Review and Future Direction of Research on Delta at Risk and Resilience to Water-Related Disasters

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***Abstract*— The number of population living in the delta cities are increasing year by year due to abundant natural resources and accessibility. However, this condition is not equivalent with the capabilities of the cities against natural disasters. The inclination toward global climate change will increase the risk of water-related disasters. Assessing the delta city resilience on infrastructure, social-ecology, and policy is necessary to reduce damage and loss. This paper aims to review the current research trend on the vulnerability of delta cities toward the water-related disasters. These disasters which define as a natural event such as flood, tsunami, storm, climate change effects cause great damage and loss in delta region. Reviewing current achievement and methodology, finding the missing gaps from previous literature, and providing the future recommendation for researcher are important for future outlook in this subject. Using Scopus database and some private institutions as a complement to sort particular papers in this topic, the results show that many studies are still centralized in Asian and European countries. Mostly, the articles focus on climate change effect and the lack of policy on disaster resilience. Adding new scenario framework, integrating with policy sector, and shifting study location to Africa or Oceania to evaluate the resilience status in delta cities against water-related disasters can be a breakthrough in this field.**

Keywords*— *water-related disasters; delta city resilience; climate change

I. INTRODUCTION

Coastal zones have attracted human due to the abundant resources and accessibility of logistic for trading and transport. The development in the coastal areas is snowballing in the past decades. Moreover, the increasing number of population along with urbanization growth will affect the seaside regions in the future. Sixty percent of the 31 megacities based on United Nations data 2016, which have more than 10 million populations, are located in seashore regions. The majority of big cities are located in the coastal zone and in the large delta. Based on the study, in 2000, 10.9% of the 6.1 billion global population lived in the coastal zone, and the number is projected to increase to 12% of 11.3 billion global population in 2060 [40].

These circumstances create high tension within coastal environment and natural resources. Beside the fragility due to geography condition, the urbanization growth will aggravate the risk and vulnerability. Moreover, devastating conditions of the delta cities are mostly led by water-related disasters, such as the Indian Ocean tsunami in 2004, Hurricane Katrina in the United States in 2005, the earthquake and tsunami in the northern coast of Japan in 2011, Typhoon Haiyan in the Philippines in 2013 [19].

Based on those reasons, measuring the capability of the delta cities against disaster is essential. For example, in Indian Ocean tsunami disaster, the recovery of damaged cities focused on long-term social and ecological effects [56]. In the past, post-disaster conditions developed awareness to build the structure to protect the residential area. However, the concept of resilience nowadays has shifted to the anticipation efforts before disasters. Integrating environmental and human behaviour factors to understand the risk will improve the response to the hazard [19].

Evaluating and assessing the delta cities resistance against water-related disasters are exceptionally necessary. This paper sets out to examine the current situation of research regarding the connection between water-related disaster and delta cities. The objectives of this study are: **Providing information on delta at risk against water disaster**, collecting and analysing papers related to resilience against water-related disasters in delta regions around the world; **Reviewing recent studies outlook**, discussing and criticizing the current trend of methodologies, approaches, and limitation of previous research; **Creating future path**, finding the missing gaps and giving suggestion to researchers for future trajectories in this topic.

II. BACKGROUND

A. Vulnerability of delta cities toward disaster

Besides of the benefits dwelling in a delta city, numerous disasters might haunt the occupants anytime. The hazard to the residents is quite high due to the increasing rate of population. Recently, research showed that 24 deltas have been sinking gradually and 85% of which experienced severe flooding in the past decades (International Geosphere-Biosphere 2014). Moreover, the threat of climate change is perceived nowadays, and it may cause sea level rise. Intergovernmental Panel on Climate Change (IPCC) mentioned that the global mean sea level has already increased by 20 mm from 2005 to 2012 and been projected to increase by around 150 mm to 239 mm due

to the RCP (Representative Concentration Pathways) scenarios in 2100 [34]. Combining sea level rise and land subsidence will escalate the exposure toward the catastrophe.

Grayman (2011) classified the major natural cataclysm related to water as [23]: Flood such as coastal flood, riverine flooding, flash flood, dam failure; Storm likes typhoon, hurricane, tropical cyclone, tornado, local storm; Climate change such as global sea water level, changing rainfall pattern; Drought; tidal wave and tsunami; Contamination; water-borne epidemics; Slides such as landslide, avalanche, mudflow

This paper will focus on four water-related disasters: flood, storm, tsunami, and climate change. These disasters are common occurrence in the delta regions. Flood is described as the inundation due to heavy rainfall in the short term and harms the people and infrastructure directly. Storm and tsunami which generally occur in the offshore can induce massive damage in the delta regions. Climate change is defined as a phenomenon which causes floods/subsidence in a long-term duration as a result of extreme weather and sea level rise.

B. Resilience to water-related disaster

Resilience, according to Holling [25], is "the endurance of a system to absorb the disruption and changes of circumstances or variables and still persist". Resilience combines the environment and society ability to deal with hazard in various ways such as learning, adapting, and reorganizing the impact [10]. Discovering the resilience capability in delta cities can be a guide to evaluate the system dealing with hazard holistically. For instance, private institutions such as C40 cities or Delta Alliance have measured the vulnerability index to develop awareness about disasters.

Many types of resilience can be assessed for looking the resistance of city. The resilience of disaster that are used in this study are [12, 19]:

1. Engineering resilience
2. Social & Ecology resilience
3. Governance resilience

In this study, we approach engineering resilience as a concept in engineering terms to build hard infrastructures which can reduce damage in the efforts to fight against disasters. Social and ecology resilience is interpreted as the system that can absorb the disturbance and build the capacity for adaption. To make it convenient, we imply social and ecological resilience as a system which can be adapted toward disaster, which is applicable for both human and the environment. Meanwhile, governance resilience is critical to avoid the governance failure when institution decision-making processes create a barrier for learning [12]. We interpret this resilience by looking at the rule and policy that create an integrated system to foster public awareness toward disaster. Therefore, Government plays an important role in this terminology.

The resilience of water-related disasters means the ability of the system in the city to recover from and stand firm against water catastrophe. Revealing the capability and readiness of individual city to face the danger of water-related disasters is essential for the residents by increasing the public perception to minimize the damage.

III. METHOD

The methods in this study focus on the extend of the research on water-related disasters and resilience that are addressed in journals, companies' documents, or in academic theses in the last 20 years. Figure 1 shows the flowchart of the method to sort the number of the papers which are related with resilience against delta city. Using the Scopus database and the keywords ("WATER DISASTER") AND ("DELTA RESILIENCE") in the abstract section, 3103 papers from various journal types were identified. After that, 1516 papers were filtered by using the same keywords but restricted to the fields of ecology, economy, geography, geology, engineering, environmental science. It is deemed necessary to limit the scope of the research only to those specific fields so that we could concentrate on the various kinds of resilience in those subjects.

The final set up was to screen the papers by adding more details as filters. We divided the water disasters to six specific categories, namely "Water Disasters", "Storm", "Flood", "Tsunami", "Climate Change", and "Extreme Weather" and combined them with the keywords "Delta Resilience". Next, the results were read carefully and the articles which were not suitable for delta region or irrelevant with the topic were discarded. This selection process produced 70 journal papers.

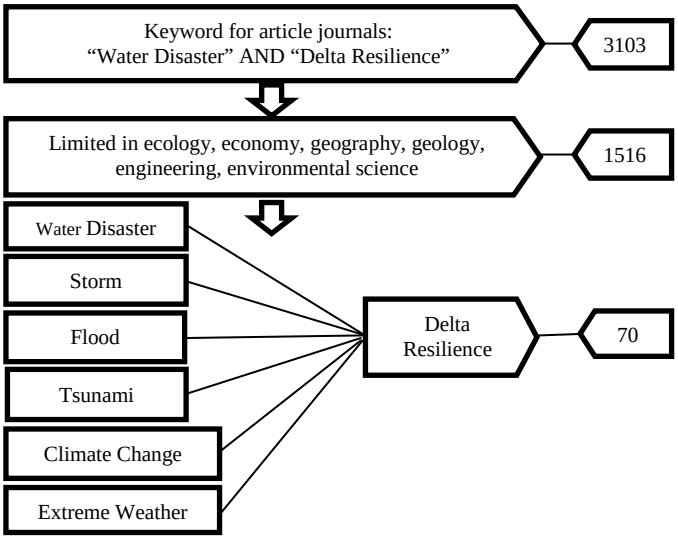

Figure 1 Sorting articles of water disaster and resilience in delta city

However, sorting on journal papers are not sufficiently enough. We added some other documents from international organizations, NGOs, or private sectors such as IPCC, World Bank, Delta alliance, JICA, etc. related with this topic. Generally, they conducted the worldwide scope survey and measuring with the same criteria. Furthermore, we tried to find the thesis book also which is discussed the resilience in the specific delta. In total with combining all the documents, this study used 83 documents for creating a review paper with detail 70 journal papers, 10 NGO or company documents, 3

books/theses. Even though, we acknowledge the limitation of the result from the selected papers, those articles can be representative for this study. Finally, nexus understanding of delta resilience against water disaster from the current research trend is covered by these documents.

IV. Result and Discussion

Among of 83 articles related to resilience against water-related disaster, we distributed the number of papers based on the region which has already studied by researcher. The distribution of papers is mainly concentrated in the Asian and European regions with the amount of 50 papers and 29 papers respectively. Meanwhile, North America and Africa are intermediate with numbers 21 and 17. There were few of researches in the Oceanian and South American, only 11 and 12 respectively

Though the number of research in Asian region is abundant, mostly are focusing on Vietnam and Bangladesh. The position of Bangladesh was in the downstream of Ganges-Brahmaputra river with 100 million people live there [7]. Similar condition occurred in Mekong delta, Vietnam, which had contributed to the agriculture crop production by almost 70% and, at the same time, constitutes the most vulnerable area to flood caused by typhoon and climate change. Similar to the Asian region, the research in European region was mostly concerned on the Netherlands, especially Rotterdam city [55]. It typifies the well advanced in urban resilience planning regarding the hard structure (dyke) and soft infrastructure (social and community awareness [59]. also the policy, the Delta Program, which was introduced by Dutch Government to guarantee safety in the present and future [49].

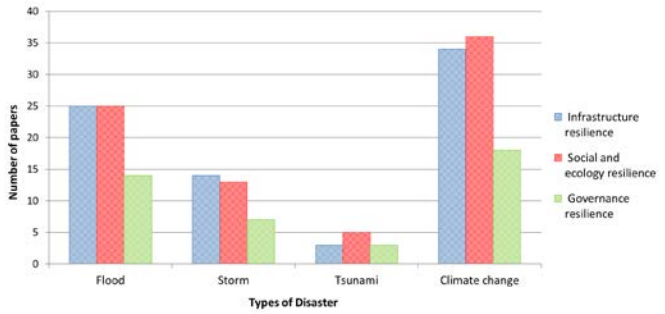

Figure 2 Papers amount of water-disasters and types of resilience

However, the types of water-related disasters in the literature recently do not distribute smoothly. As represented in figure 2, the number of research on floods and climate change dominated than the others. Regarding to resilience type, not so many papers focused on policy against disaster. However, recently the number of research on social-ecology resilience is almost equal to the number of research on infrastructure resilience. This trend brings proper development of resilience by combining social and infrastructure solution.

More than 53 papers in the last 20 years still focused on the natural science and technology capabilities to measure the ability against disasters. Comparing with method in social and policy, the number only 18 and 17 respectively. Nevertheless, there has been an increasing trend of integrating science and society today due to the rising interest in comprehensive study. For instance, the study by Renaud et al. 2013 [48] mentioned that human activities could increase the risk of reaching tipping points of the environmental change in Rhine-Meuse delta in European regions and in Ganges River in India because of the constructions of drainage systems and excessive use of groundwater for fresh water.

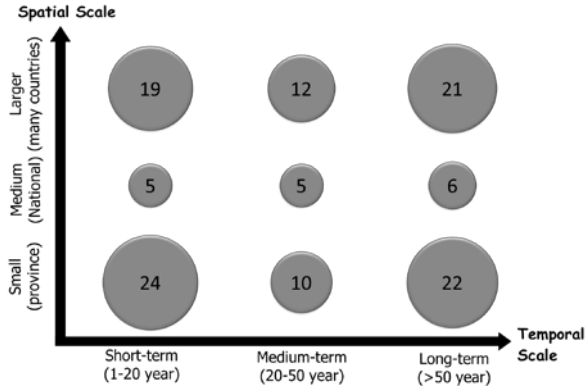

Figure 3 Study methods in terms of spatial and temporal scale

Moreover, in terms of time and spatial scale, most studies are conducted within a short-term period and small region. The temporal scale is defined as the duration of disaster or resilience in the articles. In y-axis, we divided the spatial scale into three categories, namely small for specific province or district, medium for national scope, and larger ones for the papers covering many countries. For example, the study of adapting planning of climate change in four deltas [28] is categorized as a larger scale. As shown in figure 3, many studies were conducted in a short-term period and in small area. Though, the number of studies conducted in a long-term period covering small and larger area is almost the same with the short-term ones, the condition is different once we are looking at the number of studies conducted in a national scale or medium-term period. The number of articles which have criticized the resilience delta in national scope are limited.

A. Recent achievement and reviewing current methodology

The result has indicated that the flood that frequently occurred in the Asia region created an opportunity for the researchers to conduct the study. It is evident that the highest delta regions population growth is located in Asia especially in South Asia (Bangladesh, India, and Pakistan) [40]. Less developed region and dense population compose the fragile circumstances against water-disaster. For instances, several flood incidents in Dhaka, Bangladesh in 1988, 1998, and 2004 have caused huge damaged [30]. In the early 20th century, China experienced the deadliest natural disaster in Yangzi-Huai River because of the single flood incident [23]. Even now, in the Pearl River Basin, the flood risk is increasing due to the booming of socio-economy and growing population [66]

The cutting edge in Geographic Information System (GIS) using satellite images is enhancing the global scope of the study, for example, the subsidence cities and increasing sea level because of climate change [57]. Merging with IPCC fifth Assessment Report (AR5) in 2014, the prediction of the inundation caused by climate change mainly based on the RCP

projection in 2100. In terms of the study based on time scale, IPCC provides the study that can be used as a global standard parameter to project the carbon concentration in the future. For example, the studies on the inundation in Nile River, Egypt [8], Mekong Delta, Vietnam [51,53,58], Beas River Basin, India [54] or the assessment of the mangrove vulnerability in Fiji [16] mentioned and used the results from IPCC documents to analyse and forecast disasters. Not only IPCC, but some of the documents from World Bank related to population or GDP in every country also contribute to the assessment of the vulnerability index in delta cities [62]. The global view documents and geospatial analysis development have assisted the researcher to broaden the scope in the spatial and time scale.

Drawing a conclusion with comprehensive methods has becoming popular recently. Using technology with social impact are required to get the holistic approach about resilience toward disaster. Vulnerability is not just registered by exposure to hazard but also by how people deal with the system in experiencing the hazard [9]. Furthermore, the human activities have had an interior growing risk of coastal flooding, wetland loss, and subsidence [57]. Scholars realized that the connection between social-economy and climate change factors should be accounted for in order to get more reliable outcomes. The resilience method is shifting from infrastructure resilience to addressing the social community for estimating the susceptibility of delta cities. Many researchers realized that merely considering hard structure is not enough, and ones should also involve the human activities and community resilience in the area as vital aspects to fight against disasters. If the residents still have the normalcy bias towards disasters, the exposure degree to such disasters is still high regardless of how advanced the infrastructure against the disaster is built. The study of 2004 Indian Ocean Tsunami post-disaster revealed that building infrastructure and developing cultural awareness towards disasters can increase the resilience [56]

The importance of mutual assistance among delta cities around the world has been realized. The establishment of C40 Cities Climate Leadership Group in 2005 proves the benefit of collaboration. This group connects 90 world greatest cities, two-thirds of which are located in coastal delta regions [10]. Another institution, Deltares, has developed a method for assessing flood risk of the cities worldwide based on open data. They released the index to measure the vulnerability of 38 cities against flood disaster. Creating a global parameter to measure the capability of the city is required to evaluate delta city in the same manner [62]

B. Missing Gaps

There are missing gaps in recent publications, especially in Oceanian. Oceania will experience directly the impact from rising sea water level because consists of small islands and are prone to storm disaster. Because of the GDP and population are not as high and dense as in Asian countries, it makes lack of research. Omitting this region from vulnerability assessment will create colossal shock later on.

The number of papers on a national scale and within a medium-term period is limited. Mostly the research scope only emphasizes on one particular place. Improving and evaluating the national resilience outlook in the delta regions might give an insight to the residents to increase their awareness and sensibility against disaster. Medium-term scale should also be considered while creating plan in the society because both environment and climate are dynamic. Merely focusing on long-term plan is too risky.

The larger number of articles on Asia does not mean that all the places in Asia have been covered. Many research papers only concentrate on one country for study location. For example, in Asia and Europe, the studies mostly focus on Bangladesh/Vietnam and the Netherlands respectively, accounting for more than ten papers. Though those places are prone to disasters, conducting some studies equally on other regions is essential to get the better outcome.

The current literature has yet to encompass the entire delta cities in the world. The big delta covers 75 places based on the Department of Geology & Geophysics at Louisiana State University data, the research recently just discussed 70% of the total delta locations. Whereas, the global climate change should be anticipated as soon as possible in whole deltas. The academic contributions are necessary for stakeholders as a reference to establish resilience.

Another missing gap in this study is the absence of paper on the tsunami resilience assessment. Most tsunami evaluations are only based on historical data such as from Indian Ocean tsunami 2004 or Japan tsunami 2011. Tsunami regularly causes enormous impact and traumatic memory to the society. Giving an account of tsunami will be useful to measure the vulnerability or resilience city.

C. The Future Path of Research Development

There are several future paths for academia to develop research related with disaster resilience in delta cities:

1. Integrate the policy sector to reassess the delta vulnerability index. The policy from the city or national government is crucial to fortify the people reliance which can decrease the vulnerability percentage. The index should also be covered for all the water-related disaster, not only flood.

2. Conduct the research about tsunami prediction in worldwide scope and apply profiling the risk assessment for a tsunami in delta city. Adjusting the validity of tsunami prediction is quite tricky since the absence of technology to forecast the movement of the plate. However, tsunami devastates the city rapidly and takes a long time for recovery. Thus, creating initial research for worldwide tsunami forecast will be a breakthrough.

3. Use the new scenario framework for climate change research with shared socioeconomic pathways (SSP) and share climate policy assumption (SPA) [41,59]. Integrate SSP, SPA, and RCP might complete all aspects of science, socio-economic, and policy to stipulate the resilience actions against water-related disasters.

4. Investigate some other deltas, such as Limpopo in Mozambique, Volta in Ghana, or Mahakam in Indonesia. These places are decided by referring the risk trends for delta

worldwide which was published by Tessler et al. (2015) [60] on Science. Mostly in Africa region, many big delta cities have not been addressed in scientific analysis report by the researchers. For instance, in African Development Bank held the African resilience forum for addressing fragility and building resilience for African country (https://www.afdb.org). Providing scientific paper is important to enrich the information scientifically. Moreover, the countries in the Oceanian region are needed to calculate the vulnerable index to prevent lousy havoc in the future due to sea level rise.

V. CONCLUSION

Population growth in delta regions boosts the risk toward water-related disasters. Resilience against hazard is introduced in three ways, infrastructure resilience, social and ecological resilience, and governance resilience. Reviewing papers gives the result that latest studies mostly concentrates in Asian and European regions especially on flood and climate change. Current trend methods are shifting from pure science to integrating social aspect and the scope becoming broadens due to the cutting edge of geospatial technology. IPCC documents with RCP scenario influence the study on climate change issue. However, more studies in tsunami resilience, introducing a standard parameter, and enhancing research in other deltas are highly recommended to fill the gaps in this study.

We acknowledge the limitation because the method only covers the keywords in abstract section. It is possible that there are some studies related to this topic that does not mention the words “resilience” and “disaster” in their abstracts. The water-related disasters that we discussed do not include the drought, landslide or avalanche, and water-borne disease. These disasters also have strong relations with climate change and human factors. Nevertheless, we believe that the information in this study is sufficiently enough to review the current situation and to give an insight for researchers to conduct further study.

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