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SOCIAL VULNERABILITY CHANGES AND SUSTAINABLE DEVELOPMENT IN THE FLOODED INDUSTRIAL COMPLEX AREA

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Abstract

Focusing on disaster risk management of enterprises in industrial complex areas is significant for learning from disasters; however, there has not been much exploration of longer and social-oriented perspectives. Therefore, the study detailed in this paper sought to investigate systematically the changes before and after the 2011 flood disaster in the vulnerability of Ayutthaya province, primarily focusing on the social vulnerability gaps and changes in the district, including areas that both include and do not include industrial parks/estates, in order to examine sustainability. Field surveys and statistical analyses were undertaken to explore this research. As a result, the study found: 1) Phra Nakhon Si Ayutthaya (PNSA) is the most vulnerable district; 2) the east side of Ayutthaya, which does not include industrial parks/estates, indicates high social vulnerability; 3) Bang Pa-in district, which has two industrial parks/estates, became more vulnerable after the disaster with a growing high susceptibility and exposure tendency. The study recommends that updated flood and vulnerability risk information be shared and active collaboration be undertaken among stakeholders, including central and local government administrations, infrastructure providers, private enterprises and communities, not only during disasters but also before and after the disaster in order to attain sustainable development in the industrial complex area. This research was conducted as a part of the Science and Technology Research Partnership for Sustainable Development (SATREPS) (Japanese government ODA) project.

Keywords: Social vulnerability, the 2011 Chao Phraya River flood disaster, sustainable development, industrial complex area.

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1. Introduction

Climate change and disaster risk reduction are significant challenges for our shared future. In this regard, we can find many efforts related to various fields, such as the sustainable development goals (SDGs) set by the United Nations. However, losses from disasters tend to be increasing (Wallemacq, 2018). One of the reasons for this is that disasters cannot be explained by a single discipline, such as engineering, natural science, or social science, to develop practical solutions. Disasters are complex and change as time passes and are accompanied by socio-economic changes, as well as climate change and the advancement of science and technology. This point of view is crucial to understand disasters. Social Vulnerability Index (SVI) is one of the practical tools that can be used to assess social vulnerability in a target area to examine disaster risk. There are many works of literature published on SVI, mainly after Cutter et al. (2013). They are based on the same model explained below and have used Geographic Information Systems to visualize the findings. The basic calculation methods for SVI are nearly the same based on the maximum minus minimum values equations. However, the specific methods are different, as explained in the following sections. As mentioned in the Press and Release Model by Wisner et al. (2004), disaster risk can be considered for an overlapping area between hazard and vulnerability. Natural hazards are predominantly associated with natural processes and phenomena (United Nations Office for Disaster Risk Reduction [UNDRR], n.d.), and vulnerability can be defined as "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" (UNDRR, n.d., para 1). In previous studies, mainly by natural scientists and engineers, hazard risk related to the 2011 Chao Phraya River flood has tended to be investigated and recognized as a disaster risk; vulnerability risk was not examined well, even though significant social science research has been conducted on the 2011 Chao Phraya River flood. Given the above situation, this study utilized a social vulnerability index in the industrial complex area (SVI-ICA) to understand the vulnerability risk and examined sustainability in the area from a longer perspective by comparing available data both before and after the disaster.

2. Problem Statement

2.1. The 2011 Chao Phraya River flood disaster and Industrial Parks

- **Outline of the damage**

Severe flooding occurred during the 2011 monsoon season in Thailand, beginning at the end of July and ending in mid-January 2012. The flooding resulted in a total of 813 deaths, 9.5 million people affected, and economic damage of USD 40 billion (ADRC, 2019). Damage in the agriculture, manufacturing, and service industries lowered the country's GDP (market value) by about 33 billion baht and economic growth by 3.7%. Consequently, the annual GDP growth only increased by 0.1% in 2011, a significant decrease from the estimated growth of 3.8% (H.E.V. Futrakul, 2012). In addition to these economic declines, the Chao Phraya River floods drew global attention, which indicates that the impact of the floods did not remain within Thailand, but spread all over the world, mainly through foreign companies and industrial complexes.

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- **Economic damage**

The flood had a devastating impact on the industrial complexes in central Thailand and manufacturers with their factories there. National statistics show the changes in GDP during the fourth quarter of 2011. While GDP rose by 0.7% in agriculture, it declined by 10.1% in the non-agricultural sector, resulting in a 9.0% decrease in total. The non-agricultural sector includes manufacturing, construction, and hotels and restaurants, with GDP decreases by 21.8%, 5.9%, and 5.3%, respectively (Termpittayapaisith, 2012). These results show that the manufacturing sector was by far the most affected by the floods. The impact of the floods was particularly serious on local Japanese companies in economic terms. More specifically, those Japanese companies that had based their businesses in the country earlier than others had more damage. This is because many of those companies located their factories in the industrial complexes in central Thailand (Ayutthaya and Pathum Thani provinces), with the complexes being relatively old, mostly established in the 1980s (Okazumi & Nakasu, 2015; Nakasu et al., 2013).

Well over 1,000 factories of 804 companies were inundated, including 43 companies in the Saha Rattana Nakorn Industrial Estate, 198 in the Rojana Industrial Park, 143 in the Hi-Tech Industrial Estate, 89 in the Bangpa-In Industrial Estate, 572 in the Factory Land Wangnoi, 227 in the Nava Nakorn Industrial Estate, and 44 in the Bangkadi Industrial Park (Table 01 & Figure 01). Significantly, 449 out of 804 companies were Japanese companies (Sukekawa, 2013). In 2011, Japan experienced its first annual trade deficit since 1980, in large part because of the Chao Phraya River floods, in addition to other economic factors. The expansion of economic losses caused by the 2011 floods is attributed to excess typical specialization and a supply-chain structure on which Japanese companies have commonly relied (JETRO, 2012; Okazumi & Nakasu, 2015). According to interviews with JETRO and JCC, in most cases, Japanese manufacturers in Thailand import parts from Japan or procure them from local manufacturers, put them together, and then export products to the global market.

Industrial complex areas, facilitated by Thai government policies and supply chain systems, have been enlarged along with the global economic trends in the area. Japanese enterprises advanced or relocated to the area, especially after the Plaza Agreement in 1985 and facilitated by the bankruptcy of Lehman Brothers, accompanied by strong appreciation in the Japanese yen (Nakasu, 2017).

Concerning the industrial complex areas, large-scale land-use change, and development led to drastically increased runoff, over-extraction of groundwater, and the filling in of canals and waterways. Overreliance on antiquated and poorly maintained infrastructure by both local and national governments further increased the vulnerability to the 2011 flood (Marks & Lebel, 2016).

Table 01. Affected Industrial Parks/Estates/Zones in Thailand

Industrial Parks/Estates	Region	Number of companies	Companies impacted (examples)	Reported flood height
Bang Pa-in	Bang Pa-In, Ayutthaya	90	Western Digital	>1.0m
Bangakdi	Mueang Pathum Thani, Pathum Thani	50	Nidec, Nissan, Sony, Toshiba Semiconductor	3.0m
Factory Land	Wang Noi, Ayutthaya	99	Canon Engineering, HDK, Sony	1.5m
Hi-Tech	Bang Pa-In, Ayutthaya	143	Canon Engineering, HDK, Sony	3.4m

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Nava Nakorn	Khlong Luang, Pathum Thani	227	Western Digital, Toshiba, Casio, Fujitsu, JVC, Seiko	2.0-3.0m
Rojana	Uthai, Ayutthaya	198	Honda, Furukawa, TDK, Nidec, Canon, Nikon, Panasonic, Sanyo Semiconductor	3.0m
Saha Rattana Nakorn	Nakhon Luang, Ayutthaya	43	Yamamoto	>1.0m

Note: The numbers of company and factory are different and also the total number of the companies are different from the sources
(Source: Affected Industrial Estates (Source: Guy Carpenter, Bangkok Post), November 3, 2011. The authors have altered.)

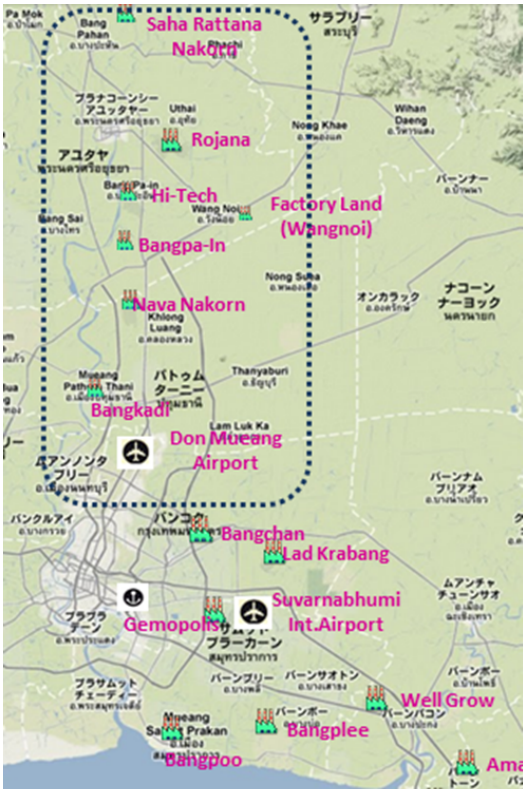

Figure 01. Affected Industrial Estates and Parks (within the dotted line)
(Provided by JETRO)

3. Research Questions

This study has attempted to clarify the present social vulnerability and social vulnerability changes before and after the disaster in order to understand the area better and to propose effective countermeasures for a sustainable future in the industrial complex area. Accordingly, the research questions were as follows:

- What were the vulnerabilities and vulnerability changes in the industrial complex areas before and after the 2011 flood disasters?
- Have districts that have industrial parks/estates become safer after the disasters?

What were the most important lessons learned from this disaster and recommendations to attain sustainable development in the industrial complex areas?

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4. Purpose of the Study

The purpose of this study was to contribute to the sustainable future in the flooded industrial complex areas by examining the social vulnerability changes from a longer perspective, which have not been investigated sufficiently. In particular, this study focused on a before and after comparison of the 2011 disaster in districts that both have and do not have industrial complexes, providing baseline knowledge for understanding disasters. This study indicates what changes have occurred after the disaster regarding a social vulnerability in order to examine sustainable development in the area, accompanied by specific recommendations.

5. Research Methods

5.1. Literature and scope of the research

Regarding the published literature, there are several approaches to investigate the 2011 flood. Marks and Lebel (2016) describe how Thailand's incomplete decentralization and administrative fragmentation has created numerous barriers to polycentric disaster governance. Hagiwara et al. (2014) explained the chain reactions of the economic damage mainly derived from the experience of Japanese enterprises and points out issues that disrupted their businesses. That paper focused on the risk management changes of the firms after the 2011 flood, indicating they have strengthened their flood countermeasures as a whole, but points to the need to consider more about the collaborations with business partners or other entities. Okazumi and Nakasu (2013, 2015) examined the devastating exacerbation of economic damage through a social background perspective and enterprise inter-relationships. Nakasu (2017) clarified the reasons why so many Japanese companies moved to the potential risk area in Thailand. The reasons are from the perspective of both the country's social factors through decentralization policies facilitated by the Thai government and also yen appreciation triggered by the Plaza agreement (1985) and the Lehman Brother's bankruptcy (2008) to propel Japanese enterprise relocation and advancement. Haraguchi and Upmanu (2015) emphasized the decision-making process of enterprises to clarify the trigger of economic damage. That paper proposed measures for related supply chain risk through setting research questions such as private investment decision-making, the diversified sources of procurement, emergent assistance from other partner companies in the same supply chain, and the degree of the recovery of customers. Tamada et al. (2013) approached the subject mainly from economic, political, hydrological, and technological perspectives with various authors. That book clarified the complexity of the 2011 flood and overviewed how human interventions affect the disaster, such as local people's lifestyle changes before the disaster, the establishment of the industrial complexes in the area, government agency conflicts, dam operation impacts, unexpected rainfall, and private company reactions. Singkran (2017) reviewed the 2011 flood from disaster management views and emphasized the need for more non-structural countermeasures and participatory collaboration among stakeholders for effective disaster management. Accordingly, while there have been publications investigating the industrial and political points of view, there has not been much investigation of longer and broader views, such as sustainability from the local society's viewpoint. Therefore, this study sought to investigate the changes in social vulnerability systematically. In particular, this study focused on interviews with Ayutthaya government officials and an investigation of statistical data by establishing a

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social vulnerability index to consider the sustainable future in the industrial complex areas. The scope of the study focused on the changes to vulnerability in the target areas before and after the 2011 disaster. The target areas were districts, sub-districts, and villages around the industrial parks, as mentioned in Figure 02. In this study, the district level was examined as the first stage (Figure 03).

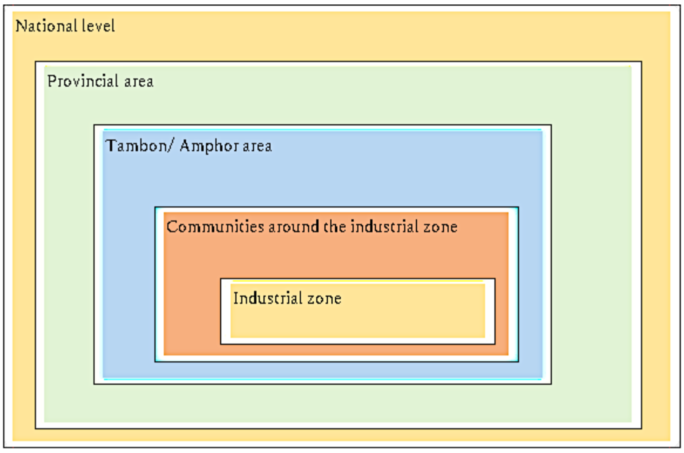

Figure 02. Target Setting
Communities: Village Level
Tambon/Amphoe: Sub-District and District Levels

Figure 03. Districts in Ayutthaya Province
West side Ban Sai is Ban Sai (1413) [*บางซ้าย* is the Thai word for Ban Sai]
South side Ban Sai is Ban Sai (1404) [*บางไทร* is the Thai word for Ban Sai]

5.2. Background of establishing the SVI-ICA

As mentioned in the previous section, Marks and Lebel (2016), Marks (2019), Okazumi and Nakasu (2015), Tamada et al. (2013), and Nakasu (2017) have investigated the socio-political background of the industrial complex areas. In particular, Nakasu (2017) explored the reasons why so many Japanese enterprises relocated to the area. In that paper, inappropriate regional development, decentralization policy, global economic events, and urbanization were identified. Besides, the industrial areas are mainly protected by a water wall to the east side of Ayutthaya. To the west side of Ayutthaya, primarily agricultural areas are used for water reservoirs to retain water, similar to a dam. Canals are also used to drain excess water. These were reported in interviews in March 2019 with the vice governor of Ayutthaya as the present significant strategic countermeasures used by the local government after the 2011 disaster. However, longer and broader perspectives, such as demographic trends, including post-disaster situations, are required to understand the sustainability of the area. By recognizing those aspects, this study used a social vulnerability index and examined social vulnerability changes.

5.3. Exposure, Susceptibility, and Capacity

After referring to the Pressure and Release Model (PAR model) and other literature to identify a district's social vulnerabilities to natural disasters (Wisner et al., 2004), the authors created three categories – exposure, susceptibility and capacity – then, identified variables used to assess the social vulnerability of districts, as shown in Table 02. The variables were determined within the limitation of the available data. Population and factory area density was used to establish the exposure index. Child population density, elderly population density, household income poverty, disable population density, and non-Thai immigrant workers population density were considered in calculating susceptibility. Road density, volunteer population density, and school teacher population density were used for capacity. The most updated datasets are mainly from 2018.

Table 02. Indicators of Exposure, Susceptibility, and Capacity

Index	Indicator	Unit	Original Values Range
Exposure	Population density	Pop/km2	Bang Sai (1413) <93> PNSA <530>
	Factory area density	Numbers/km2	Phak Hai <0.25> Wang Noi <6.38>
Susceptibility	Child pop. density 0-5 years old	Pop/km2	Bang Sai (1413) <4.23> PNSA <26.59>
	Elderly pop. density 60 years old and over	Pop/km2	Bang Sai (1413) <17.48> PNSA <88.11>
	Household income poverty (under 38,000 p.a.)	Numbers	Bang Pahan, Bang Sai (1413) <0> Phachi <59>
	Disable pop. density	Pop/km2	Bang Sai (1413) <3.48> PNSA <24.7>
	Non-Thai (from Laos, Myanmar, Cambodia) pop. density	Pop/km2	Bang Ban/ Maha Rat <0.04> Bang Pahan <1.75>
Capacity (Hard and Soft)	(H) Road density	Rate	Wang Noi <0.45> Bang Sai (1404) <4.92>
	(S) Volunteer pop. density (Health + DDPM)	Pop/km2	Lat Bua Luang <2.98> PNSA <19.45>
	(S) School teachers pop. density (Kindergarten-Secondary <Public/Private/Vocational>)	Pop/km2	Bang Sai (1413) <0.82> PNSA (14.23)

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5.4. Establishing SVI-ICA

To develop the social vulnerability index in the industrial complex area (SVI-ICA), firstly, data was collected at the maximum level, including field surveys in Ayutthaya province, visiting Ayutthaya government offices and also a local university. After the process, there was a discussion of the variables to be used for establishing SVI-ICA, as well as creating each index: exposure, susceptibility and capacity. Each indicator, selected reasons and methodologies referred to the abundant recent literature, such as de Brito et al. (2018), di Girasole and Cannatella (2017), Fatemi et al. (2017), Fekete (2019a, 2019b), Ge et al. (2017), Morimoto (2019), Ostadtaghizadeh et al. (2015), Sorg et al. (2018), Stafford and Abramowitz (2017), Tavares et al. (2018). In particular, the study referred to Birkmann et al. (2013) and Morimoto (2019) to apply MOVE framework with the mentioned PAR model (Wisner et al., 2004) and Fekete (2019b) is referenced for demographic viewpoints. The equations applied the Human Development Index method developed by the United Nations Development Programme (UNDP), as indicated below in Eq. (1) and Eq. (2). Finally, each index was calculated by adding each value of the indicators.

[(LN(x)- LN(Min(x)) / (LN(Max(x)) - LN(Min(x))] **Eq. (1)** (for exposure and susceptibility)

[(LN(Max(x))- LN(x)) / (LN(Max(x)) - LN(Min(x))] **Eq. (2)** (for capacity)

LN: Natural Logarithm

The study did not establish SVI-ICA by merely combining each component, but used principal component analysis, as indicated in Table 03. For the principal component analysis, all the variables related to exposure, susceptible and capacity were used in the calculation. As a result, the first component can be interpreted as "resistance to natural disasters," the second component as "susceptible to natural disasters," and the third component as "exposure to natural disasters." With consideration of the weight of each component, proportions of variance are used. The equation for establishing the SVI-ICA is Eq. (3):

*SVI-ICA = - 0.45*Res + 0.23*Sus + 0.18*Exp* **Eq. (3)**

PC1: Resistance to Natural Disasters (Res)

PC2: Susceptibility to Natural Disasters (Sus)

PC3: Exposure to Natural Disasters (Exp)

Table 03. Principal Component Analysis for SVI-ICA

Variables	PC 1	PC 2	PC 3	Contribution of Variables (0-1)
Population density	-0.95309	-0.16229	0.18824	0.97016
Factory area density	-0.06402	-0.23953	0.62692	0.45450
Child pop. density 0-5 years old	-0.90067	-0.25693	0.26167	0.94568
Elderly pop. density 60 years old and over	-0.96623	0.04164	0.07206	0.94053
Household income poverty (under 38,000 p.a.)	-0.21299	-0.19044	-0.80170	0.72435
Disable pop. density	-0.91305	0.23882	-0.19010	0.92683

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Non-Thai (from Laos, Myanmar, Cambodia) pop. density	-0.52930	-0.11391	0.79111	0.91899
(H) Road density	0.83255	-0.30688	0.12053	0.80184
(S) Volunteer pop. density (Health + DDPM)	0.04555	-0.97872	0.05935	0.96350
(S) School teachers pop. density (Kindergarten-Secondary <Public/Private/Vocational>)	0.04555	-0.97872	0.05935	0.96350
Proportion of Variance (PV)	45.13740	22.67709	18.28406	
Cumulative PV	45.13740	67.81450	86.09856	

6. Findings

6.1. Exposure, Susceptibility and Capacity by District in Ayutthaya

- Exposure

As shown the results in Figure 04 (Exposure), those districts subject to more exposure tend to be to the east side of Ayutthaya province. The reason for this is that the industrial parks and estates exist on the east side, such as Saha Rattana Nakhon, Rojana Industrial Park, High-Tech Industrial Estate and Bang Pa-in Industrial Estate, and Factory Land Wang Noi. The west side is mainly dominated by agricultural land, therefore, the exposure index indicates a relatively low exposure value for those areas. Based on the Ayutthaya government, this situation is considered for countermeasures after the 2011 flood as mentioned in 6.5.

- Susceptibility

Figure 04 (Susceptibility) indicates the susceptibility of the districts in Ayutthaya Province. Phra Nakhon Si Ayutthaya (PNSA) has the highest susceptibility because susceptible people, as shown, tend to concentrate in the district capital. Bang Pahan is the second-highest because child, elderly, disable, and non-Thai immigrant workers densities are at high rates being a district close to the capital and industrial parks/estates. Nakhon Luang, which has Saha Rattana Nakhon Industrial Estate, is very low because of low rates of child and elderly densities. The susceptible districts are concentrated on the east side and central area, except Nakhon Luang.

- Capacity

Capacity can be seen in Figure 04 (Capacity). PNSA has the highest capacity since volunteer and schoolteacher densities are high, as well as road density. On the other hand, Wong Noi district, which has factory land, has the lowest capacity. Uthai district, which has Rojana Industrial Park, has the second-lowest. Compared to the other industrial parks and estates, which have higher capacities, these two districts, Wang Noi and Uthai, should be considered with respect to capacity future disaster countermeasures.

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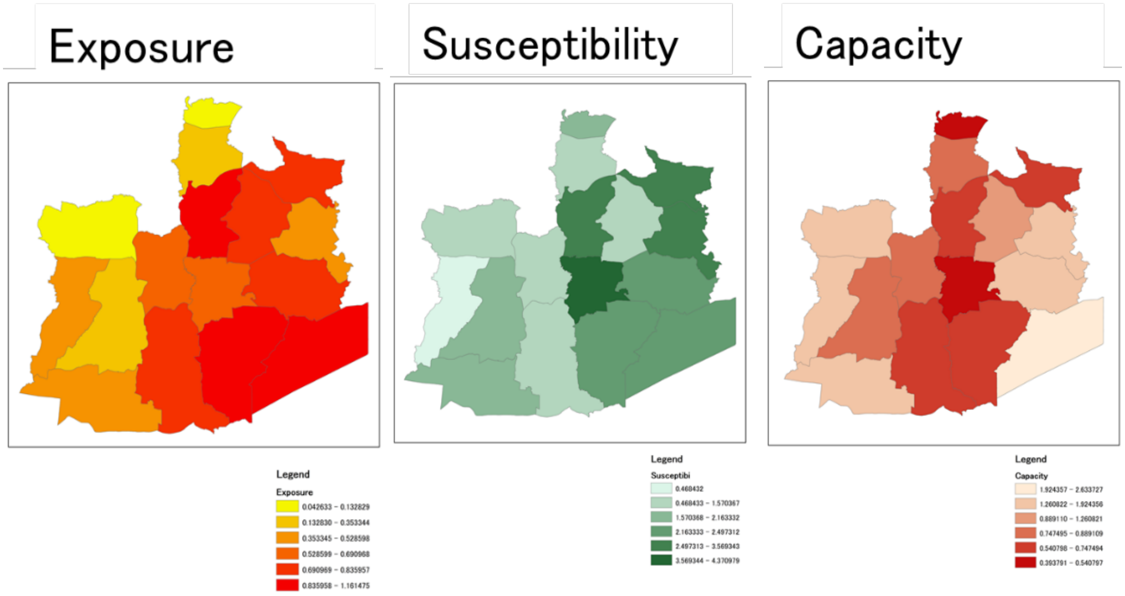

Figure 04. Exposure, Susceptibility, and Capacity (The darker means higher values)

6.2. SVI-ICA by District

Figure 05 shows SVI-ICA on the map. Each value can be seen in Table 04. This data indicates that PNSA is the most vulnerable; Bang Pahan is the second; Bang Pa-in, which has High Tech and Ban Pa-in industrial estates, is also very high. On the other hand, Bang Sai (1413) is the least vulnerable. Other low vulnerability districts tend to be agricultural areas. However, Nakhon Luang, which has Saha Rattana Nakhon Industrial Estate, shows very low vulnerability.

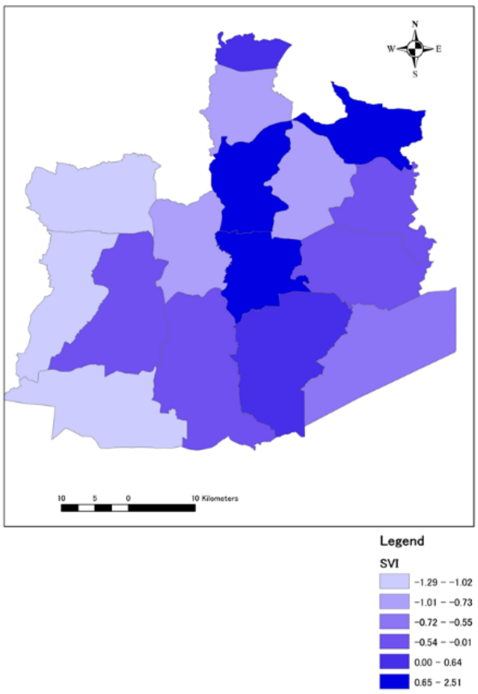

Figure 05. Social Vulnerability Index for Industrial Complex Area (SVI-ICA)
(The darker means higher values)

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Table 04. SVI-ICA results

Sub-District	Resistance	Susceptibility	Exposure	SVI-ICA
Sena	0.14288	0.93175	-0.89323	-0.01077
Uthai	-0.56026	-2.10347	-0.02952	-0.23699
Wang Noi	-0.31903	-4.07335	1.3685	-0.54698
Lat Bua Luang	1.80301	-0.72782	-0.24985	-1.02373
Maha Rat	1.6499	1.01452	-1.22834	-0.73022
Phachi	-1.36816	-1.75916	-1.66261	-0.0882
Phra Nakhon Si	-5.2907	0.69829	-0.15142	2.514166
Phak Hai	1.33396	-0.74251	-1.56129	-1.05209
Ban Phraek	-0.26562	1.79138	-0.79217	0.388956
Bang Sai (1404)	1.36462	1.74044	0.60006	-0.10577
Bang Pa-in	-0.65	0.56183	1.23358	0.643765
Bang Pahan	-1.94537	1.23571	3.14365	1.725487
Bang Ban	1.20466	0.52408	-1.77273	-0.74065
Bang Sai (1413)	3.6791	0.16383	1.82179	-1.28999
Nakhon Luang	2.13417	0.21992	0.76446	-0.77219
Tha Ruea	-2.91316	0.52457	-0.59086	1.325218
Min				-1.28999
Max				2.514166

6.3. Cluster analysis and visualization of the differences

Based on the findings of the principal component analysis and SVI-ICA, this study conducted a cluster analysis to clarify the different characteristics of each district on SVI. Figure 06 indicates the clusters and shows the district characteristics of vulnerabilities that can be divided into four groups. These are reflected in the PC1 (Res) – PC2 (Sus) relationship on the scatter graph shown in Figure 07. As Figure 07 indicates, each district can belong to one of four groups by the degrees of resistance and susceptibility to natural disasters. The first group, "high resistance and high susceptibility (weak)," is Bang Sai (1413) (BS4), Maharat (MR), Nakhon Luang (NL), Bang Sai (1404) (BS3), and Lat Bua Luang (LBL). The second group, "relatively high resistance and high susceptibility (weak)," is Ban Phraek (BPK), Sena (SNa), Bang Ban (BB), and Phak Hai (PH). The third group, "relatively low resistance and low susceptibility (strong)" is Phachi, U Thai (UT), and Wangnoi (WN). The fourth group is "low resistance and high susceptibility (weak)" is PNSA, Tha Rua, Bang Pahan and Bang Pa-in (BPI). The fourth group can be identified as the most vulnerable group to be considered by this analysis.

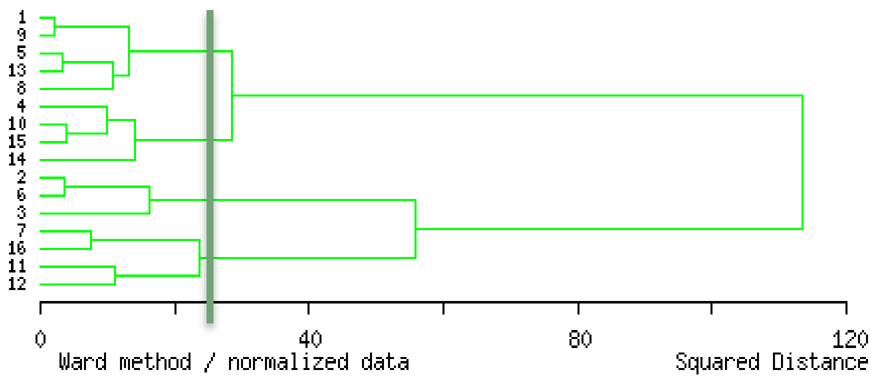

Figure 06. Cluster Analysis

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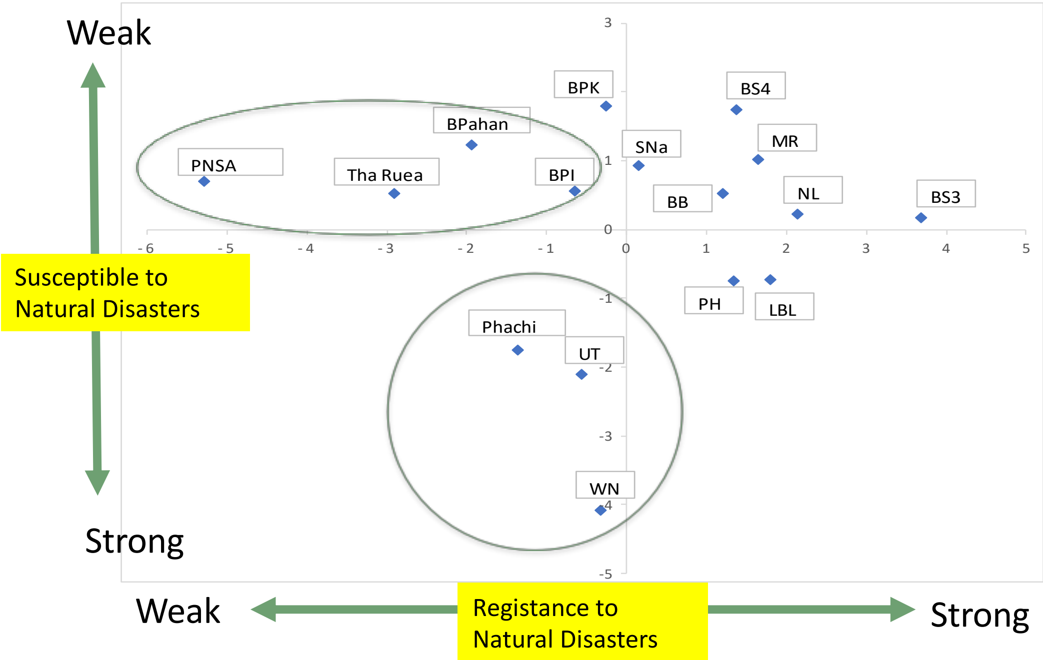

Figure 07. Principal Component and Cluster Analyses on the Scatter Graph

6.4. Comparisons with before the 2011 flood disaster: Exposure, susceptibility and demographic changes

Given the limitation on available data, only the exposure and susceptibility indicators before the 2011 disaster were calculated. In addition, as a part of exposure comparison by longitudinal perspective, population changes of each district were also examined.

- Exposure Index and Population Density

  As indicated in Table 05, industrial parks/estates areas exposure index (Exp. Index) and population densities (Pop. Dens) became higher than before the disaster, such as in Uthai, Wang Noi, Bang Pa-in districts. In particular, Bang Pa-in's change is more significant than PNSA. On the other hand, in agricultural areas, district indices and population densities tend to be lower or negative as compared to before the 2011 disaster.

Table 05. Exposure Index and Population Density Changes

Sub-District	2018		2010		Gaps	
	Exp. Index	Pop. Dens.	Exp. Index	Pop. Dens	Exp. Index	Pop. Dens
Sena	0.55	153	0.54	151	0.0021	2
Uthai	1.17	247	1.14	231	0.0225	16
Wang Noi	1.56	248	1.51	221	0.6517	27
Lat Bua	0.67	148	0.65	144	0.0155	5
Maha Rat	0.44	114	0.43	114	0.0025	0
Phachi	0.92	244	0.93	238	-0.0010	6
Phra	1.40	530	1.40	498	0.0000	32
Phak Hai	0.15	120	0.17	124	-0.0167	-4
Ban	0.40	179	0.41	178	-0.0050	1
Bang Sai	1.02	145	1.01	143	0.0057	2

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Bang Pa-in	1.43	212	1.32	172	0.1142	41
Bang	1.45	300	1.46	293	-0.0088	7
Bang Ban	0.75	108	0.75	108	0.0063	0
Bang Sai	0.45	93	0.45	94	0.0000	-1
Nakhon	0.89	109	0.86	104	0.0354	5
Tha Ruea	1.25	296	1.26	292	-0.0136	4

- Susceptibility Indices and Child and Elderly Densities

  Decreased child density and increased elderly density numbers are apparent for almost all the districts, as indicated in Table 06. Districts with industrial parks/estates, such as Wang Noi and Bang Pa-in, have become more susceptible than before the 2011 disaster. In particular, susceptibility in Bang Pa-in should be considered with respect to disaster countermeasures.

Table 06. Susceptibility Index and Children & Elderly Density Changes

Sub-District	**2018**			**2010**			**Gaps**		
	Sus. Index	**Child. Dens.**	**Eld. Dens.**	**Sus. Index**	**Child. Dens.**	**Eld. Dens.**	**Sus. Index**	**Child. Dens.**	**Eld. Dens.**
Sena	2.16	7.4	28.2	2.23	9.1	21.8	-0.0632	-1.7	6.4
Uthai	2.45	12.7	39.1	2.48	15.8	28.3	-0.0303	-3.1	10.8
Wang Noi	2.50	14.2	31.4	2.43	16.1	21.8	0.0672	-1.9	9.7
Lat Bua	1.89	7.6	23.7	1.92	9.9	17.0	-0.0279	-2.3	6.8
Maha Rat	1.14	4.6	22.5	1.64	6.8	28.3	-0.4958	-2.2	-5.8
Phachi	2.90	11.5	44.8	2.99	14.5	34.3	-0.0866	-3.0	10.5
Phra	4.37	26.6	88.1	4.37	31.2	61.0	0.0000	-4.6	27.1
Phak Hai	1.35	4.5	25.4	1.54	6.5	20.5	-0.1839	-2.0	5.0
Ban Phraek	2.11	7.5	37.5	2.19	9.5	28.3	-0.0796	-2.0	9.2
Bang Sai	1.55	6.2	27.8	1.60	7.8	20.6	-0.0506	-1.6	7.2
Bang Pa-in	2.38	12.3	29.3	2.22	11.6	20.5	0.1556	0.7	8.8
Bang	2.98	13.5	60.4	3.07	17.3	44.6	-0.0860	-3.8	15.8
Bang Ban	1.57	4.5	23.1	1.48	4.4	16.7	0.0942	0.1	6.4
Bang Sai	0.47	4.2	17.5	0.58	5.5	14.1	-0.1094	-1.3	3.3
Nakhon	1.34	5.4	19.5	1.36	6.6	14.4	-0.0198	-1.2	5.1
Tha Ruea	3.57	13.2	59.2	3.63	16.5	43.2	-0.0631	-3.3	16.0

- Population Change

Annual average population change was calculated by the total population change between the target initial years and the end of the years. The proportion of annual average population change was calculated using the number of the interval years. Uthai and Nakhon Luang districts have a strong tendency to decrease population. Only two districts, Bang Pahan and Bang Phreak, had positive population changes. Others had negative population changes (Table 07); in particular, Uthai, which has Rojana Industrial Park, and Nakhon Luang, which has Saha Ratta Nakhon Industrial Estate, had huge population decreases, as mentioned the above.

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Table 07. Population Changes

Sub-District	2011-2018	Changes (an. ave.)	2008-2011	Changes (an. ave.)	Gap (an. Ave.)
Sena	230	0.1%	319	0.3%	-0.2%
Uthai	2339	0.7%	2312	1.4%	-0.7%
Wang Noi	4939	1.2%	2650	1.4%	-0.2%
Lat Bua Luang	879	0.4%	401	0.4%	0.0%
Maha Rat	-51	0.0%	165	0.3%	-0.4%
Phachi	574	0.3%	341	0.3%	-0.1%
Phra Nakhon Si Ayutthaya	3472	0.7%	2355	0.9%	-0.3%
Phak Hai	-663	-0.4%	-165	-0.2%	-0.2%
Ban Phraek	91	0.2%	-161	-0.6%	0.7%
Bang Sai (1404)	277	0.1%	556	0.4%	-0.3%
Bang Pa-in	8033	2.5%	3929	2.7%	-0.2%
Bang Pahan	727	0.3%	152	0.1%	0.1%
Bang Ban	49	0.0%	97	0.2%	-0.1%
Bang Sai (1413)	-199	-0.2%	12	0.0%	-0.2%
Nakhon Luang	825	0.5%	972	1.2%	-0.7%
Tha Ruea	380	0.2%	203	0.2%	0.0%

- Countermeasure Changes

Concerning recent countermeasure changes in Ayutthaya, the local government introduced strategies and various projects after the 2011 disaster. These measures protect the industrial complex areas mainly by hard countermeasures, along with the utilization of the agricultural area as reservoirs after the harvest time and during the flood period, as well as use the canals to release excess water. These are well-considered and appear to be very useful. However, more effective countermeasures could be considered. In particular, the social changes in the area tend not to be examined and the application of the countermeasures usually considers the same social situations as before the disaster.

6.5. Discussions: Social Vulnerability Gaps and Changes

Based on the results, the exposure changes before and after the flood has a statistically significant difference between districts that have and do not have industrial parks/estates (The Wilcoxon Rank Sum Test value (w)=48, p=0.004>0.05). Notably, five districts, Phak Hai, Tha Ruea, Bang Pahan, Ban Phraek and Phachi, which have no industrial parks/estates, have negative exposure index changes. Negative exposure index change means the districts have tended to lose population and industry. Bang Pa-in, on the other hand, is the only district that has two industrial estates and a considerable population density, as well as an increasing exposure index change. Therefore, the exposure change provides both positive and negative aspects to consider sustainable development. Concerning susceptibility, there is no statistically significant difference between districts with and without industrial parks/estates ($w=37, p=0.06>0.05$), although Bang Pa-in, Bang Ban, and Wang Noi have become more susceptible after the 2011 disaster. These districts have higher elderly and child densities after the disaster. These changes require more capacities to cope with disasters for sustainable development. In this study, capacity changes could not be measured because of the limitations of available data; however, the issue is clarified as mentioned.

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Concerning SVI-ICA, the recent data clearly shows there is statistically no significant difference between districts with and without industrial park (*w=22, p=0.86>0.05*). The data also indicates that PNSA is the highest, and the east side of Ayutthaya, which has no industrial parks/estates, such as Bang Pahan and Tha Ruea, are the second and the third highest districts. Bang Pa-in district, which has two industrial estates, is the fourth highest district. These recent SVI-ICA figures with past mentioned exposure and susceptibility changes indicate PNSA, the east side districts without industrial parks/estates, and Bang Pa-in district need more focus for disaster countermeasures than other areas.

7. Conclusion

7.1. Main Contributions and Recommendations

As a result, this study identifies the prioritized districts for disaster countermeasures, which have the highest SVI-ICA: PNSA, the east side districts without industrial parks/estates districts with high social vulnerability, and Bang Pa-in which has two industrial parks/estates have become more vulnerable after the disaster with growing high susceptibility and exposure tendency. There were no significant gaps found between districts with and without industrial parks/estates; however, disaster countermeasures for the west side of Ayutthaya province, which has farmland without industrial parks/estates, should also be considered. The area has tended to lose population and industry. Disaster risk should not only consider hazards, such as precipitations and topography, along with hard countermeasures, such as water walls, but the social vulnerability with social change should be examined as well.

7.2. Limitations and Challenges: Data Availability

Data availability is the core limitation and challenge for this study. Table 08 below shows the challenges with an ordering number and the countermeasures that were undertaken (ADPC, 2019).

Table 08. Challenges and Countermeasures for Data Collection

1. Unable to identify the data source.
>>The project team was able to identify the appropriate agency or organization as a source of information or an alternative source of information.
2. The website or database of government agencies was down or inaccessible.
>>The project team was able to obtain the information directly from the government agency if the data was not available online – in some cases obtaining the data by the direct way was preferred because the quality and level of data were trustworthy.
3. The collected data was outdated.
>>Liaising directly with the agency or alternative agency meant that up-to-date and better quality data was available.
4. Some data was highly classified and non-sharable for public use.
>>The classified data was obtainable by following the official channel of data request.
5. The collected data did not satisfy the requirement, for example, no data at the sub-district level, no record of gender, etc.
>>The ADPC team was able to map out and engage additional or alternative agencies from whom information could be obtained.
6. Raw data was not summarized for the number of genders or classified into the sub-district level.
>>Explored a new tool/software to be used for data collection.

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7. Some raw data was less user-friendly for a new user. For example, GIS data.
>>The research team was able to adapt the information into a useable format.
8. Documents sent via post were lost.
>>The information was obtained by utilizing alternative modes of collection.
9. Poor fax and telephone signals.
>>The data was obtained by utilizing various modes of contact and making visits to the agency where necessary.
10. There was a change of person-in-charge and no hand over among them or missing documents.
>>The data was obtained by being proactive in identifying an alternative focal person from who to coordinate with at respective agencies.
11. Time consumption of getting data after sending official requirement, for example, it took 2-5 days in response from one agency.
>>Plan in advance for future assignments; refer to the mapping of agencies undertaken for this exploratory survey for undertaking further similar studies in the future.
12. No data was available from secondary data sources.
>> Removed the variables from the table and made a note in the gap of available data to inform possible primary data collection in the future.

(Source: ADPC, 2019)

7.3. Future Directions

- SATREPS Project: Need to Have an Integrated and Longer Perspective

The Japanese government ODA, SATREPS project, was launched (2018-2022) under the title "The Project on Regional Resilience Enhancement through Establishment of Area-BCM at Industry Complexes in Thailand." This project uses space, geospatial, and other related data and develops and applies the data not only for industrial complex business continuity management, but also for local governments and related stakeholders in the areas to enhance regional resilience (JST, 2019). In particular, the project sets up new community research to understand the relationship between local people and industrial parks/estates/zones in the area. The project also focuses on the local people's well-being, including employees and their families, for sustainable development in the area. This new perspective provides the project, as well as a bilateral science and technology cooperation scheme, a new challenge and will be a significant step to align with the United Nations Sustainable Development Goals (SDGs).

- For a Sustainable Future with Industries

The 2011 Chao Phraya River flood clarifies the existence of globalized economic activities and the vulnerability of manufacturing industries. The industrial concentrations in developing countries caused by low price competition of products and increasing industrial-economic risk became apparent. The lessons learned are the need for risk management to adjust to changing global conditions. As well, national and local governments must understand the needs regarding information about risk and providing such information to foreign enterprises when they invite businesses from abroad, along with understanding global economic trends. For instance, information on the potential risks and how to cope with such risks by the national and local governments with stakeholders should be provided. Also, it is necessary to implement risk assessment using internationally standardized and recognized processes. At the same time, the companies have social responsibilities to disclose risk information, such as what business they are doing, what kinds of risks exist for the local people and what they can do during the disaster for the communities.

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At the same time, local governments and communities should know their social vulnerabilities and related changes in order to understand the risk clearly and also set up countermeasures according to the hazard risk. The 2011 Chao Phraya River flood was a trigger to acknowledge the necessity of risk management for companies, localities and governments in the context of a changing global industrial economy (Singkran, T, 2017). Regional planning considering potential risks of the changes, the roles of the companies, regions and nations, risk and risk assessment and information disclosure, as well as sharing risk information among related stakeholders, are issues to be prepared for and recognized for regional sustainability and resilience in the future. The mentioned SATREPS project is an example of the first step to tackle these issues; however, broader views are required and more discussion should be undertaken.

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