FLOOD HAZARD IMPACT ANALYSIS IN THE DOWNSTREAM OF VU GIA –THU BON RIVER SYSTEM, QUANG NAM PROVINCE, CENTRAL VIETNAM

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Central Vietnam is highly vulnerable to flood disasters. Due to the trend of increased weather extremes, the vulnerability keeps to be further exacerbated causing high risk of casualties and damages. Also, the complication of the physical processes and socio-economic issues in this area is great challenge for practitioners and communities to have full understand flood pattern and associated risk. Therefore, this study selected Vu Gia – Thu Bon river basin, one of the largest system in Vietnam, to apply an integrated approach, including 1D flood simulation (using MIKE NAM and MIKE-11), Arc-GIS based mapping and conceptual DPSIR (Driver-Pressure-State-Impact-Response) framework to develop inundation maps of 10%, 5% and 1% frequencies and potential impacts in the study area. These results are considered as primary information to tailor effective flood disaster management plan in the long run.

Key Words: Flood hazard, inundation mapping, DPSIR framework, Vu Gia Thu Bon basin.

1. INTRODUCTION

Quang Nam Province located in Central Vietnam is known as highly disaster-prone region. Having the basin of Vu Gia -Thu Bon (VG-TB) river system, one of the largest river systems in Vietnam, every year, the province has to confront with various natural hazards, mainly water-related, such as typhoon, storm surge, flooding, drought, landslide and erosion. Although province undergoes rapid economic development but this area is still poor and highly vulnerable. On the other hand, the low-lying area in Quang Nam Province is characterized by far complicated hydro-morphological process which results in frequent catastrophic water related disasters, especially flooding. Coping with flooding is always top priority of Viet Nam Government and local community, there is, however, still gap due to lack of an integrated approach that can link scientific knowledge of the source and the pattern of flooding and flood hazard management practice and as a result, the associated consequences continue to raise¹⁾. In addition, according to IPCC 4th Assessment Report (2007) and Ministry of Environment and Natural Resources (MONRE) of Vietnam, the country is projected to be seriously

affected by global warming which will potentially result in increased disaster risk for coastal community²⁾. In line with the outcomes of these reports, the analysis of hydro-meteorological records revealed rather visible climate change trend as well as increased flood frequency, severity and uncertainty in the region during last decades.

Nevertheless, it is important to emphasize that apart from negative consequences, from the history, it is well known that abundant water resource and annual flooding also bring rich rice field and many livelihood for local people. Even now, around 70-80% of population living in river delta and coastal zone of Quang Nam Province earns their living by agriculture, aquaculture and exploiting natural resources. Therefore, building up the local resilience or so call “living with the flood” strategy is vital for sustainable development. To achieve this goal, following questions must be addressed:

- Which flood (i.e. magnitude) will happen in the future?
- What are possible consequences and impacts?
- How possible and likely extension of these consequences and impacts?
- How can these consequences and impacts be mitigated effectively?

This paper discusses the application of combination of statistical, mathematical modeling, ArcGIS software and conceptual cause-effect approach in order to simulate the flood pattern in the study area and based on that, to develop the inundation maps and propose relevant mitigation measures. The outcome of the study is synthetic understanding of flood extension with the frequencies 10%, 5% and 1% and corresponding inundation maps. Then, the potential consequences caused by these flood events are analysed and mitigation measures are tailor-made to be applicable and effective for the study area. These outcomes would help provide decision makers and local community useful information to enhance their resilience living with the flood.

2. METHODOLOGY

Flood inundation simulation: There are two steps to simulate the flood inundation in study area:

- First step: Modeling package of MIKE NAM and MIKE11 is used to simulate the river flow from rainfall³⁾. MIKE NAM is a deterministic, lumped conceptual rainfall-runoff model which consists of four linear layers, including the snow storage layer, surface storage layer, lower zone storage layer and underground storage layer. In general, rainfall, evaporation and temperature are the input data needed for this model and the output of the model is the outflow over time^{3),4)}. To estimate the final NAM parameters, the model was calibrated with data series of selected flood events. The optimization of auto-calibration process is carried out by adjusting nine NAM parameters of surface – root zone and groundwater storages until acceptable NASH index is achieved. Then, river flow by using hydrodynamic module of MIKE11, which was developed to solve the Saint-Venant equation by means of a finite difference scheme. The input of this module include river system network, cross sections, boundary conditions³⁾.

- Second step: for further flood impact assessment, the verified model is utilized to develop flooding scenarios with frequencies of 10%, 5% and 1% selected based on design standard for flood protection works issued by Vietnam Government. These results was then analyzed and visualized in the form of flood hazard maps (i.e. river flood depth maps) by using ArcGIS software for flood frequencies of 1%, 5% and 10%.

Conceptual framework: The study applied the modified DPSIR, Driver – Pressure – State – Impact – Response, framework to analyse the potential impacts caused by flood pattern as developed in previous part. The DPSIR framework has being

suggested as an advantageous method to define cause–effect relationship, highlighting the connection among the causes of environmental problems, their impacts and the society’s response to them, in an integrated way. The advantage of this DPSIR is being able to clarify and analyse complex multi-sectorial inter-relationship. Therefore, it has been widely applied in river delta region where is usually characterized by complex and diversified features, such as densely population, extensive agricultural activities, growing urbanization and services, biodiversity, floodplain landscape etc^{5),6),7)}. As shown in **Fig. 1**, the framework structures the indicators of environmental and human systems in five groups connected by two types of links: a direct causal chain (solid line) and feedback links (dotted lines) between the Responses and their targets (Drivers, Pressure, State and Impacts) .

Fig. 1 Original DPSIR Framework developed by EEA in 1999

3. STUDY AREA AND DATA USED

(1) Study area.

River system: VG-TB river system is originated in the Truong Son mountain range at the elevation of 1,600m. The system is formed by two main rivers, namely Vu Gia and Thu Bon, flowing through major part of Quang Nam province and discharging into the sea at three inlets named Han, Dai va Lo. The total basin area is of 10,350km² with the length of Thu Bon river itself of 206km and tributary density of about 0.47km/km² creating rather complicated hydrological system⁸⁾. Its upper part is short and steep with a narrow riverbed, steep banks and many cascades. In the middle and downstream reaches, the riverbed is rather wide and shallow (**Fig. 2**). In the downstream reach, the river bed becomes flat and the banks is low, allowing overflow into fields and villages during the flood season.

Rainfall, typhoon and hydrological regime: Average annual rainfall is approximately 3000–4000mm and torrential rain for many days is a typical weather characteristic in this region during wet season. Another issue of concern caused by rainfall is extreme fluctuation in annual precipitation. Moreover, maximum monthly rainfall can be caused by typhoons but can also occur without typhoon. Every year, 2-4 typhoons make landfall in this region bringing huge rainfall and whirlwind. As a result of high topographical slope (i.e. 25% in average) and torrential rainfall for days VG-TB river system experiences extreme flash floods in mountainous area and deep inundation in the downstream plain and coastal area. Every year, the flood season is from September through December with multiple peaks. One of the typical characteristics of floods in VG-TB downstream is that it strongly depends on tidal regime, which can be only 1 or 2 days during low tide or up to 3 -5 day during high tide^{1),2)}.

Socio-economic conditions: The downstream of VG-TB river basin is highly dense area with density as high as 1,000 people/km². The living standard and average income of local people is rather low and unstable compared to other regions of Vietnam. The major economic activities in this area are agriculture, aquaculture, fishery and tourism, which all strongly depends on natural resources and be influenced by natural conditions and thus, highly vulnerable to water related hazards.

(2) Data used. For hydrological data, this study used the complete time series of flood events in 1999 (Sep 1st – Dec 31st) and in 2001 (Sep 1st – Dec 31st) for model calibration and ones in 2006 (Sep 1st – Dec 31st) and 2009 (Sep 1st – Dec 31st) for verification. System network setting and boundary

conditions were set up, including: (i) Upper boundary: Discharge flow at Nong Son and Thanh My hydrological gauges (**Fig. 2**); (ii) Lower boundary: water (tidal) level measured at Han, Lo and Dai inlets and (iii) Discharge flow of tributaries. For cross sections, there was measurement of 197 cross sections over the river course length of 336km of Vu Gia, Thu Bon and other main tributaries provided by Department of Water Resource, Ministry of Agriculture and Rural Development all Moreover,

4. RESULT AND DISCUSSION

(1) Simulation results. The calibration and verification results were obtained with acceptable NASH index ranging from 0.70 to 0.95 meaning that the observed and computed water levels are in good agreement. Also, for peak discharge usually having large error, the difference between observed and simulated values is less than 10%.

(2) Inundation maps. Usually, for flood hazard maps, inundation depth is classified more or less evenly^{9),10)}. For this study, after field survey and consultation with local people about the past flood disasters, inundation classification applied in this study takes into account level of consequences, e.g. property loss and casualties, which includes 5 classes: <0.5m; 0.5m ÷ 1.0m; 1.0m ÷ 2.0m; 2.0m ÷ 3.0m and >3.0m. Based on this classification, the modeling results is visualized in the form of inundation maps with selected frequencies, i.e. 10%, 5% and 1% (an example is shown in **Fig. 3**). These maps illustrate that the most serious inundation occurs from the junction of the two rivers, Vu Gia and Thu Bon, the Cua Dai estuary, especially in the communes namely Dai Minh, Dai Cuong, Dai Thang, Dai Hoa (Dai Loc district), Dien Quang, Dien Trung, Dien Phong (Dien Ban

Fig. 2 Topographic map of VG-TB basin

district), Duy Phuoc, Duy Thanh and Duy Vinh (Duy Xuyen district). For detailed analysis, the inundation extension area of each classification is calculated and presented in **Table 1**, which illustrates total inundation areas as much as of 43,610ha, 46,525ha and 48,870ha for the frequencies of 10%, 5% and 1%, respectively meaning that extended cultivated land, aquaculture lots and residential area in the low lying delta, mainly in Duy Xuyen, Dai Loc and Dien Ban districts, is completely under deep water. It is also noted that the increase in flood magnitude (with lower frequencies) results in the larger total inundation extension. However, rather than causing an even increase of all classes, the flood with higher magnitude (or lower frequency) results in substantial extension of deep inundated areas (with water depth of 1m and higher). For instance, while the inundation areas of water level less than 0.5m in all three scenarios are almost the same, the areas of water level of 1.0 - 3.0m for frequency of 1% is much more compared to those in scenarios of 5% and 10%.

(3) Assessment of flood hazard impacts by DPSIR framework. The simulation result described above reveals that the issue of concern is not only the total inundation area but more critically, the area with deep water. If compared flood events of 10% and 1%, such increased flood magnitude results an increase of about 3,500ha inundated which is contributed mainly by rather deep water area (including about 1,600ha of level 1.0m–2.0m and about 1,000ha of level 2.0–3.0m).

Table 1. Calculated inundation area (in hectare)

Classification of water depth	Flood frequency		
	10%	5%	1%
<0.5m	2,120	2,730	2,310
0.5m ÷ 1.0m	3,530	4,930	2,950
1.0m ÷ 2.0m	6,600	6,690	5,800
2.0m ÷ 3.0m	7,210	7,600	6,720
> 3.0m	24,150	24,575	31,090
Total inundation area	43,610	46,525	48,870

Moreover, the flood hazard risk in the study area is projected to increase in the coming period because climate change would cause wetter rainy season and less rainfall in dry season²⁾. As shown by simulation result, such tendency would certainly result in increased flooding and inundation, especially the increased extent of deep inundation. The latter is the most critical issue of concern. Therefore, in this study the modified DPSIR was utilized to identify and analyze the causal connection between nature of flood occurrence, its potential impacts on local people and ecosystem and proposed mitigation measures. The key question that needs to be addressed by DPSIR analysis is what types of flood risk the people in VG-TB downstream would have to cope with and how they should do to reduce and manage such risk. To obtain the answer to this question, we need to define the various components of the modified DPSIR framework that are illustrated in **Fig. 4** and explained as following:

DRIVER: The flood pattern with increased rainfall trend described earlier is considered as main driving force in this modified DPSIR analysis.

Fig. 3 Inundation map of frequency of 1% as an example

PRESSURE: As a result of flood pattern and topographic conditions, deep water inundation is rather dominated. This factor is much more critical than the case of the same flood volume covering large but shallow inundation. Another pressure that needs to be taken into account is an increased flood uncertainty that would cause serious socio-economic consequences despite of insignificant magnitude of rainfall and induced flood.

STATE: According to modeling result combined with survey information, the status of inundation is classified into 5 groups: Up to knee (<0.5m); Up to shoulder (0.5 - 1.0m); Up to 1st storey (1.0-2.0m); Up to 2nd storey (2.0-3.0m) and Complete submerge (>3.0m).

IMPACT: The inundation levels result in different level of consequences, which can be expressed in a form of 2-dimensionnal matrix, type and significance. Regarding to the type of consequences, they can be divided into four groups, namely social, physical, economic and environmental

environmental. On the other hand, the consequences can also be grouped according to their significance. In compliance to inundation classification, there are five levels of impact significance, i.e Level 1 as less significant and Level 5 as most significant.

RESPONSE: to minimize the consequences and impacts caused by flood inundation in the study area, various measures can be applied, which include structural (flood retention ponds, river dyke, upstream dike and reservoir, river bed dredging for proper flood drainage etc) and non-structural (early warning, land use planning, evacuation plan, institutional and policy development (e.g. community based disaster management, insurance) etc). Conventionally, in Vietnam, people concentrate more in coping with post disaster impact, which is, in most cases, not effective and as the result, the loss and damages continue to raise year after year especially in the context of increased erratic weather phenomenon induced by climate change. DPSIR framework can illustrate the different routes of response: by reducing pressure,

Fig. 4 Modified DPSIR framework for flood threat analysis in VG-TB downstream in the context of climate change

by controlling and adapting to the state and by recovering the loss and damages. The advantage of the DPSIR framework is ability for structuring the analysis of the complicated linkages from the source of flooding problem to the consequential impacts and so that for being able to propose effective measures to solve the problem.

5. CONCLUSION

VG-TB river system in Quang Nam Province is strongly characterized by steep bed slope and complicated hydrological regime. These factors result in sudden and extreme flood hazard, which certainly the risk for human safety and environmental integration. Therefore, in order to be able to understand the flood pattern and its consequences, this study applied an integrated approach, including flood simulation by MIKE-NAM and MIKE 11, GIS-based inundation extent visualization and statistical analysis of past flood record in the local area under climate change impact. The modeling calibration and validation come up with quite good result (NASH index at all the main gauges is higher than 0.7, even up to 0.95). Also, for peak discharge usually having large error, the difference between observed and simulated values is less than 10%. The model with such calibrated parameters was then used to simulate flood events of frequencies 10%, 5% and 1%. For further analysis, the corresponding maps were developed to present the inundation extent and inundation depth. The most flooded area is low-lying communes, including Dai Minh, Dai Cuong, Dai Thang, Dai Hoa (Dai Loc district), Dien Quang, Dien Trung, Dien Phong (Dien Ban district), Duy Phuoc, Duy Thanh and Duy Vinh (Duy Xuyen district). In addition, these maps showed that the flood with lower frequency causes substantial increase of total inundation area and more critically, mainly the increase of deep water. By the other words, the increase of total inundation is mainly due to the increase of deeply flooded area. This issue is an important concern as the statistical analysis and reviewing of international and national researches revealed the tendency of increased erratic weather phenomenon and consequently, extreme flow discharge threatening local community safety and sound environment. Within framework of this study, only qualitative assessment of flood consequences was carried out for different inundation level: <0.5m (up to knee), 0.5m-1.0m (up to shoulder of an adult), 1.0m-2.0m (up to 1-story house roof), 2.0m-3.0m (up to 2-story house roof), and >3.0m (everything is submerged).

This paper has also shown the modification of DPSIR framework for environmental management

to be applicable for analyzing qualitatively the potential impacts occurred at certain inundation levels as classified above by using a modified DPSIR framework. This conceptual framework can promote insight into sequence of flood risk occurrence and thereby, recommend where and which measures must be taken place to prevent and reduce PRESSURE or to control and adapt to STATE (inundation levels) or mitigate and recover post disaster IMPACTs.

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REFERENCES

- 1) Quang Nam DONRE: "Managing water in Asia's river basins: Charting progress and facilitating investment: The Vu Gia – Thu Bon Basin (Project on Japan Special Fund). 2011.
- 2) Vietnam MONRE (Ministry of Natural Resources and Environment): Climate Change, Sea Level Rise Scenarios for Vietnam (Project Report). 2012.
- 3) DHI: MIKE 11 Manual. 2007.
- 4) Hafezparast M, Araghinejad S, Sayed Ehsan Fatemi, Bressers: A Conceptual Rainfall-Runoff Model Using the Auto Calibrated NAM Models. Hydrology Current Research, Volume 4, Issue 1, 2013.
- 5) Omann I, Stocker A, Jager J: Climate change as a threat to biodiversity: An application of DPSIR approach. Ecological Economics Journal 69, pp 24-31, 2009.
- 6) Rounsevell MDA, Dawson TP, Harrison PA: A conceptual framework to assess the effects of environmental change on ecosystem services. Biodiversity Conservation Journal 19, pp 2823-2842, 2010.
- 7) Bell S: DPSIR = A Problem Structuring Method? An exploration from "Imagine" approach. European Journal of Operational Research 222, pp 350-360, 2012.
- 8) VAST (Vietnam Academy of Science and Technology): Flood Survey in Vu Gia-Thu Bon basin (Project Report). 2012.
- 9) Alaghmand S, Abdullah Rozi bin, Abustan Ismail, Md Azlin Md Said, Behdokht Vosooon GIS-based river basin flood modeling using HEC-HMS and MIKE11-Kayu Ara river basin, Malaysia. Journal of Environmental Hydrology, Volume 20, 2012.
- 10) Dawei H: Flood Risk Assessment and Management. University of Bristol, UK. Bentham Book (eBook, ISBN 978-1-60805-047-5). Bentham, 2011.

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