Assessing the Vulnerability of an Island Water System Subject to Climate Change and Tourism Development: A System Dynamics Approach

Thuc D. Phan[a,b], Oz Sahin[c], Marcello Sanò[b], Hai Q. Pham[d], Hieu N. Dao[e], Luan S. Mai[f], Tuyen V. Pham[f]

[a]Institute of Research and Development, Duy Tan University, Da Nang, Vietnam; [b]Griffith Centre for Coastal Management, Gold Coast, Queensland, Australia; [c]Griffith School of Engineering and Built Environment, Gold Coast, Australia; [d]VNU University of Science, Hanoi, Vietnam; [e]Cat Ba National Park, Hai Phong, Vietnam; [f]Cat Ba Langur Conservation Project, Hai Phong, Vietnam
***Email:* pduythuc@gmail.com *or* thuc.phan@griffith.edu.au**

Keywords: *decision-making support tool; climate change; island water system; socio-economic stressors; water scarcity*

Abstract: The management of water systems in islands of developing countries presents many challenges in the face of climate change and tourism development. Such systems are high levels of uncertainty and complexity driven by dynamic interactions amongst multiple climatic and non-climatic drivers with many feedbacks. Understanding complex interactions and feedbacks in the systems is, therefore, critical to inform decision-making regarding the adaptation options that will be required to ensure adequate water supplies to meet population growth and tourism development in current and future climate changes.

In this study, a system dynamics (SD) modelling approach was applied to assess the vulnerability and effectiveness of potential adaptation options for a scarce water system in the Cat Ba Island, Vietnam under current conditions and with respect to projected climatic and non-climatic changes. This island is highly vulnerable to water shortages due to its island position, and high levels of climate change and tourism development.

Relevant historical data collection and causal loop diagram (CLD) development were conducted with local stakeholders to determine the model structure and the system archetypes. The CLD provides the relationships and interactions amongst climatic and non-climatic drivers as well as potential adaptation options, represented by four reinforcing loops (R1 to R4), and six balancing loops (B1 to B6). Two main systems archetypes were discussed, they are "*Limits to growth"* illustrating the relationships between tourism development, population growth and water availability in the Cat Ba Island, and *"Tragedy of the commons"* presenting the groundwater exploitation from drilled wells and dug wells.

Key main variables from the CLD, five future climatic and non-climatic scenarios and six main adaptation options were incorporated into the SD model to assess the vulnerability and effectiveness of potential adaptation options for the island water system over 37 years, from 2014 to 2050. At this stage, the SD model are being finalised after validating from local stakeholders in the Cat Ba Island to obtain the required accuracy for decision-making supports.

The SD model results will help decision-makers understand the interactive effects of a range of climatic and non-climatic drivers on the vulnerability and the robustness of potential adaptation options of the scarce water system over time. Collective adaptation actions will be then facilitated to efficiently secure water resources to support socio-economic development for the island in the face of climate change.

1. INTRODUCTION

Decision makers face many challenges in the management of water resources in the islands of developing countries where water supply depends on drilled and dug wells, reservoirs and household water tanks which are strongly driven by changes in local precipitation, temperature and sea level. These changes coupled with high rates of population growth, urbanization and tourism development have the potential to cause severe water scarcity in these developing countries' islands. Understanding these factors affecting the vulnerability of the island water systems, and assessing the robustness of potential adaptation options are, therefore, needed to develop a long-term strategy for safeguarding a growing water demand from socio-economic development.

The island water systems involve multiple interactions and relationships amongst climatic and non-climatic drivers with many feedbacks, such as changes in sea level, precipitation, temperature and socio-economic development. Temporal and spatial variation among these driving factors contributes to more complexity and uncertainty of the island water systems. A holistic understanding the dynamics behaviour of the island water systems leads to more effective learning and management in for identifying robust adaptation options which could deal with both current and future conditions (Füssel, 2007). Therefore, it is appropriate to apply a system dynamics (SD) modelling approach to help decision-makers understand the dynamics behaviour of the system driven by multiple interactions between interdependent components with many feedbacks and initiate better management strategies (Sahin et al., 2016).

An SD model provides a holistic framework that numerous scenarios of both climatic and non-climatic drivers can be incorporated into one comprehensive model to understand interactions between hydrologic systems and socio-economic development and explore outcomes through an adjustable dashboard display (Sahin et al., 2016; Phan et al., 2018). An SD modelling approach has previously been applied in the management of water supply and demand systems subject to a range of climatic and non-climatic changes (Liu et al., 2009; Sušnik et al., 2015; Phan et al., 2018). Few previous studies, however, have considered multiple interacting climate drivers (e.g. sea level rise, precipitation decline and their influences on the operations of drilled wells and reservoirs) in combination with socio-economic stressors (e.g. population growth and tourism development) acting on the water system of a highly developed tourism island in a developing country.

In this study, an SD model is employed to assess the vulnerability and robustness of potential adaptation options for a scarce water system in the Cat Ba Island, Haiphong, Vietnam in current conditions and to projected climate change and tourism development over 37 years, from 2014 to 2050. Scenarios on precipitation decline, sea level rise, population growth, and per capita water use increase and tourism development were developed based on historical data and projections to understand the dynamic behaviour of the island water system over time. The model is developed and validated as a learning tool for decision-makers to improve their understanding on how potential future changes might alter long-term water, thereby affecting the water demand from population growth and tourism development in the island. These results could assist decision makers to develop strategies for water resource management adapting to climatic and non-climatic changes in the island in the future.

2. CASE STUDY AND MODEL DEVELOPMENT

2.1. System dynamics modelling approach

An SD model is developed to study the behaviour of complex systems and interactions among multiple, disparate external factors in situations where stocks and flows are fundamental and complex systems as well as consensus building capture time delays and internal feedback loops that alter system behaviour (Sterman, 2000). An SD model comprises three main components: stocks (e.g. groundwater availability, household water tanks and reservoirs); flows (e.g. water flows from drilled wells and dug wells) and converters which control flow rates (e.g. population growth rate and salinity level).

In this study, the SD model is developed using mental models of local stakeholders, interview results of 961 households and historical data analysis. The model is operated on a monthly time step (total of 444 months), encompassing the period of 37 years, from 2014 to 2050, which includes a five year calibration period (2014 to 2018) and a 32 year prediction period (2019 to 2050). Simulations targets the year 2050 because it provides a long-term perspective from which the long-term dynamic behaviour of the water system and the consequences of the plausible future scenarios could be assessed to inform adaptation decision-making. The model was then validated by two focus group discussions with local stakeholders in in the island to closely mimic the real system and reach an agreement among stakeholders on the model's predictions that could be used for decision-making supports.

2.2. Case study and model's elements

The case study for the SD model is the Cat Ba Island in Haiphong city in northern Vietnam (Figure 1). The Cat Ba Island is the largest of the Cat Ba Archipelago which has been recognised as a world biosphere reserve by UNESCO since 2004 as it has a large degree of diversity of landscape and ecosystems with more than forty white sandy beaches integrated with natural forests and rocky cliffs. The Cat Ba Island is mostly covered by tropical rain and limestone forests and has six communes and one town situating around the island with a population of 18,789 people in 2018 (CHDS, 2019).

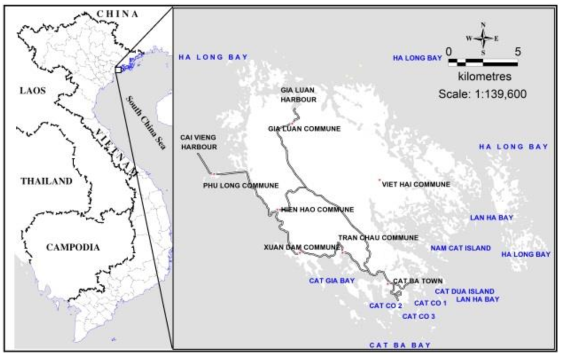

Figure 1: Cat Ba Island – the case study

A range of historical datasets (Table 1) were collected and examined to identity interrelations among climatic and non-climatic drivers of the vulnerability of the Cat Ba Island water system.

A questionnaire was developed to interview households in the island to understand their perspectives on the management of the island's scarce water system under climate change and socio-economic development. There were 18,789 people corresponding to 4,902 households in 2018 (HPSO, 2019) located in Cat Ba town and six communes in the Cat Ba Island. A 20% of the total households in each commune and town was planned to be sampled in the survey. Finally, a total number of 961 respondents were randomly interviewed by face-to-face from 9 March to 15 May 2019.

Focus group discussions were organised to revise the questionnaire and develop causal loop diagrams (CLDs). The participants in the focus group discussions comprised a range of water and climate change specialists from decision makers from Hai Phong City, as well as water resource managers and water resource users in the Cat Ba Island.

Table 1: Datasets for the development of the causal loop diagram and calibration of the SD model

No	Date type	Period	Unit	Source
1	Monthly sea level at Hon Dau National Station	Forty seven years from 1972 to 2018	cm	NNMWS (2019)
2	Monthly precipitation at Phu Lien Station	Sixty one years from 1958 to 2018	mm	NNMWS (2019)
3	Monthly temperature at Phu Lien Station	Sixty one years from 1958 to 2018	^{0}c	NNMWS (2019)
4	Tourists, hotels, boats and relevant tourism infrastructures in Cat Ba Island	Sixteen years from 2003 to 2018	people, hotels, boats	CHDS (2019)
5	Population (birth and death rates, immigrants)	Sixteen years from 2003 to 2018	people	CHDS (2019)
6	Monthly salinity levels and water exploitation in six drilled wells	Five years from 2014 to 2018	ppt	CHWSP (2019)
7	Monthly water levels and water exploration in two reservoirs	Five years from 2014 to 2018	m^3/s	CHWSP (2019)
8	Per capita water use	Water consumption per person	Liter/person/day	Phan et al. (2018)

The CLD (Figure 2) provides the relationships among key elements and feedback loops which are used to develop the SD model applied to assess the vulnerability and robustness of potential adaptation options for the island's water system under climate change and socio-economic development.

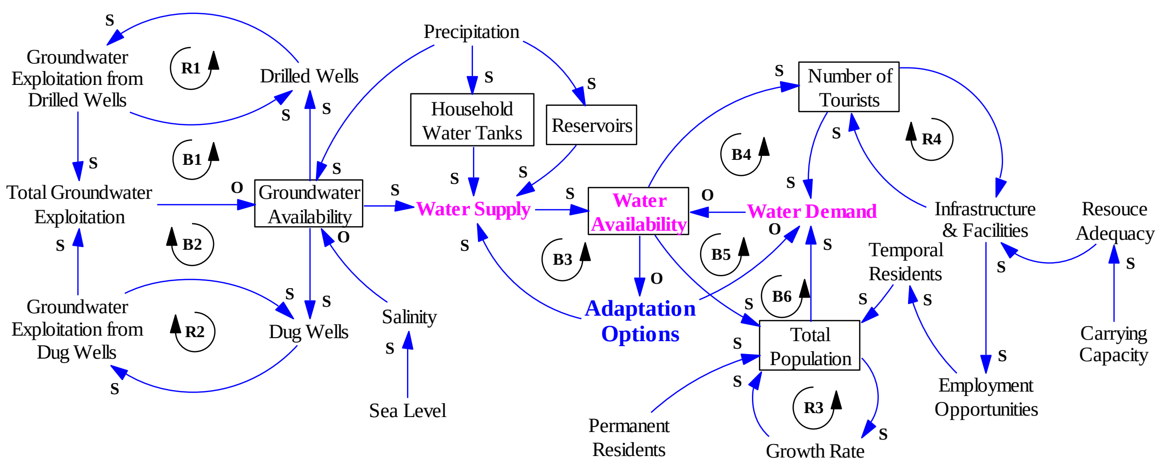

Figure 2: A causal loop diagram shows the relationships among the key elements and feedback loops of an island water system

S: same direction; O: opposite direction; R: reinforce; B: balance; ≠: delay

The CLD (Figure 2) shows that the water system in the Cat Ba Island is influenced by temporal and spatial changes in water demand and water supply over time, which is captured by four reinforcing loops (R1 to R4) and six balancing loops (B1 to B6). R loops (positive feedbacks) represent actions that are repeatedly affecting each other so as to continuously grow or decline, while B loops (negative feedbacks) seek stability and help in controlling the system to return to normal or work against reinforcing loops (Sterman, 2000). The interactions between R and B within the island water system over time not only produce the desired effects but also produce serious unintended consequences in the system, due to long term delays and hidden cause-effect relationships (Maani

& Cavana, 2007), thereby making the system become more dynamic and highly complex under climate change and socio-economic development.

The Cat Ba Island is considered to be one of the most beautiful places in Vietnam. It has become a preferred destination for tourists from all parts of Vietnam as well as from around the world (Mai & Smith, 2015). As a result, the number of tourists to the island has increased significantly over the last decades (Figure 3), leading to construction of a high number of facilities, such as hotels and restaurants in the island (Figure 4). In addition, there has been a rapid increase (1% per year) in the size of island's population due to the high birth rate and influx of migrants (Figure 5). The population growth and tourism development are two main driving forces for water consumption and will drive increases in the water demand through time. These relationships are indicative of exponential growth of two reinforcing loops, R3 and R4 (Figure 2).

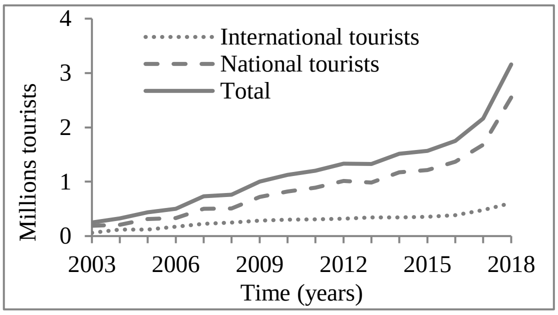

Figure 3: Tourists coming to the Cat Ba Island over a 16 year period, from 2003 to 2018

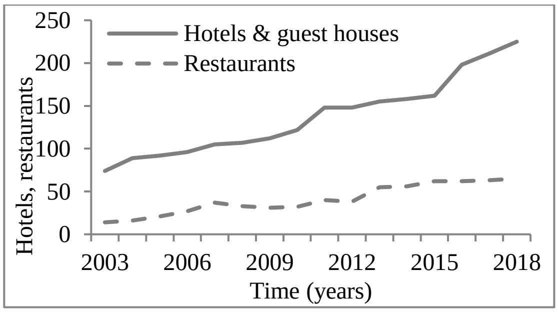

Figure 4: Hotels, guest houses and restaurants in the Cat Ba Island over a 16 year period, from 2003 to 2018

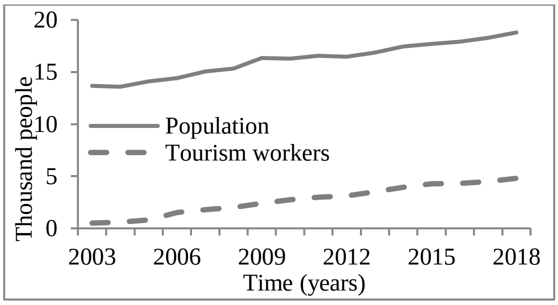

Figure 5: Population and tourism workers in the Cat Ba Island over a 16 year period, from 2003 to 2018

However, the island faces many challenges in water resources management. More specifically, water supply sources of the Cat Ba Island mainly depend on drilled and dug wells, reservoirs and household water tanks which are strongly driven by interactions in decreased precipitation (Figure 6), sea level rise (Figure 7) and increased temperature (Figure 8). The interactions among these factors will temporally affect the water availability in the island's drilled and dug wells, household water tanks and reservoirs. These changes, coupled with high rates of population growth and tourism development have caused to high water shortages in the last several summers in the Cat Ba Island, especially in the summers of 2017 and 2018. The water shortages are expected to be more serious over coming decades, thereby probably constraining socio-economic development for the Cat Ba Island in the future.

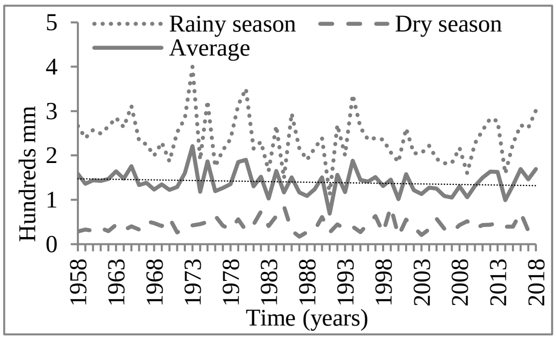

Figure 6: Precipitation in the Cat Ba Island over a 61 year period, from 1958 to 2018

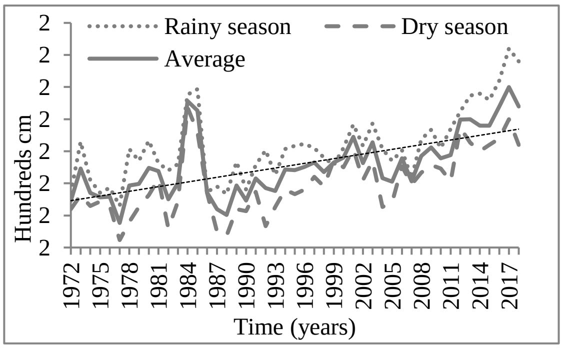

Figure 7: Sea level in Hon Dau Station, Hai Phong over a 47 year period, from 1972 to 2018

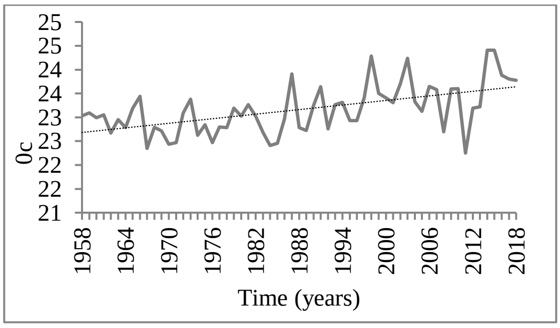

Figure 8: Average temperature in Hai Phong region over a 61 year period, from 1958 to 2018

The change in water supply relative to water demand leads to changes in the water availability of the island through time. If water supply is less than water demand, resulting in a water deficit, actions will be required to secure future water for the Cat Ba Island by increasing water supply and/or reducing water consumption. Six main adaptation options were identified from interviewed results and the focus group discussions as potential options: (1) building more reservoirs to store water in rainy seasons for dry seasons; (2) building a large tube to transport water from the mainland to the island; (3) encouraging households to construct more household water tanks to collect and store rainwater; (4) installing a desalination plant to convert seawater to freshwater; (5) drilling more wells to extract ground water and (6) increasing water price to save water consumption from households and hotels. Five of these adaptation options (1 to 5) act as increasing future water supply, representatively present as a balancing loop (B3) in the CLD. One of them (6) acts as reducing future water demand from households, hotels and restaurants, represented as a balancing loop (B5) in the CLD.

Analysing systems archetypes can assist in the identification of system leverage points (Senge, 2006) as a reference to generate strategies to improve the system. In the CLD, two main systems archetypes, which capture the key behaviours and dynamics of the island water system, are discussed: they are "*Tragedy of the commons*" and "*Limits to growth*".

Tragedy of the commons systems archetypes

The tragedy of the commons systems archetypes is commonly seen in the use and management of natural resources, and public goods where everyone wants to maximize benefits from common resources but the resources are limited. Eventually, the resources are significantly depleted, eroded or entirely consumed (Senge, 2006). This common sense is closely related to the groundwater exploitation from drilled wells and dug wells in the Cat Ba Island, clearly illustrated in R1, R2, B1 and B2 (Figure 2).

The drilled wells will increase water extraction from groundwater for water consumption. However, if more drilled wells are built, the ground water availability around the drilled wells' areas will be decreased, thereby affecting the water exploration from households' dug wells. Local people in the areas of operating drilled wells stated that their dug wells are increasingly drought because of exploiting groundwater from drilled wells in the areas.

Limits to growth systems archetypes

The most obvious "*Limits to growth system archetype"* is the relationships between tourism development, population growth and water availability in the Cat Ba Island (Figure 9). Infrastructure and facilities were built to meet a high demand from coming tourists. However, land budget in the island is limited and thus it constrains more building of hotels and restaurants. In addition, water availability in the Cat Ba Island is another issue that limits the development of socio-economic development, especially the tourism development. In the last two summers, 2017 and 2018, the water availability in the island was insufficient to supply for a high water demand from tourism development.

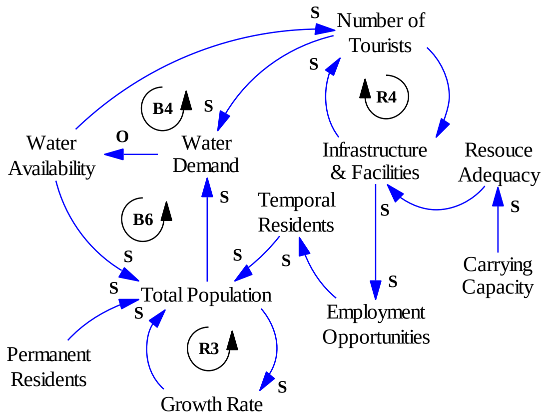

Figure 9: Tourism development, population growth and water availability as a *"Limits to growth"* systems archetype

2.3. Scenario development

Five future scenarios and changes in key data inputs (sea level rise, precipitation decline, population growth, tourist increase and water use per capita increase) are developed based on historical data analysis and projections to investigate the vulnerability and effectiveness of potential adaptation options of the island's scarce water system under projected changes for the year 2050.

A relative sea level rise scenario of 30cm by 2050 was used in this study based on both historical sea level and projections in Hai Phong region. Over 47 years, from 1972 to 2018, sea level at Hon Dau station in Haiphong region rose about 20 cm (Figure 7) and sea level rise projections for the Hai Phong region under the Fifth Assessment Report of IPCC's RCP4.5 and RCP8.5 in 2013 indicated that sea level will rise by between 14 cm and 36 cm by 2050 (MONRE, 2016). A relative sea level rise of 30cm will produce an increase of salinity intrusion in drilled wells as a consequence, limiting the groundwater availability in the drilled wells.

A precipitation decline scenario of 10% by 2050 was developed based on the historical precipitation in Hai Phong region and projections. Over 61 years, from 1958 to 2018, precipitation in Haiphong region decreased by 5.8% (Figure 6), and MONRE (2016) conducted precipitation projections, based on the Fifth Assessment Report of IPCC in 2013 indicated that under RCP4.5 and RCP8.5, precipitation will decrease about 10% by 2050. A precipitation decline scenario of 10% will change water availability in the reservoirs, drilled wells, dug wells and household water tanks.

Scenarios of relative sea level rise of 30cm and precipitation decline of 10% by 2050, coupled with historical data of monthly sea level, monthly precipitation, monthly groundwater exploitation, monthly salinity levels at drilled wells, and monthly water levels and monthly water exploitation in two reservoirs were used to quantify their relationships which were incorporated into the SD model to assess the temporal changes in water availability in the reservoirs, drilled wells, dug wells and household water tanks.

The interviewed results of 961 households in the Cat Ba Island indicated that 824 households used water tanks to store and collect rainwater, and 139 households used water from their dug wells for their daily activities. The monthly estimated water uses from their dug wells and water tanks were used to extrapolate the monthly water consumption for a whole island in the SD model over time.

The population of Cat Ba Island was around 18,789 people corresponding to 4,902 households in 2018, with a mean annual growth rate of 1% between 2003 and 2018 (HPSO, 2019). Water use for urban was 150L/person/day and rural areas was 100L/person/day in Hai Phong city (DONRE, 2015; Phan et al., 2018). This study also estimated that by 2050 per capita water consumption for urban and rural residents would be 180L/person/day and 150L/person/day, based on the historical data and temperature projections in Hai Phong region. Over the past 61 years, from 1958 to 2018, temperature in Haiphong region also increased about 1^0C (Figure 8). Temperature increase projections for the Hai Phong region conducted by MONRE (2016) indicated that under the Fifth Assessment Report of IPCC's RCP4.5 and RCP8.5 in 2013, temperature will increase about 5^0C to 7^0C by 2050. Considering these data and the effects of income and weather factors on per capita water consumption, per capita water consumption is calibrated at 120L/person/day currently and is assumed to be 180L/person/day in 2050.

The tourists coming to Cat Ba Island was around 315,800 in 2018, with a mean of annual growth rate of 2% between 2003 and 2018, and their average stays in the island were two days and nights (CHDS, 2019). This information was used to calculate the water consumption for tourists coming to the island over time.

3. DISCUSSION AND CONCLUSION

The management of water resource system in the Cat Ba Island, Vietnam presents many challenges in the face of climate change and tourism development. This paper aims to apply an SD modelling approach to assess the vulnerability and effectiveness of potential adaptation options for the Cat Ba Island's scarce water system under climate change and socio-economic development.

Historical data collection and CLD development were conducted to understand the interactions and relationships amongst different climatic and non-climatic drivers on the island water system. This is one of the first important steps to determine a system structure which includes positive and negative relationships between variables, feedback loops and delays for every system dynamics projects (Sterman, 2000). The system structure is then analysed to identify system archetypes which are essential for understanding the common dynamic processes that characterize the behaviour of the system (Maani & Cavana, 2007). Two main systems archetypes were discussed; they are "Limits to growth" and "Tragedy of the commons".

Determining system boundary, system structure and system archetypes are crucial to understand the complex and dynamic water systems driven by multiple factors, thereby developing a comprehensive understanding and optimizing water system models under climatic and non-climatic changes for decision-making supports (Mirchi et al., 2012; Phan, 2017).

The historical data and the CLD indicated that water demand has been significantly increased over last decades due to tourism development and population growth which have been changing rapidly in the Cat Ba Island. However, water supply from drilled and dug wells, household water tanks and reservoirs is highly vulnerable to water shortage due to precipitation decline, temperature increase and sea level rise which are expected to be continually changed in the future. Complex interactions between these factors can alter patterns of groundwater availability and water flows in streams, thereby affecting the operations of drilled and dug wells, reservoirs and household water tanks in the island. As a result, the Cat Ba Island faced to water shortage for socio-economic development over the last several summer seasons. Adaptation options will be, therefore, required to secure future water for the Cat Ba Island by increasing water supply and/or reducing water consumption. Six main adaptation options were identified and suggested by local stakeholders in the focus group discussions and interviewed results. Five of seven adaptation options act to increase water supply and one of them act to decrease the water consumption from households and hotels. The interactions and relationships among all these variables as well as potential adaptation options on the vulnerability of the Cat Ba Island water system are represented by four reinforcing loops (R1 to R4) and six balancing loops (B1 to B6).

Understanding the interactions and relationships among climatic and non-climatic drivers on the vulnerability of the island water system through collecting historical data and developing the CLD with local stakeholders is important steps which can be used to develop the SD model. Key main variables from the CLD, five future climatic and non-climatic scenarios and six main adaptation options were incorporated into the SD model to assess the vulnerability and robustness of potential adaptation options for the island water system from 2014 to 2050. At this stage, the SD model are being finalised after validating from local stakeholders in the Cat Ba Island to obtain the required accuracy for decision-making supports.

This study has a high potential for novelty as it incorporates both climatic and non-climatic drivers into one framework to assess the vulnerability and effectiveness of adaptation options for an island's scarce water system in a developing country. Specifically, it provides an understanding of the present and future vulnerability of the highly developed tourism island with high rates of tourism development, together with changes in sea level, precipitation and temperature. This study will directly contribute to the development of a collective and deceive action plan that aims to secure efficiently water for the island's socio-economic development in the future.

ACKNOWLEDGEMENT

This study is supported by Australian Government through the Australian Alumni Grants Fund (Grant number: SGF – R2 – 00199). We are grateful to local stakeholders significantly contributing to the CLD development and historical data collection.

REFERENCES

CHDS. (2019). *Socio-economic data in Cat Ba Island, Hai Phong, Vietnam*. Retrieved from Cat Hai Division of Statistics, Hai Phong, Vietnam:

CHWSP. (2019). *Salinity levels and exploitation capacities of drilled wells and reservoirs in the Cat Ba Island*. Retrieved from Cat Hai Water Supply Plant, Hai Phong, Vietnam:

DONRE. (2015). *A master plan for water resource management in Hai Phong City up to 2020, and a vision to 2030*. Retrieved from Haiphong City, Vietnam:

Füssel, H. M. (2007). Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainability Science, 2*(2), 265-275. doi:10.1007/s11625-007-0032-y

Liu, T. M., Tung, C. P., Ke, K. Y., Chuang, L. H., & Lin, C. Y. (2009). Application and development of a decision-support system for assessing water shortage and allocation with climate change. *Paddy and Water Environment, 7*(4), 301-311. doi:10.1007/s10333-009-0177-7

Maani, K. E., & Cavana, R. Y. (2007). *System Thinking, System Dynamics: Managing Change and Complexity*. New Zealand: Pearson.

Mai, T., & Smith, C. (2015). Addressing the threats to tourism sustainability using systems thinking: a case study of Cat Ba Island, Vietnam. *Journal of Sustainable Tourism, 23*(10), 1504-1528. doi:10.1080/09669582.2015.1045514

Mirchi, A., Madani, K., Watkins, D., & Ahmad, S. (2012). Synthesis of System Dynamics Tools for Holistic Conceptualization of Water Resources Problems. *Water Resources Management, 26*(9), 2421-2442. doi:10.1007/s11269-012-0024-2

MONRE. (2016). *Climate change and sea level rise scenarios for Vietnam*. Retrieved from Ministry of Natural Resources and Environment, Hanoi, Vietnam:

NNMWS. (2019). *Climate data in Hai Phong City, Vietnam*. Retrieved from National Northeast Meteorological and Weather Stations, Hai Phong, Vietnam:

Phan, T. D. (2017). *An Integrated Approach for Assessing the Vulnerability and Adaptation of a Coastal Water Supply and Demand System Subject to Climatic and Non-Climatic Changes.* (Doctoral Thesis), Griffith University, Nathan, QLD, Australia.

Phan, T. D., Smart, J. C. R., Sahin, O., Capon, S. J., & Hadwen, W. L. (2018). Assessment of the vulnerability of a coastal freshwater system to climatic and non-climatic changes: A system dynamics approach. *Journal of Cleaner Production, 183*, 940-955. doi:10.1016/j.jclepro.2018.02.169

Sahin, O., Siems, R. S., Stewart, R. A., & Porter, M. G. (2016). Paradigm shift to enhanced water supply planning through augmented grids, scarcity pricing and adaptive factory water: A system dynamics approach. *Environmental Modelling and Software, 75*, 348-361. doi:10.1016/j.envsoft.2014.05.018

Senge, P. M. (2006). *The fifth discipline: the art and practice of the learning organization* (Rev. ed.). New York: Doubleday/Currency.

Sterman, D. J. (2000). *Business dynamics: Systems thinking and Modelling for a complex world*. United States of America: The McGraw-Hill Companies.

Sušnik, J., Vamvakeridou-Lyroudia, L. S., Baumert, N., Kloos, J., Renaud, F. G., Jeunesse, I., Mabrouk, B., Savic, D. A., Kapelan, Z., Ludwig, R., Fischer, G., Roson, R., & Zografos, C. (2015). Interdisciplinary assessment of sea-level rise and climate change impacts on the lower Nile delta, Egypt. *Science of the Total Environment, 503*, 279-288. doi:10.1016/j.scitotenv.2014.06.111