Quantifying Flood Risk and its Exposure Using Catastrophic Model. A Case Study of the Pathumthani Province

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***Abstract*—Urbanization has resulted in several developments as well as adverse effects such as congestion, environmental degradation, and precipitation of urban hazard risks, especially in suburban areas that have changed significantly in spatial land use patterns from agricultural land to urbanized land, leading to a considerable ecological change. Due to this rapid change from agricultural to urban land, quantifying urban risk and the adverse effects of urban expansion are still challenges facing future development. Integrating several datasets from various sources is also a key challenge in urban big data analysis in Thailand. Moreover, due to its regularity, flooding in local areas may be overlooked by society. Therefore, the aims of this study were to (1) gather urban datasets for analysis as a time-series dataset, and (2) quantify and (3) classify flood risk exposure based on statistical historical data. We used several open-source datasets provided by various authorities and satellite image data to establish an urban flood risk dataset. The expected outcomes of this study were derived urban flood-related datasets in time-series patterns which further developed into urban flood catastrophe prediction models.**

Keywords—risk analysis, urban data, disaster management, catastrophe model, flood mitigation.

I. INTRODUCTION

Several Sustainable Development Goal (SDG) indicators are related to disaster risk reduction [1]. The 2030 SDGs seek to achieve disaster risk reduction by addressing disaster risk factors using a sustainable development approach, establishing accurate and consistence indicators to measure the effectiveness of disaster risk reduction efforts, and tracking, monitoring, and strengthening co-benefits and partnerships [2]. Disasters can result in severe losses depending on the severity of the catastrophe and the extent of preparation during the normal phase. The impact of disasters also depends on the amount of local interests in preparation and mitigation activities, familiarity with disaster-associated risks, and effectiveness of investment.

The Pathumthani province is considered as a vicinity in the Bangkok Metropolitan Region and has gradually changed from agricultural land to an urban area. The amount of urbanized area in Pathumthani increased by approximately 41.6 % in twelve years (2007 – 2019) whereas that of agricultural area decreased by 12.5 % (Table I). Moreover, according to the data collected by Climatological Center at the Thailand Metrological Agency (TMA), there are at least 44 types of events (e.g., river flood, torrential rainfalls, monsoon, thunderstorm) that lead to climatological disasters. Most climatological disasters in Pathumthani between 1987-2016 resulted from flooding (20 cases), monsoon (6 cases), and thunderstorms (5 cases), resulting in causalities, blackouts, and damage to houses and assets [3] (Table II).

TABLE I. LAND CLASSIFICAITON IN PATHUMTHANI BETWEEN 2007-2019

Year	Land Classification (Sq.Km).			
	Urban	*Agriculture*	*Water*	*miscellaneous*
2007	328.1	947.4	56.7	193.7
2009	361.5	961.2	55.8	147.4
2011	395.3	904.6	57.7	168.3
2012	403.0	899.3	54.7	168.8
2015	439.1	845.8	55.3	185.7
2017	448.3	843.1	61.5	173.0
2019	464.4	828.8	63.6	169.0

a. Source: Land Development Division (2021)

TABLE II. CLASSIFICATION OF CLIMATOLOGICAL DISASTER EVENTS THAT OCCURRED IN PATHUKMTHANI BETWEEN 1987-2016

Type of disasters	Counts of event
Flood inundated	*1*
River flood	4
Torrential rainfall	1
Thunderstorm	4
Thunderstrom and wind turbance	5
Thunderstorm and hail	1
Monsoon	6
Monsoon and wind turbance	1

Type of disasters	Counts of event
Flood inundated	*1*
Monsoon and hail	1
Flooding	20
Total	44

[b] Source: Climatological Center (2022).

Given these data, this study was designed with three objectives: (1) to gather a historical flooding dataset for analysis as a time-series dataset, (2) to quantify and classify flood risk exposure based on statistical historical data, and (3) to do literature review regarding to flood historical data.

A. Disaster Risk Reduciton Process

Disaster risk refers to potential losses due to disasters and is determined in terms of four components: (1) hazard – threats from natural or man-made disaster, (2) exposure – quantification of victims or loss based on hazard, (3) vulnerability – susceptibility of people to the harmful impacts of disaster event, and (4) capacity –capability of a system to cope with losses and recover from disaster during the event and the recovery phase. [4] The relationship among the four factors is shown in Fig. 1.

Fig. 1. Components in disaster risk reduction

Hazards can be classified into three categories: (1) slow onset hazard – occurs slowly and takes years to develop in severity, (2) rapid onset hazard – occurs quickly with little warning, and (3) catastrophic hazard – large scale disaster event that affects large numbers of people. [5]

Fig. 2. Typologies of hazards

Disaster Risk Reduction (DRR) comprises a pre-disaster phase, a disaster phase, and a post-disaster phase. In the pre-disaster phase, the focus is usually on risk management process such as prevention, mitigation, and preparedness activities (Fig. 3).

Fig. 3. Disaster management cycle
Source: adapt from [6]

During the disaster phase, response activities such as extending basic relief, conducting search and rescue operations, and providing medical lifeline services take place. In the post-disaster phase, activities such as rehabilitation and recovery, reconstruction, and development to restore normalcy are undertaken. The latter two phases mainly focus on crisis management. [6]

B. Catastrophe Modelling

Catastrophe modelling has become a fashionable approach in disaster risk reduction countermeasure [5], especially when applying it as an effective disaster countermeasure [6]. Catastrophe modelling has been used in multidisciplinary situations such as insurance to quantify and predict economic losses due to disaster events, since the losses caused by disaster feature uncertainty [7]. Catastrophe modelling considers four components: (1) hazard, (2) vulnerability, (3) exposure, and (4) financial issues. [8]

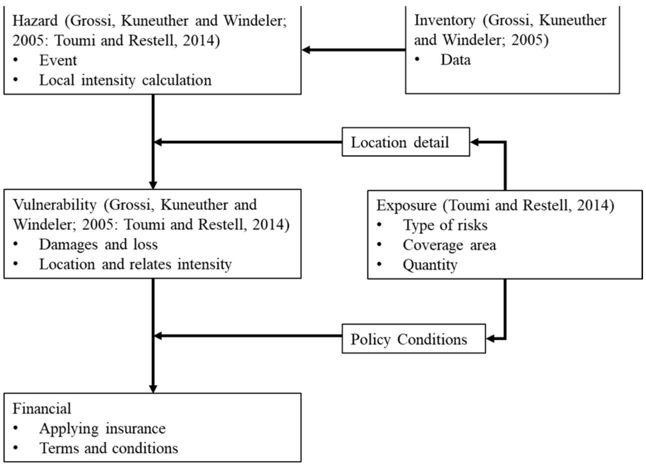

Fig. 4. Catastrophe modelling calculation
Source: Adapt from Grossi et. Al (2005) [8]. And Toumi and Restell (2014)

II. Methodology and Study Area

This study used the idea of catastrophe modelling for risk management based on the information presented in [9] by using probability modelling. Historical data were used in this analysis. We gathered several datasets through open data sources from the National Statistics Office (NSO), the Bureau of Registered Population (BORA), the Department of Disaster Prevention and Mitigation, and the Geo-Informatics and Space Technology Development Agency (GISTDA). Several data were used in the data used in this study. However, due to the long period of data constrain and the availability of accessible open data.

This analysis is considerably as an event of severe disaster and its loss are independent with another event. Toward the quantification of loss caused by flood risk based on the calculation of Exceedance Probability (EP) curve that intended to quantify severe flood risk to analyse in this study. The equations for the probability of occurrence are as follows. [10]

$$P(e_i occurs) = p_i \tag{1}$$

$$P(e_i not\ occurs) = (1 - p_i) \tag{2}$$

Therefore, the quantification of loss in year i can be derive as:

$$E[L] = p_i L_i \tag{3}$$

The overall expected loss for the flood dataset of events, referred to as the average annual loss (AAL), can be calculated as follows:

$$AAL = \sum_i p_i L_i \tag{4}$$

The exceedance probability of given loss can be calculated as follows:

$$EP(L_i) = P(L > L_i) \tag{5}$$

$$EP(L_i) = P(L > L_i) = 1 - P(L \leq L_i) \tag{6}$$

$$EP(L_i) = 1 - \prod_{j=1}^{i}(1 - p_j) \tag{7}$$

where

$P(e_i Occurs)$ refers to the probability of the event (flood disaster) occurring

$E[L]$ refers to expected loss in target year i

L_i refers to loss from flooding in year i

$EP(L_i)$ refers to the exceedance probability for a given level of loss

The study area, shown in Fig. 5, was located in the Pathumthani province, considered as a single province of the Bangkok Metropolitan Region. Pathumthani is situated distantly to the north of Bangkok (the capital city of Thailand), with the ratio of the urbanized area to total area of greater than 42.30 %. The immigration rate of Pathumthani is +2.24, which is the highest of all provinces in the metropolitan area around the Bangkok Metropolitan Region [11, 12]. Currently, Pathumthani is undergoing rapid expansion, which is leading to increased traffic congestion. This has been a main problem in the suburban areas of Bangkok and can be considered as the ratio of travel volume to road capacity (Vehicle Ratio (VCR)) during the morning rush hour with value greater than 1.00 [13, 14]. Further, flooding is a widespread issue in urbanized areas such as industrial, residential, and agricultural areas [15]. Floods occur in many areas due to water does not flow fast enough [16].

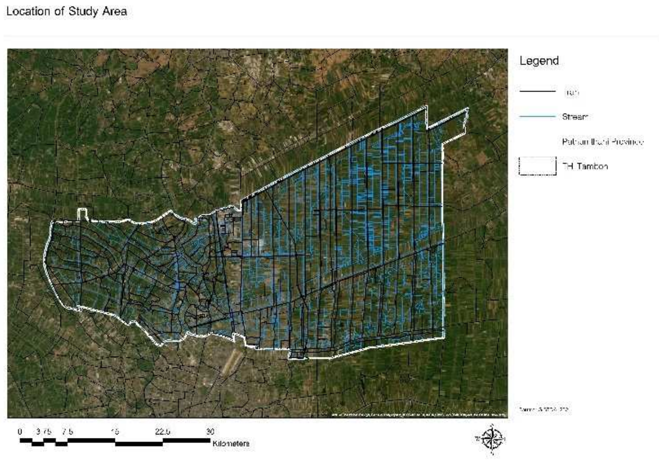

Fig. 5. Study area

III. Results and Discussion

The disaster management procedure currently being implemented in Thailand is classified into four levels of response depending on the severity of flooding and the flood inundated area. During the flood in the year 2011, the Thai government had implemented the Strategic National Action Plan (SNAP) in combination with the Incident Command System (ICS), which delegated decision-making power to local governors to tackle the threats caused by flooding. The collaboration between communities and local governments was done in accordance with the level of flood severity. [17]

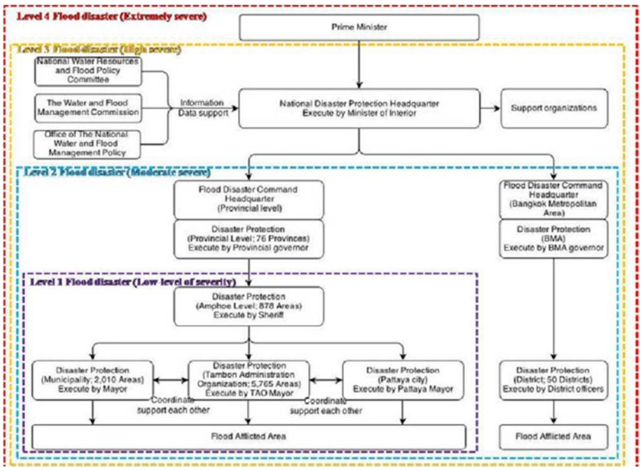

Fig. 6. Disaster response based on level of severity

The rainfall data gathered by the Pathumthani Methodological Station show a gradual increase in maximum annual rainfall volume from 2012-2020, which is consistent with the maximum rainfall volume. (Fig. 7)

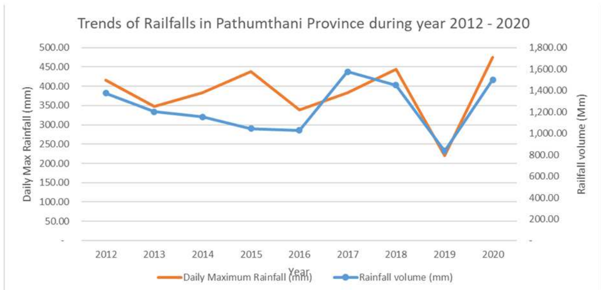

Fig. 7. Rainfall in the Pathumthani province over the 2012–2020 period
Source: Pathumthani Methodological Station, 2021

The historical data on flood-prone area gathered by the GISTDA across 2005-2020 show that most of the Pathumthani province is considered to be flood-inundated area. However, according to the disaster records kept by the Disaster Prevention Agency and the satellite data from GISTDA, there has been no significant loss due to flooding in Pathumthani since 2015. (Fig. 8). Specifically, several flood inundation areas are present in urbanized areas such as industrial, residential, and agricultural areas.

According to the estimation of economic loss per individual victim. This study used macroscopic data collected by the National Statistical Office (NSO) from 2009-2020. The result of this analysis can be shown in Fig. 9

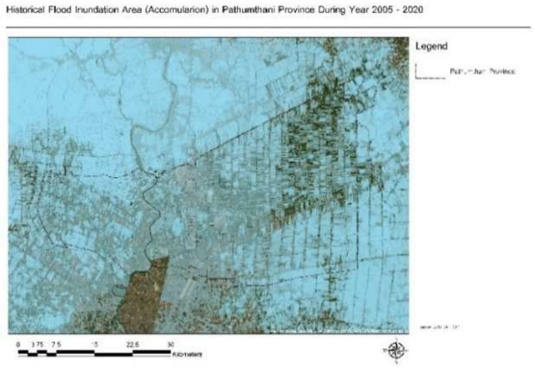

Fig. 8. Historical Flood Inundation area in Pathumthani Province During Year 2005 - 2020
Source: GISTDA, 2021

Fig. 9. Estimated loss per victim based on historical data
Source: National Statistics Office, 2022

The flood disaster loss data collected by the Department of Disaster Prevention and Mitigation show that the number of victims and amount economic loss during gradually increased from 2009-2011, whereas there were fewer severe flooding events since 2011. However, due to the limitation of data, this analysis quantified economic loss due to flooding per person and economic loss based on the national level (Table III). Moreover, the results of the analysis, presented in Table III, show that the estimated economic loss per person gradually decreased since 2012. This is because the number of severe flood events decreased, and the economic losses were not as severe as those caused by the catastrophic flooding events in 2011. It should be noted that the calculation results in Table III mainly focus on historical recorded data from the National Statistical Office (NSO) gathered during 2009-2020, which calculated the estimates of direct economic loss per victims. Economic loss in this calculation were collected from the recorded data. Economic loss covered losses of both public assets (roads, bridges, and public facilities) and residents' personal assets (housing and agriculture assets). [18]

TABLE III. HISTORICAL DATA OF FLOOD OCCURRENCE IN PATHUMTHANI BETWEEN 2009-2020

Year	**Calculation on exceed probability loss in severe flooding (National level)**			
	Case	***Number of victims (person)***	***Loss (THB)***	***Estimated Economuc Loss per persons (THB per person)***
2009	5	8,881,758	5,252,613,976	591.39
2010	7	13,485,963	16,338,772,341	1,211.54
2011	4	16,224,302	23,839,219,356	1,469.35
2012	3	2,353,027	716,000,844	304.29
2013	30	5,923,380	1,841,217,148	310.84
2014	4	1,810,748	323,578,804	178.70
2015	4	558,915	162,063,478	289.96
2016	6	1,128,447	271,167,957	240.30
2017	7	2,678,474	1,050,281,997	392.12
2018	5	1,009,289	542,067,800	537.08
2019	-	1,593,434	179,424,271	112.60
2020	65	1,198,934	223,003,002	186.00

Flooding data for Pathumthani between 1995-2016 show that severe flooding occurred in Pathumthani annually, with notable severe flooding occurring in 2011. It should be noted that the number of affected houses and the total number of flooding victims each year were calculated in annual as total number in each year. Historical data on flooding in Pathumthani between 1995-2016 in accordance with the calculations of probability loss and economic loss show that, based on an analytical timeframe, Pathumthani was affected by severe flooding in 1996 and 2011. This corresponds to the flooding events in 1996 in Bangkok and other vicinities (slow onset, lasting approximately one month) and the severe flood disaster in 2011, which became an unforgettable event in the history of Thailand. Moreover, although economic loss was recorded, it may not have been specific to any victims since economic loss may have occurred in terms of public assets.

According to the estimation of economic loss and the number of exposures based on victim shown that the probability of occurrence. The annual probability of severe flooding events was calculated as follows: the number of flood events subtracted by number of days in annual. The results show that there is approximately 0.5% to 3% of occurrence per year. The results of exposure estimation are shown in Table IV.

TABLE IV. CALCULATION OF EXCEED PROBABILITY LOSS IN SEVERE FLOODING

Year	Calculation on exceed probability loss in severe flooding (Pathumthani province)					
	Number of events (times)	***Number of days***	***Annual prob.***	***Total Victims (persons)***	***Economic loss (THB)***	***E[L] (THB)***
1995	6	365	0.0164	-	16,097,489	263,999
1996	12	366	0.0327	2,775	1,023,610,779	33,472,072
1997	-	365	0.00	-	-	-
1998	-	365	0.00	-	-	-
1999	2	365	0.0054	206,078	8,807,147	47,559
2000	-	366	0.00	-	-	-
2001	1	365	0.0027	2,752	2,419	7
2002	1	365	0.0027	-	-	-
2003	-	365	0.00	-	-	-
2004	2	366	0.0054	-	490,244	2,686
2005	-	365	0.00	-	-	-
2006	1	365	0.0027	308	-	-
2007	1	365	0.0027	-	-	-
2008	1	366	0.0027	-	256,798	693
2009	1	365	0.0027	283	63,390	171
2010	5	365	0.0136	107	78,801,159	1,071,696
2011	3	365	0.0082	65,042	2,070,019,252	16,974,158
2012	2	366	0.0054	1,408,797	514,479	2,778
2013	1	365	0.0027	1,691	2,997,816	8,094
2014	1	365	0.0027	9,644	-	-
2015	1	365	0.0027	-	172,668	466
2016	1	366	0.0027	595	6,583	18
Average Annual Loss (AAL)						52,074,261

Annual probability (Annual Prob.) was calculated and the results show that Pathumthani is at a low level of severe flood risk even though the area was affected with flood inundation recently. The exceed probability distribution (Fig. 10) shows that, when comparing between exceed probability and direct economic loss, the severity of flood inundation in 2011 had a lower probability of occurrence but caused huge amounts of direct economic impacts, whereas flooding in in 1996 had higher probability of occurrence but the estimated economic loss was lower than the estimated economic loss in year 2011. (Table IV) Moreover, although the probability of flood occurrence in Pathumthani is considerably low and the direct economic loss is seeming limited, challenging the quantifying economic loss, especially in in-direct economic loss, and data collection on the number of flood inundation dates are important for further discuss.

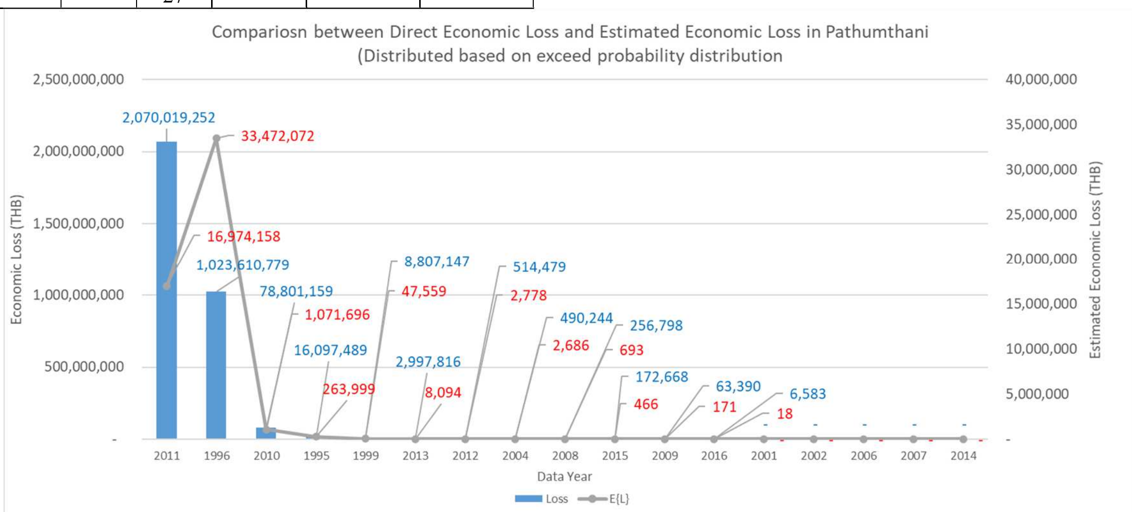

Fig. 10. Comparison between direct economic loss and estimated economic loss due to flood inundation between 1995 - 2016
Source: National Statistics Office, 2022

During the analytical timeframe (1995 - 2016), a large catastrophic event occurred in Thailand in 2011 that was widespread throughout the central region of Thailand (event 2 in Table IV). That event can be considered a slow-onset disaster event due to its prolonged duration (July 2011-January 2012). Although the results of the analysis show that Pathumthani was not likely to experience an adverse effect from flooding recently (no severe flooding since 2015 and one event of climatology recorded in one year), further analysis involving other kinds of hazards, such as fire disasters or wind turbulence, may be necessary since the likelihood of such events occurring seems to be high (60 fire disaster cases were reported in 2019 and 16 cases were reported in year 2020). It shown that other threats of urban disaster should be more concerned rather to flood inundation event. [19]. Another challenge facing disaster preparation is the threat that urbanization and migration may gradually increase the amount of number of people who are living in suburban area, which considerably as an exposure, whereas the efforts toward capacity building for disaster risk reduction are still experiencing challenges, especially in relief, insurance, etc.

Challenging issues towards the quantification of disaster loss based on catastrophe modelling such as data quality issue – consistency of data, completeness, and accuracy [20], scientific knowledge, historical data, and mathematical modelling which are difficult to quantify uncertainties of data in CAT modelling [21]. Other measurement in disaster management at the local level should focus more on how to quantify economic loss and number of victims, and how to use the results of estimations to plan relief and resources management. Moreover, considering towards data structure that necessarily to be clearer in estimation, and monitoring the stability of disaster risk reduction to achieve sustainable development. Further studies toward land use changes and negative effects of urbanization should be more concerned in local level such as flood response, road safety during flood inundation, and mobility patterns based on spatial modelling should be further explored [22]. Other important approach to quantifying the severity of risk in urban area as a time-series of disaster occurrence could be levelized intention of flood management and response.

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REFERENCES

[1] UNDRR "SDGs with Targets related to Disaster Risk". PreventionWeb.net https://www.preventionweb.net/sustainable-development-and-drr/sdgs-targets-related-disaster-risk?msclkid=50d1bd34c47c11eca3bcefab28697271 (accessed Apr. 14, 2022)

[2] UNISDR "Disaster Risk Reduction and Resilience in the 2030 Agenda for Sustainable Development". PreventionWeb.net https://www.preventionweb.net/files/46052_disasterriskreductioninthe2030agend.pdf?msclkid=76109a1fc47b11ec9262da0d736212a5 (accessed Apr. 14, 2022)

[3] Climatological Center Thailand Metrological Agency. "Domestic Disaster Records." March 2022. Distributed by Climatological Center. Climate.tmd.go.th/disaster/content?page=41

[4] R. T. Dominigo, "The Mathematics of Pandemics – The formular for Disaster." Linkedin. https://www.linkedin.com/pulse/mathematics-pandemics-formula-disaster-version-april-13-prof-rene?msclkid=150fabfec47811ec87571ce729576fbf (accessed Apr. 14, 2022)

[5] Development Workshop France. "Slow & rapid onset disaster" dwf.com https://www.dwf.org/en/content/slow-rapid-onset-disasters?msclkid=c0dba72ec47a11ecbda07344cf0bdab2 (accessed Apr 14, 2022)

[6] H. Khan, L. G. Vasilescu and A. Khan, "Disaster Management Cycle-a Theoretical Approach," in *Journal of Management and Marketing*, Vol 6., Jan. 2008, pp. 43-50

[7] A. Calder, A. Couper, J. Lo and S. Postlewhites, "Catastrophe Model Blengind Techniques and Governance." The actuarial profession. https://www.actuaries.org.uk/system/files/documents/pdf/catastrophe-model-blending.pdf?msclkid=0fa45fa8c47711ec939a6e1c9e060ca5 (accessed Apr. 14, 2022)

[8] P. Grossi and H. Kunreuther, in *Catastrophy Modeling: A New Approach to Managing Risk,* J. D. Cummins Ed., Springer Science + Business Media, 2005

[9] R. Toumi and L. Restell, "Catastrophe Modelling and Climate Change", Llyod, 2014, pp.9

[10] P. Grossi, H. Kunreuther, and D. Windeler, "An Introduction to Catastrophe Models and Insurance," in *Catastriphe Modelling: A New Approach to Managing Risk*, Boston, MA, United States of America: Springer, 2005, ch 2, pp.23-42.

[11] P. Iamtrakul and J. Klaylee, "Guidelines to Promote Sustainable Development Toward A Case Study of Phathum Thani Province," in *Administration Journal*, Vol. 11, 2018, pp.80-100

[12] P. Iamtrakul, S. Chayaphong and J. Klaylee, "The Study on Polycentric for Sustainable Rail Transit Development," in *Journal of the Faculty of Architecture KingMongkut's Institite of Technology*, Vol. 26, 2018, pp. 124-136

[13] P. Iamtrakul, A. Padon and J. Kalylee, "Analysis of Urban Sprawl and Growth Pattern Using Geospatial Technologies in Megacity Bangkok Thailand," in presented at the 5th International Conference on Geoinformatics and Data Analysis, Paris, France, Jan. 21-23, 2020.

[14] Bureau of Highway Safety Department of Highway, "Travelled Vehicle – Kilometer on Highways Reoirt in 2018." March 2019. Distributed by Bureau of highway Safety. http://bhs.doh.go.th/files/VK/VK2561.pdf

[15] P. Iamtrakul and K. Hokao, "The Study of Urbanization Patterns and their Impacts on Road Safery," in *Lowland Technology International*, Vol. 14, December 2012, pp. 60-69

[16] I. Raungratanaamporn, C. Denpaiboon and P. Iamtrakul, "Evaluation of Storm Surge Map for Safety Improvement in Bangkok Metropolitan Region, Thailand," in *Lowland Technology International*, Vol. 13, December 2011, pp.19-26

[17] I. Raungratanaamporn, S. Pakdeeburee, A. Kamiko, and C. Denpaiboon, "Government-Communities Collaboration in Disaster Management Activity: Investigation in the Current Flood Disaster Management Policy in Thailand" in Procedia Environmental Science, Vol 20, 2014, pp.658-667

[18] National Statistical Office. "Natural Resources and Environmental statistical data." March 2022. Distributed by National Statisticl Office. http://statbbi.nso.go.th/staticreport/page/sector/th/21.aspx

[19] Pathumthani Department of Disaster Prevention and Mitigation. "Pathumthani Disaster Cases." March 2022. Distributed by Pathumthani Disaster. Pte.disaster.go.th/inner.pathum-7.63/cms/inner_1995

[20] A. Lavakare and K. Mawk, "A Guide to Catastrophe Modelling," in *Risk Management Solution*, G. Dobie and R. Lythe Eds. Middlesex, NJ, USA, 2009, pp. 12-14

[21] Lythe, Eds., "The Review Worldwide Reinsurance: A Guide to Catastrophe Modelling," in *Risk Management Solution*,

[22] P. Iamtrakul, J. Klaylee, and N. Chollacoop, "Urban Planning Measures for Smart City Development," in *Procc. of International Structural Engineering and Construction*, pp. 1-6 doi: 8. 10.14455/ISEC.2021.8(1)