4 hours. The coping mechanism is to use the public bike or abstained from leaving the premises due to the roadblock. According to the news [30], the municipality cleaned the drainage in 2019, however the frequency was not confirmed. It is proven that the municipality has done its function according to the 1953 Municipality Act [31] that the city's municipality has to maintain the drainage in addition to other infrastructure maintenance. In addition, the municipality added the water pump to help drain flooding from the area to relieve the flood duration. There is adaptation even though the municipality is function as regulator. However, the frequent flood still occurs and further investigation is still required. The flooded situation may be categorized into a sequential table for qualitative content analysis according to the qualitative content method [32]. As given in Table 1, each cause has its impact and adaptation, where these issues can be used to address solutions.

5. DISCUSSIONS

The flood factors for peri-urban in this case study could be related to surface run-off and coping management. In addition, causes of floods, effects, and responding measures are discussed below.

Table 1: Matrix of summarized driver elements of pluvial flood risk related to impact, effects, adaptations and expects for the peri-urbanization as TKM in case studies of Km.44 Estate and MMC Industrial Region

Drivers	Impacts	Effects	Adaptation Actions	Expected Results
Urban growth (Vulnerability of **sensitivity**)	• Green and blue space minimized • Mixed waste water increased	• Rainfall storage area reduced • Increasing of drainage loads • Flood drainage overflow to private roads and main road • Reducing water quality in drainage network with surrounding areas • Contaminated water sources as canals were interacting environments	• Apply sponge city plan by replace concrete areas into grass [15] and water plants on spaces or pavements • Adding water bank to treatment waste water [15] • Integrated cooperation between communities and related governments as TKM, DOH and companies.	• Reducing flooding • Traffic is not congestion when it rains • Standardized water utilizing • Suitable drainage system for the disposal of pure waste water and rainfall
Population growth (Vulnerability of exposure)	• Solid waste (SW) and waste water have been increased	• Higher demand of public utility	• Reduced usage plastics • Design transfer centers of SW to protect against hygiene, i.e. separate type and increase base height of SW collection centers	• Performance drainage channel and system as well as public utility
Climate change (Hazard)	• Rainfall not stable	• Currently waste water management cannot support high rainfall peak events	• Maintenance drainage system as develop novel drainage channels and stripping drainpipes with water hyacinth removing	• High performance drainage system • Sustainable environment and life • Water in canals can flow properly

Source: Analysed by the research team

5.1 Surface run off and internal drainage management

The explored issue revealed that the internal drainage of the estate was insufficient and was not adequately maintained. The conditions reduce the drainage capacity and as one of major causes of floods. In addition to the estate's internal drainage loads, the surface run-off from the larger are was also onto the outlet at Paholyothin Road. There is a need for intervention to manage the surface run-off which aims to counter the flood by integrating the natural soil porosity to absorb and retain water. This is also aligned with the need to manage wastewater. The rain gutter could be implemented at a low cost to separate sewage water and rainwater. Hoyer et al [9] reviewed the principle and case studies of stormwater management in Europe. The transferability may be required for further research.

5.2 The compatibility of responding drainage management and flood risk

It was found that the stormwater flood management involves several authorities also at different levels. In general, the municipality could manage the drainage within its area. However, Km.44 Estate could be a case as an overloaded and bottlenecked flood. The large amount of water has to be discharged into Paholyothin Road, which was not directly under municipality management. The operational flow where the system had been designed holistically is unable to operate locally. Although with under-passage drainage with a pump under Paholyothin Road, once flood occurs, the municipality could not operate the machine and utilize the underpass. The holistic water and drainage management in the local scale would be more efficient with clearer defined responsibilities and linkages among concerned authorities including both operation and maintenance.

6. CONCLUSIONS AND RECOMMENDATIONS

Land use in the study area and surroundings have been rapidly changed in the past decades resulting in limited drainage capacity requiring proper responding measures for the increasing and more fluctuated stormwater. The current drainage infrastructure is not able to accommodate the increasing need, while the water run-off from the heavy storm is directed from all the expanded surface onto the main outlets at the main road's outlet, becoming a major bottleneck of the drainage system. Local authorities and communities linked to flood control are not integrated, which is one of the key contributors to the problems. Clear and coherent responsibilities could potentially reduce the bottleneck and interrelated problems in local flood management.

As this study is limited to a single case analysis and limited size, it may not be generalized to other peri-urban areas for different flood risks and management contexts. However, the case study could lead to potential engaging local stakeholders and respondents to be able to capture the dynamic complex of local stormwater risk and adaptation, especially related to autonomous adaptation and its consequences as well as interactions among key players. The case study and its methodological framework can also be used for integrating different local components. Further studies should be carried out to enhance water-related management performance at different scales, including local flood risk, requiring synergies of shared responsibilities among agencies at local and larger scales.

ACKNOWLEDGMENT

The authors would like to acknowledge National Research Council of Thailand and the National Natural Science Foundation of China for financial support of a joint research project leading to this paper. We would like to also express our gratitude to Tha Khlong Municipality, Km.44 Estate, Pathum Thani's Provincial Public Works and Town & Country Planning Office, Landsat 5, 7 and 8 image courtesy of the U.S. Geological Survey (USGS), Google Earth Engine, and ALOS PULSAR of Alaska Satellite Facility (ASF) for support of data. In addition, we would like to thank all respondents in the study area who provided feedback and helpful opinions during our field survey and observations.

REFERENCES

[1] Allen, A., & Kurian, M., & McCarney, P. (eds.) (2010). Neither rural nor urban: service delivery options that work for the peri-urban poor. *Peri-urban Water and Sanitation Services: Policy, Planning and Method*, 27–61. https://doi.org/10.1007/978-90-481-9425-4

[2] Davivongs, V., Yokohari, M., & Hara, Y. (2012). Neglected canals: Deterioration of indigenous irrigation system by urbanization in the west peri-urban area of Bangkok Metropolitan Region. *Water (Switzerland)*, *4*(1), 12–27. https://doi.org/10.3390/w4010012

[3] Braud, I., Fletcher, T. D., & Andrieu, H. (2013). Hydrology of peri-urban catchments: Processes and modelling. *Journal of Hydrology*, 485, 1–4. https://doi.org/10.1016/j.jhydrol.2013.02.045

[4] Novotny, V., Ahern, J., & Brown, P. (2010). Ecocities: Evaluation and Synthesis. *Water Centric Sustainable Communities*, (September), 539–593. https://doi.org/10.1002/9780470949962.ch11

[5] Koussis, A. D., Lagouvardos, K., Mazi, K., Kotroni, V., Sitzmann, D., Lang, J., … Malguzzi, P. (2003). Flood forecasts for urban basin with integrated hydro-meteorological model. In *Journal of Hydrologic Engineering*, 8. https://doi.org/10.1061/(ASCE)1084-0699(2003) 8:1(1)

[6] Parkinson, J. and Mark, O. (2005). Urban stormwater management in developing countries, *IWA Publishing*, London, 5. https://doi.org/10.2166/9781780402574

[7] Haque, AN., Dodman D. and Hossain MM. (2014). Individual, communal and institutional responses to climate change by low-income households in Khulna, Bangladesh, *Environment and Urbanization*, 26(1), 112–129. https://doi.org/10.1177/0956247813518681

[8] Jiang, Y., Zevenbergen, C., & Ma, Y. (2018). Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy.

Environmental Science and Policy, *80*(June 2017), 132–143. https://doi.org/10.1016/j.envsci.2017.11.016

[9] Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., … Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, *12*(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314

[10] Duan, W., He, B., Nover, D., Fan, J., Yang, G., Chen, W., … Liu, C. (2016). Floods and associated socioeconomic damages in China over the last century. *Natural Hazards*, *82*(1), 401-413. https://doi.org/10.1007/s11069-016-2207-2

[11] ADPC (n.d.). Introduction to hazard vulnerability and risk, Retrieved October 1, 2019 from www.adpc.net/CASITA/Bangkok-workshop/Day 2/Introduction_to_Hazard_Vulnerability_and_Risk.pdf

[12] Armenakis, C., Du, E., Natesan, S., Persad, R., & Zhang, Y. (2017). Flood risk assessment in urban areas based on spatial analytics and social factors. *Geosciences*, *7*(4), 123. https://doi.org/10.3390/geosciences7040123

[13] BGS (2019). What are SUDS and how do they work? Retrieved October 10, 2019 from https://www.bgs.ac.uk/research/engineeringGeology/urbanGeoscience/suds/what.html

[14] Melbourne Water (2017). Introduction to WSUD Retrieved October 10, 2019 from https://www.melbournewater.com.au/planning-and-building/stormwater-management/introduction-wsud

[15] Climate Adapt (2014). Urban storm water management in Augustenborg, Malmö, Retrieved October 10, 2019 from https://climate-adapt.eea.europa.eu/metadata/case-studies/urban-storm-water-management-in-augustenborg-malmo

[16] Euanontat, M. (2013). SUD implementation in UK residential area.

[17] GISTDA (2019). Thailand flood monitoring system. Retrieved October 10, 2019 from http://flood.gistda.or.th/

[18] Jular, P. (2017). 2011 Thailand floods in the lower Chao Phraya River Basin in Bangkok Metropolis. Retrieved October 25, 2019 from https://www.gwp.org/globalassets/global/toolbox/case-studies/asia-and-caucasus/case-study_the-2011-floods-in-chao-phraya-river-basin-488.pdf

[19] Bryman, A. (2008). Social research methods, 3rd edition, *Oxford University Press*, Oxford, 747.

[20] Patrick, B. and Dan, W. (n.d.). Snowball sampling: problem and techniques of chain regerrral sampling. Retrieved September 15, 2019 from https://pdfs.semanticscholar.org/8881/d08f6f1ab5b65630f86978ec7d14a7978499.pdf

[21] Dataset: United States Geological Survey, Department of the Interior. LANDSAT-5, 7 and 8, ETM+ SLC-on. Scene multi. (20, 11, 2019). Reston, VA. Available: USGS Explorer http://earthexplorer.usgs.gov through Google Earth Engine platform

[22] Research Methodology (n.d.). Qualitative data analysis. Retrieved October 15, 2019 from https://research-methodology.net/research-methods/data-analysis/qualitative-data-analysis/

[23] Dataset: ASF DAAC 2015, ALOS PALSAR Radiometric Terrain Corrected high res; Includes Material © JAXA/METI 2007. Accessed through ASF DAAC 15 June 2020. DOI: 10.5067/Z97HFCNKR6VA

[24] Thai Meteorological Department. Climate of Thailand, Retrieved October 20, 2019 from http://www.tmd.go.th.

[25] Chantamas, Y., Anantasuksomsri, S. and Tontisirin, N. (2017). Review of urban flood impact reduction due to climate change adaption driven by urban planning management in Pathum Thani province, Thailand, Retrieved October 10, 2019 from http://www.cuurp.org/wp-content/uploads/2018/08/2560_SA_Review-of-Urban-Flood-Impact-Reduction_IRSPSD.pdf

[26] Hara, Y., K. Takeuchi and S. Okubo (2005). Urbanization linked with past agricultural landuse patterns in the urban fringe of a deltaic Asian mega-city: a case study in Bangkok, Landscape and Urban Planning, 73(1), 16–28.

[27] Sheng, Y. K. and A. Rahman. (1995). Housing women factory workers in the northern corridor of the Bangkok Metropolitan Region, in T G McGee and Ira M Robinson (editors), *The Mega-Urban Regions of Southeast Asia, UBC Press*, Vancouver, 133–149.

[28] Sundharawanich, C. (1997). 100th Year Rangsit Canal, Institute of Thai Studies, Chulalongkorn University, Bangkok, 390.

[29] Innnews (2019) Over 10 years! flooding in Km.44 sitill persist (In Thai) Accessed: 10 October 2019 at https://www.innnews.co.th/regional-news/news_504343/

[30] Siriwat (2019). Pathum Thani and the continuous flood mitigation in Km.44 estate (In Thai). Retrieved October 10, 2019 from https://www.khaoratchakarn.com/19883/

[31] Wantanakorn, M. and Mansamak, D. (n.d.) Duty of municipalities (In Thai) Retrieved October 10, 2019 from http://wiki.kpi.ac.th/index.php?title=อำนาจหน้าที่ของเทศบาล

[32] Limthongsakul, S., Nitivattananon, V. and Aridwidodo, S. D. (2017). Localized flooding and autonomous adaptation in peri-urban Bangkok, *Environment & Urbanization*, 29 (1), pp. 51-68.

APPENDIX A

Table A1. Interviews' logbook (2019)

Code	Date	Interviewees
1	10 Oct, 2019	Two merchants are in the market of Km.44 estate*a
2	10 Oct, 2019	Two merchants are around high flood risk area as private road intersection*a
3	10 Oct, 2019	Two merchants are nearby high flood risk area at main and private crossroads*a
4	10 Oct, 2019	A villager, the community committee member and worker is around Km. 44 estate and vicinity*a
5	10 Oct, 2019	A taxi driver is service in TKM and vicinity*a
6	17 Oct, 2019	A Director of the Division of Public Works of TKM municipality*c
7	17 Oct, 2019	An Officer of Sub-division of Disaster Prevention and Mitigation of TKM municipality*c
8	17 Oct. 2019	Village legal entity*b

*a Semi-structured(face-to-face) interview, *b Semi-structured interview by phone call and *c Structured interview and meeting.