INTERNATIONAL WORKSHOP

NATURAL RESOURCES AND RISK MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE

Organised by
Hanoi University of Natural Resources and Environment (HUNRE)

With the support and collaboration of:
National Foundation for Science and Technology Development (NAFOSTED)
Ibaraki University, Japan
Yonsei University, South Korea

PUBLISHING HOUSE FOR SCIENCE AND TECHNOLOGY

AN INOVATIVE APPROACH FOR FLOOD RISK ASSESSMENT IN THE CONTEXT OF CLIMATE CHANGE CONDITIONS - THE CASE OF THE VU GIA THU BON RIVER BASIN

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Abstract

Assess a quali-quantitative riverine flooding risk under present and future conditions analysing the impacts of climate change together with the variation of the exposure and vulnerability in the studied area. The risk is a combination of hazard, vulnerability and exposure. In the qualitative approach, the risk is obtained from the combination of hazard and damage (d=vxe) where the last one is obtained combining, through a multi-criteria decision analysis approach (mcda), 32 qualitative indicators. In the quantitative approach, the risk is obtained from functions that describe the damage correlated to the water depth. Climate change modifies the frequency and magnitude of the hazard. Under the present and future conditions (2030 and 2050 horizons), qualitative approach is applied to calculate the population exposed to the flood risk (intangible risk) while, quantitative approach is applied to quantify the annual expected economic loss (tangible risk). The comparison of the results at medium and long terms, empathizes the effects of climate change at 2050 while, at 2030 flooding risk is influenced mainly by exposure and vulnerability.

Keywords: Hazard; Vulnerability; Exposure; Damage; Tangible risk; Intangible risk.

1. Introduction

The statistical analysis of the world-wide disasters shows an exponential increase over time of the disasters for flooding (Figure 1).

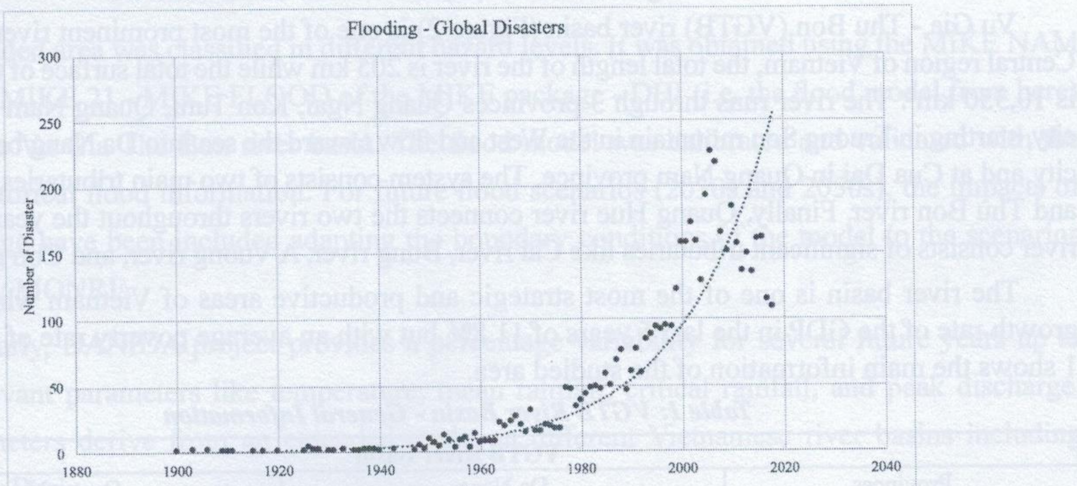

Figure 1: Number of disasters for flooding from 1900 to 2019 (Ref. EMDAT (2019): OFDA/CRED International Disaster Database, Université catholique de Louvain - Brussels - Belgium)

Many authors consider climate change as the main cause of increase of disasters due to the higher value of the extreme and dangerous natural events frequency. However, the scientific and academic world cannot give an univocal answer to the question: "*What is the incidence of climate change factor on the increase of catastrophes?*".

To answer this question, many authors have tried to convines the other factors that can make worsen natural disaster risk such as growth in polulation and the amount of capital at risk (Bouwer, 2011; (Delley M, 2005), encroachment the floodplain with rapid economic development practices (Wheater, 2009); In these situations, risk is considered as the combination of hazard and vulnerability ((S.L, 1996)

Starting from the belief that climatic change effects are underway and it is wrong, simplified and pretentious to assign to them the only reason of the disasters increase, this work focus on the other factors that contribute to generate a disaster and how these are related to the climatic changes. It will not analyze whether climate change effects are natural or anthropic (hockey stick dispute).

The case study is Vu Gia Thu Bon river basin, one of the most flood-prone region in Vietnam. The potential damage for riverine flooding "Risk for Riverine Flooding" at the present conditions, at mid-term conditions (year 2030) and at long-term conditions (year 2050) will be analyzed for this area.

Flooding risk scenarios will be compared to identify the most relevant parameters that contribute to the disaster risk assessment, in addition to the climatic changes.

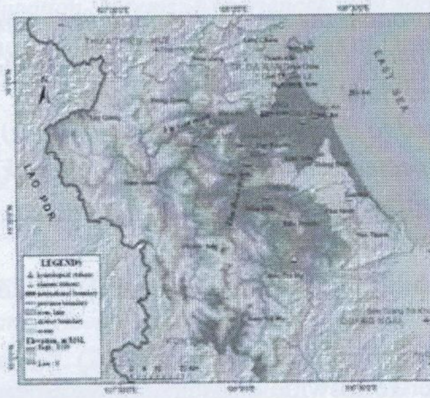

Figure 2: Vu Gia - Thu Bon river basin

Vu Gia - Thu Bon (VGTB) river basin (Figure 2) is one of the most prominent river basins in the Central region of Vietnam, the total length of the river is 205 km while the total surface of the river basin is 10,350 km^2. The river runs through 3 provinces Quang Ngai, Kon Tum, Quang Nam and Da Nang city, starting in Truong Son mountain in the West and flow toward the sea into Da Nang bay in Da Nang city and at Cua Dai in Quang Nam province. The system consists of two main tributaries: Vu Gia river and Thu Bon river. Finally, Quang Hue river connects the two rivers throughout the year. The Vu Gia river consists of significant tributaries like Cai river, Bung river, A Vuong river, and Con river.

The river basin is one of the most strategic and productive areas of Vietnam whit an average growth rate of the GDP in the last 5 years of 11.8% but with an average poverty rate of 66.8%. Table 1 shows the main information of the studied area.

Table 1: VGTB River Basin - General Information

	VGTB River Basin		
Provinces	Da Nang		Quang Nam
Main Cities	Da Nang	Hoi An	Tam Ky
Population	1.9 millions of inhabitants (year 2017)		
Number of Communes/Wards	254 + 56		
Main Economic Activities	Agriculture (25%)	Industry (37%)	Services (38%)
GDP (BVND) (year 2017)	23.4 (Da Nang)	56.8 (Quang Nam)	80.2 (VGTB)

The main damages and disasters in the river basin are caused by tropical storms, flooding, drought, saline intrusion and landslide, of these, the most dangerous natural phenomena are storms and floods that causing the most significant damages in terms of human lives and property. Storms occur from May to July and October to November. Storms are typically associated with heavy rain leading to flooding. According to the provincial reports, from 1997 to 2009, the disasters due to these natural events caused 765 deaths, 63 missing persons and 2,403 injuries, with total property damage of over 18,000 BVND in Quang Nam and Da Nang city.

2. Approach and methodology

2.1. Risk assessment methodology

The potential damage generated by riverine flooding was obtained studying the flood risk in three different time horizons: *present, 2030s and 2050s*. The methodology foresees to obtain the Risk Assessment as a combination of three fundamental elements: Hazard (H), Vulnerability (V) and Exposure (E), as shown in Figure 3.

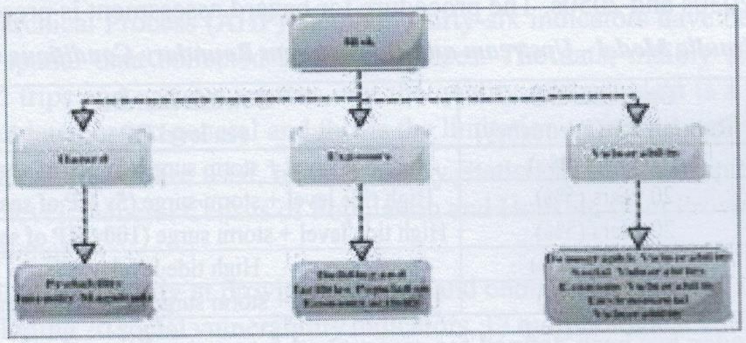

Figure 2: Risk assessment concept

$$R = f(H,V,E)$$

The flooded area was classified in different hazard levels. It was obtained using the MIKE NAM - MIKE 11 - MIKE 21 - MIKE FLOOD of the MIKE package - DHI (i.e. the flood model from here) set up for the Vu Gia Thu Bon river basin. The flood model was calibrated and validated with the available historical flood information. For future flood scenarios (2030s and 2050s), the impacts of climate change have been included adapting the boundary conditions of the model to the scenarios developed by MONRE.

Particularly, DANIDA project provides a percentage variability for several future years up to 2100 of relevant parameters like temperature, mean rainfall, critical rainfall, and peak discharge. These parameters derive from an extended study on different Vietnamese river basins including VGTB River Basin.

The results show that the sea levels will increase 12 - 13 cm in 2030 and 23 - 24 cm in 2050 along the estuaries in Central Vietnam.

The temperature is expected to increase by 0.7 - 0.9°C in 2030 and nearly by 2 °C in 2050 (Figure 4), while rainfall will increase significantly, especially the maximum daily rain will increase by more than 20% in 2030s, while in 2050s by nearly more than 30% (Figure 5).

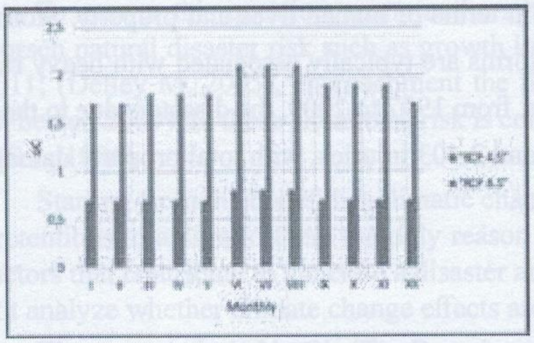

Figure 3: VGTB - Temperature Projection

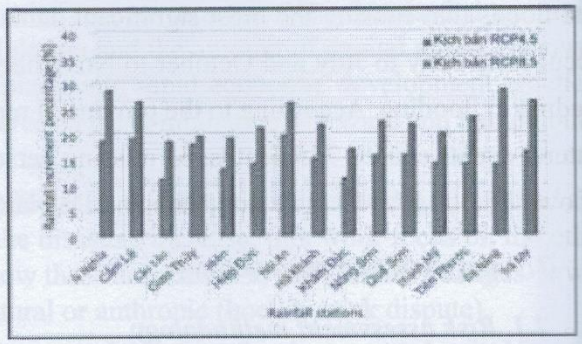

Figure 4: VGTB River Basin - Rainfall change at meteorological stations

For each scenario five combinations of upstream and downstream Boundary Conditions (BC) have been identified (Table 2). The hydraulic model, calibrated using the historic flooding data of 2007 and validate using the historic flooding data of 2009, was used to define water depth for the present condition, 2030s and 2050s. The procedure for hazard assessment is presented in Figure 6.

Table 2. Hydraulic Model - Upstream and Downstream Boundary Conditions Combination

HM	Upstream BC Rainfall RP (Frequency)	Downstream BC sea level RP
1	100 years (1%)	High tide level + storm surge (**5y RP of sea level)**
2A	20 years (5%)	High tide level + storm surge (**5y RP of sea level)**
2B	20 years (5%)	High tide level + storm surge (**100y RP of sea level)**
3	10 years (10%)	High tide level
4	50 years (2%)	High tide level + storm surge (**20y RP of sea level)**

The exposure index has been defined for present and future conditions in two steps: (1) land use types were grouped into homogeneous class of importance; (2) each class of goods and properties was assigned a value of exposure indicator "e_i".

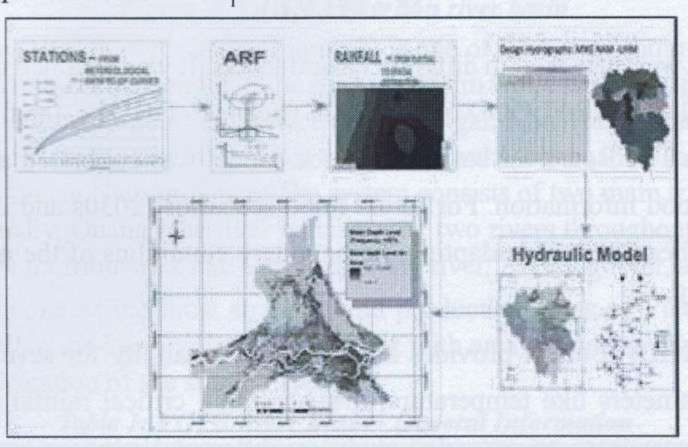

Figure 5: Flow chart - Hazard Assessment

From the Land Use map (MONRE 2015) 65 land use types have been identified. For future conditions, based on development plans and information collected at the national, provincial and local levels, land use changes in the future (2030 and 2050 scenarios) were estimated.

The results, normalized respect the maximum exposure index, have been presented in the exposure maps under present and future conditions. The procedure for exposure assessment is presented in Figure 7.

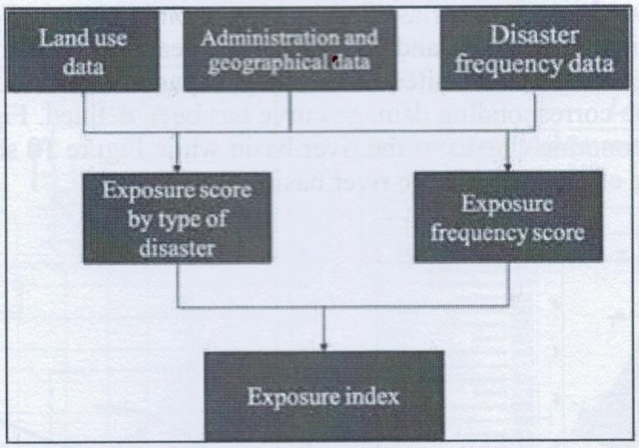

Figure 6: Flow chart Exposure Assessment

The vulnerability index is the result of a multi-criteria decision analysis (MCDA). Three categories of vulnerability have been assessed: goods, social, and morphological. The MCDA uses the Analytical Hierarchical Process (AHP) method. Thirty-six indicators have been developed from statistics data and spatial data collected in the provinces. The data, mainly statistical data, were collected from field trips and various sources, but the quality of these data is a big problem: many data are missing, outdated or too general and this is the limitation to the vulnerability analysis.

Three main data sources were used, namely Yearly Statistical Books from Sub- Department of Statistics at district level, General Census of Population and Housing from Provincial Department of Statistics and digital maps.

After testing data availability at province, district and communal level, 36 actualized indicators were estimated, including 20 social vulnerability indicators, 13 morphological vulnerability indicators, 3 goods vulnerability indicators. Almost all indicators are updated to 2015. All morphological vulnerability indicators were estimated from digital map using spatial analysis tools. Many data were available only at district level and not down scalable to commune level, so, for this reason in many cases the communes had the same value of these vulnerability indicators. Figure 8 describes how these indicators have been combined while Pairwise method was used for their combination.

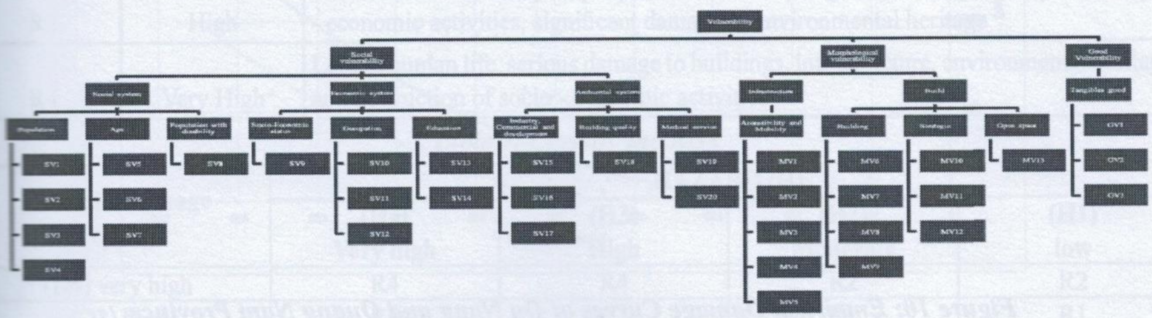

Figure 7: Flow chart Vulnerability Assessment

The limitation of the data used to define exposure and vulnerability permits to assess a qualitative risk only, not being enough and of the right quality for the economic quantification of the risk. To overcome this limitation, the combination of exposure and vulnerability was assessed, also, using the damages curves that define the correlation between the extent of hazard and damage level.

Land use of the river basin was reclassified in 11 economic classes. For each economic class, using the global flood disaster database and the results of researches on damage curves realized and applied in other countries such as the United States, Italy, Myanmar, Sri Lanka, Red River Basin and Mekong River Basin, the corresponding damage curve has been defined. Figure 9 describes, for the present condition, the economic classes of the river basin while Figure 10 shows the damage curves of some of the economic classes used in the river basin.

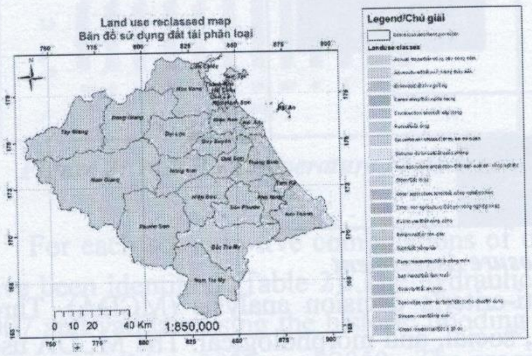

Figure 8: Map of Economic classes - Present Scenario

Figure 9: Damage Curves for Public Buildings, Fruit Crops Vegetables, Industrial and Aquiculture Economic Classes

Depth-damage functions should be applied only where real data can be collected, although the extrapolation to similar areas is a common practice accepted by the literature (Apel et al., 2006). However, the extrapolated functions must be calibrated and validated for the studied area.

From the provincial reports, yearbooks and other statistical information the relationship between the water level (WL) of Hoi An and Cam Le stations and the damages (D) registered from 1983 to 2017 on the Da Nang and Quang Nam provinces have been built (Figure 11).

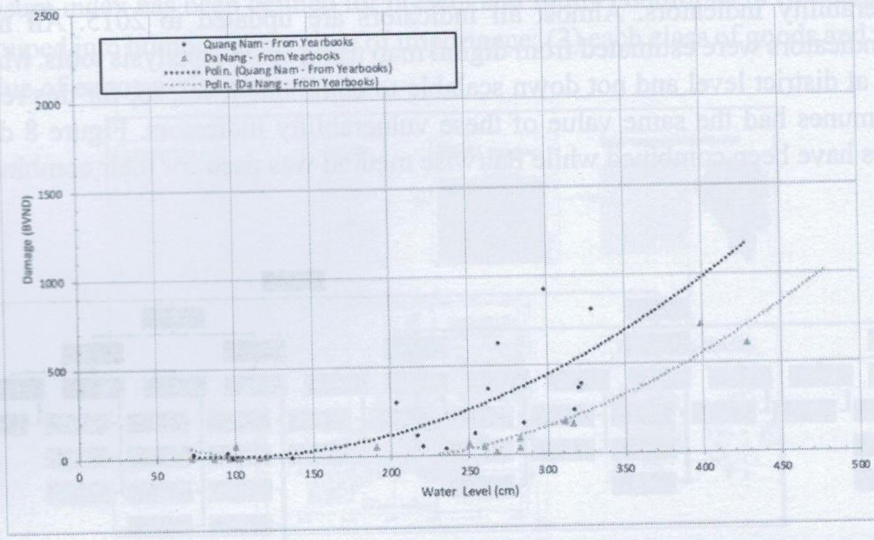

Figure 10: Empirical Damage Curves of Da Nang and Quang Nam Province

The results of Figure 8 have been correlated to the simulated water level (WL) of Hoi An and Cam Le stations, with the objective to obtain the damage curves associated to the frequency of 1%, 2%, 5% and 10%. Figure 12 shows an example of the procedure applied for a frequency of 10% while Tab. 3 resumes the results obtained for each frequency and Figure 13 shows the law of correlation between damage and return period of the river basin.

The validation of the potential damages (economic losses) of the river basin was obtained comparing the result obtained using the damage functions with the results described in Tab. 3 and

Figure 13.

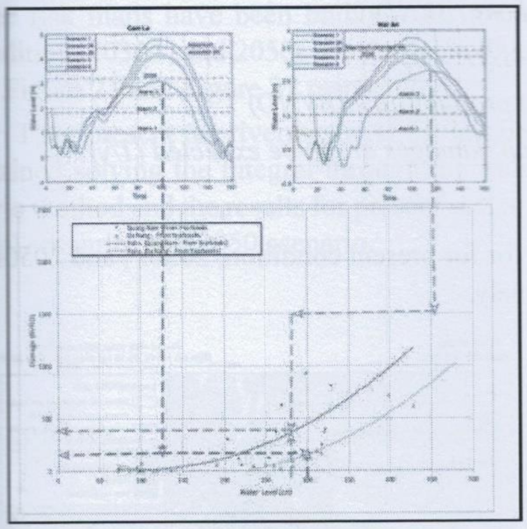

Figure 11: Example of Historical Damage associated with the Flood Frequency - of Da Nang and Quang Nam

Table 3. VGTB River Basin - Estimated Economic Loss

Frequency	Estimation Economic Loss	Return Period (years)
10%	549	10
5%	924	20
2%	1418	50
1%	1793	100

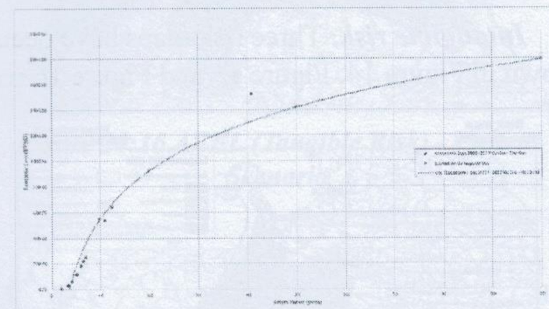

Figure 12: VGTB - Law of correlation between damage and return period

Two different types of risk were assessed:

Intangible risk: achieved combining the flooding Hazard (H) with the Damage (D = VxE), last one obtained using the Vulnerability and Exposure indexes.

Tangible risk: achieved from damage functions that, for specific classes of land use, relating water depth with the Damage.

Intangible risk was classified in 4 qualitative levels in Table 4 by mean of Table 5

Table 4. Risk level

Index	Risk Level	Qualitative Classification
R1	Low	Social, economic and environmental damages are marginal
R2	Moderate	Minor damage to buildings, infrastructure, and environmental heritage without impairing the individual's safety and the functionality of buildings
R3	High	Problems for the safety of people, functional damage to buildings, disruption of socio - economic activities, significant damage to environmental heritage
R4	Very High	Loss of human life, serious damage to buildings, infrastructure, environmental heritage, and destruction of socio - economic activities

Table 5. Classify the Risk

Potential damage (E x V)	HAZARD (H)			
	(H4) Very high	(H3) High	(H2) Moderate	(H1) low
(D4) very high	R4	R4	R2	R2
(D3) high	R3	R3	R2	R1
(D2) moderate	R2	R2	R1	R1
(D1) Low	R1	R1	R1	R1

Tangible risk: achieved from damage functions that, for specific classes of land use, relating water depth with the Damage. It measures the Annual Expected Economic Loss (AEEL) obtained as combination of the potential damages with different probability of occurrence

$$\mathrm{AEEL} = \int_0^{\mathrm{pmax}} \mathrm{D(p)dp}$$

Where

$AEEL$ = *Annual Expected Economic Loss (BVND/y)*

P = *The flood exceedance probability (1/y)*

$D(p)$ = *The Flood Damage at different probabilities (BVND)*

p_{max} = *The highest probability for which damages are to be expected (1/y)*

3. Results and discussions

Intangible risk: Three risk maps have been built for for present condition, 2030s , and 2050s are shown in Figure 14, Figure 15 and Figure 16 respectively.

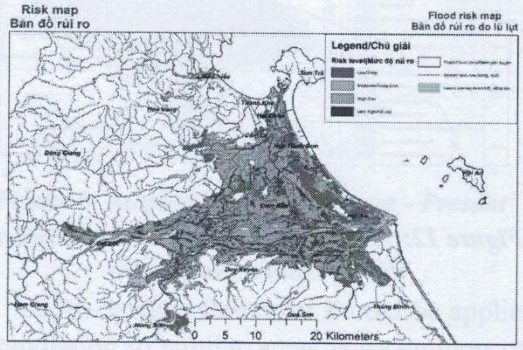

Figure 13: Flood Risk Map (Intangible Risk) - Present Scenario

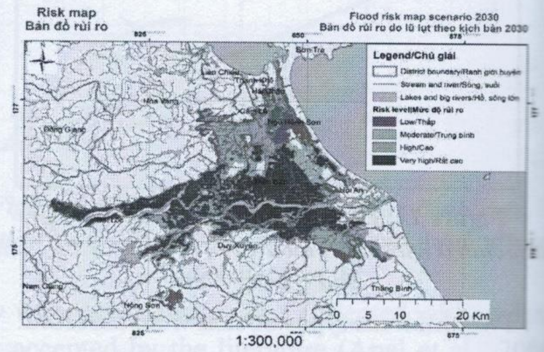

Figure 14: Flood Risk Map (Intangible Risk) - 2030 Scenario

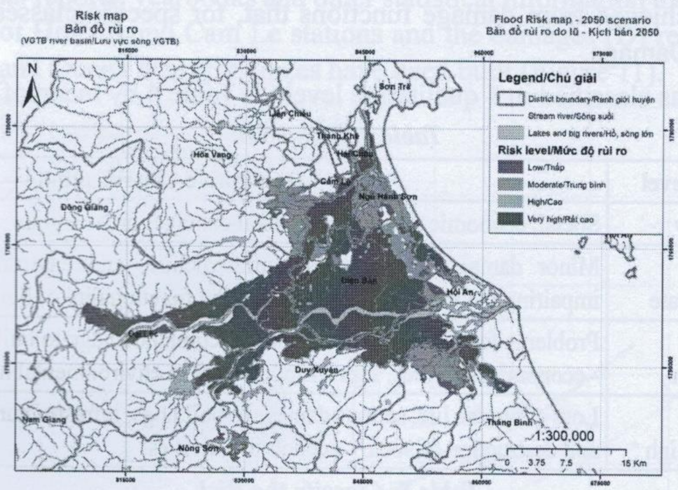

Figure 15: Flood Risk Map (Intangible Risk) - 2050 Scenario

The result shows the increasing of risk level through time horizon from present to 2030s and 2050s. This is due to a change of the vulnerability index (Figure 17), while the contributions of exposure (Figure 18) and climatic changes (Figure 19) are limited to the scenario 2050.

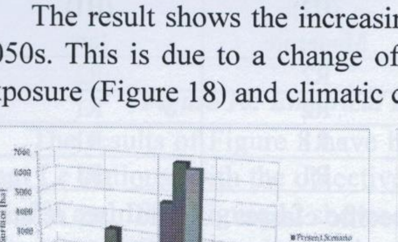

Figure 17: Vulnerability Index

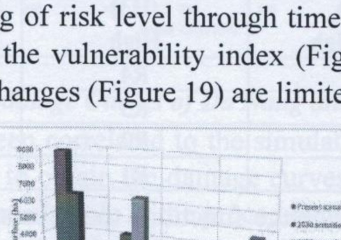

Figure 18: Exposure Index

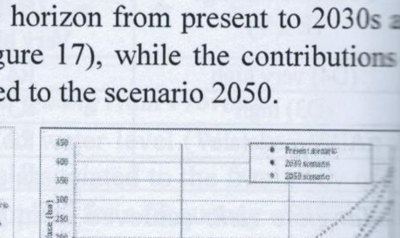

Figure 19: Hazard Level

Tangible risk: Similar to Intangible risk, three risk maps have been built for for present condition, 2030s , and 2050s are shown in Figure 20, Figure 21 and Figure 22 respectively.

They present the river basin AEEL has been obtained solving the integral through the Monte Carlo method and the results for present scenario, 2030 scenario, and 2050 scenario.

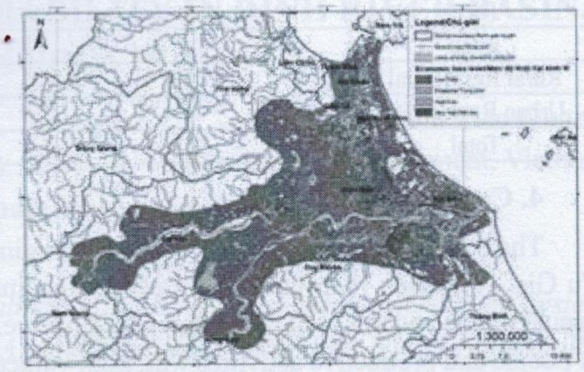

Figure 20:16 AEEL (Tangible Risk) - Present Scenario

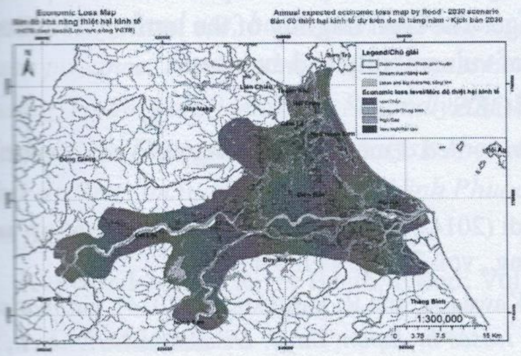

Figure 21:17 AEEL (Tangible Risk) - 2030 Scenario

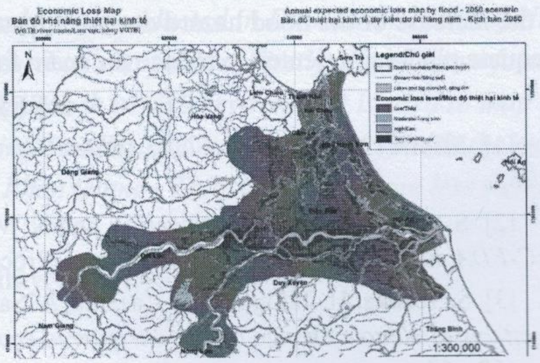

Figure 22: AEEL (Tangible Risk) - 2050 Scenario

The comparison between the economic loss estimated (Table 3) and the potential economic loss calculated using the damage function pointed out, in some cases, a consistent variation (Tab. 6).

Table 6. Comparation between Economic Loss Estimated and Calculated

Frequency	Return Period (years)	Economic Loss Estimated (BVND)	Economic Loss Calculated (BVND)	Variation (%)
10%	10	549	731	24.9%
5%	20	924	923	-0.1%
2%	50	1418	1108	-28.0%
1%	100	1793	1222	-46.7%

The reasons must be found in the limitation of the historic damage information and in the missing of a standard procedure to collect, systematize and store these data.

The Tangible risk or Annual Expected Economic Loss (AEEL) for present and future scenarios (Table 7) confirm this result and shows an increase of approximately 89% from the current scenario to 2030 and of 101% from the present scenario to 2050.

Table 7. AEEL under Present and Future Conditions

Economic Classes	Annual Expected Economic Loss Estimated (Billion VND)		
	Present condition	2030	2050
Aquaculture	1	1	1
Commercial	22	31	32
Fruit tree vegetable	41	61	11
Green Vegetable	27	34	0
Industrial	10	160	173
Public Building	130	188	193

Rice	7	9	9
Road	25	30	31
Rural Residential	88	100	203
Urban Residential	4	58	63
Total	355	672	716

4. Conclusions

The most significant riverine floods are originating from storm surge and heavy rains because the Vu Gia - Thu Bon river basin has steep mountains and relatively short rivers. The delta suffers from annual floods and this area is ecologically sensitive. The fragility of this area and the high concentration of people and productive activities whit high vulnerability are, in the short term (2019 - 2030), the main reason for a potential disaster due to the riverine flooding. The effects of climate change are incident in the long term (2019 - 2050) when the areas classified with high vulnerability and exposure are compounded by the increase of the flood hazard due to climate change. The high fragility of the territory requires an adequate planning oriented to reduce the main factors of vulnerability and exposure.

REFERENCES

[1]. FEMA (2018). *Hazus Flood Model User Guidance*. Fed. Emerg. Manag. Agency, no. August, pp. 1 - 263.

[2]. S. A. Mohammadi, M. Nazariha, and N. Mehrdadi (2014). *Flood damage estimate (quantity), using HEC-FDA model. Case study: The Neka river*. Procedia Eng., vol. 70, pp. 1173 - 1182.

[3]. S. Tezuka, H. Takiguchi, S. Kazama, A. Sato, S. Kawagoe, and R. Sarukkalige (2014). *Estimation of the effects of climate change on flood-triggered economic losses in Japan. Int. J. Disaster Risk Reduct.*, vol. 9, pp. 58 - 67.

[4]. M. Allaire (2018). *Socio-economic impacts of flooding: A review of the empirical literature*. Water Secur., vol. 3, no. October, pp. 18 - 26.

[5]. R. Albano, A. Sole, J. Adamowski, A. Perrone, and A. Inam (2018). *Using FloodRisk GIS freeware for uncertainty analysis of direct economic flood damages in Italy. Int. J. Appl. Earth Obs. Geoinf.*, vol. 73, no. February, pp. 220 - 229.

[6]. S. Win, W. W. Zin, A. Kawasaki, and Z. M. L. T. San (2018). *Establishment of flood damage function models: A case study in the Bago River Basin, Myanmar*. Int. J. Disaster Risk Reduct., vol. 28, no. November 2017, pp. 688 - 700.

[7]. Mekong River Commission (2009). *Flood Protection Criteria for the Mekong Delta, Vietnam*. Flood Manag. Mitig. Program. Compon. 2 Struct. Meas. Flood Proofing Low. Mekong Basin, vol. 6, no. December, pp. 1 - 88.

[[8]. M. Pregnolato, A. Ford, S. M. Wilkinson, and R. J. Dawson (2017). *The impact of flooding on road transport: A depth-disruption function*. Transp. Res. Part D Transp. Environ., vol. 55, pp. 67 - 81.

[9]. J. Koponen, C. Paiboonvorachat, and A. Munoz (2018). *The Council Study: The Study on the Sustainable Management and Development of the Mekong River Basin, including Impacts of Mainstream Hydropower Projects. Thematic Report on Impacts of Non-Irrigated Agriculture Development and General Trends in Major Land*. no. January, p. 129.

[10]. Delley M, C. R.-L. (2005). *Natural Disaster hotspots: a global risk analysis*. Washington, DC: International Bank for Reconstruction and Development /The World Bank and Columbia University.

[11]. L, C. (1996). *Vulnerability to environmental hazards*. Progress in Human Geography , 20(4) 529-539.

[12]. Wheater, H. a. (2009). *Land use, water management and future flood risk*. Land Use Policy. [illegible] - S264.