A study on the effects of sea level rise on mangrove ecosystem in Giao Thuy district, Nam Dinh province

Van Doanh Vu*, Hong Tinh Pham, Thi Thu Trang Bui

Hanoi University of Natural Resources and Environment

Abstract:

Climate change and sea level rise (SLR) have greatly affected the coastal land use of the Nam Dinh province. It has especially impacted the mangrove forests in coastal plain areas. According to the monitoring data from management units, saline intrusion due to SLR tends to expand in scope, affecting and reducing the area of mangrove ecosystems. From this situation, it can be seen that the impact assessment and estimation of economic loss in coastal provinces such as Nam Dinh is incredibly necessary to help the localities proactively respond to climate change and SLR, which is in line with the national target program on climate change. This research, which uses methods of evaluating economic values, aims to quantitatively assess the extent of damage caused by SLR on an area of mangrove forests in Giao Thuy district, Nam Dinh province. The valuation of these impacts will provide a basis for scientists, research institutions, and localities to proactively mitigate and adapt to climate change. Research results show the damage of climate change and SLR to the coastal mangrove forests in Giao Thuy and the risk to agricultural land use in the Nghia Hung and Hai Hau districts. These results also provide warning of the potential damage caused by SLR to dike and irrigation systems in the coastal districts of the Nam Dinh province, which follow Xuan Truong, Giao Thuy, Hai Hau, and Nghia Hung.

Keywords: climate change, mangrove ecosystem, SLR.

Classification number: 5.2

Introduction

Currently, the mangrove forests in the Giao Thuy district and Nam Dinh province are known for their direct use values such as firewood supply, forest products, marine fishing, and beekeeping for honey, medicinal plants, and ornamental creatures, etc. Their indirect use values include supporting aquaculture activities, carbon accumulation (CO_2), and the prevention and mitigation of natural disasters. Some non-use values are those related to biodiversity. However, these values will no longer be available if the mangrove area is reduced. In recent years, along with the increase in temperature, extreme climates and extreme phenomena have caused a marked increase in the heat from the sun, very cold and damaging weather, heavy rain, and storms in the Nam Dinh province. Together with SLR and saline intrusion, a great impact on the inhabited area and quality of the mangrove forests in the coastal areas of Nam Dinh province, especially in the Giao Thuy district, are occurring.

In coastal plain areas such as the Nam Dinh province, SLR has a great influence on coastal land use. This is especially true for agricultural land, among which mangroves are one of the groups most sensitive to the impact of climate change and SLR. In 2013, the area of inundated land in the province was 34,020 ha and was mostly concentrated in the coastal districts of Nghia Hung, Giao Thuy, and Hai Hau (Institute of Environmental Hydrology and Climate Change, 2013) [1]. According to the estimates from the Ministry of Natural Resources and Environment - MONRE (2016), if the SLR is 100 cm, over 60% of the coastal districts such as Hai Hau, Giao Thuy, and Nghia Hung in the Nam Dinh province are at risk of flooding [2]. Saline intrusion tends to expand its influence in terms of scope. According to the actual measurement data from the Centre for Environmental Resources Monitoring and Analysis, Nam Dinh Department of Natural Resources and Environment, on December 21st 2014, the salinity of the Red river measured at the mouth of Tai sluice gate in the Xuan Tan commune, Xuan Truong

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*Corresponding author: Email: doanh2002vn@gmail.com

(19 km from the sea) was 2.6‰. The salinity in the Ninh Co river, at Tan Ly wharf, Nghia Son commune, Nghia Hung (20 km from the sea) was 3‰ and in the Day river, at boat wharf 10, Nghia Son commune, Nghia Hung (28 km from the sea) was 0.2‰ [1].

A geological study by Miyagi (1998) shows that habitat change in the mangroves depends on the rate of change of SLR. When the rate of SLR is greater than the limit of the peat accumulation rate, mangroves will be submerged in seawater and will die [3]. Research by Thi Kim Cuc Nguyen, et al. (2012) [4] and Gilman, et al. (2007) [5] also show that depending on regional topographic conditions and the degree of change in water level, mangroves may decline or expand.

Recently, when the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts was established in 2013 and the Paris Agreement on Climate Change was adopted in 2015, the impact of climate change and SLR on coastal and mangrove forest areas have been increasingly studied both in Viet Nam and around the world.

In order to quantitatively assess the extent of SLR damage to mangroves, this study focuses on calculating the economic losses of mangrove forests caused by SLR in Giao Thuy district, Nam Dinh province in 2020, 2030, 2040, and 2050 corresponding to SLRs of 12, 18, 24, and 32 cm (RCP6.0 scenario) based on the map of "Nam Dinh land use planning till 2020" [2]. These research results will provide a basis for researchers, organizations, and localities to take a proactive and appropriate response concerning forest protection measures in the context of climate change.

Study data and methods

Data

Secondary data collection: this research used the data and documents from the 2010-2016 Nam Dinh Statistical Yearbook from the General Statistics Office, the 2016 scenario of climate change and SLR for Vietnam (MONRE), and related studies on the economic value of the affected subjects.

Primary data: data and documents (on affected areas of mangrove forests, damage levels, etc.) are obtained from field surveys, community consultations, and expert consultations with the use of the Delphi method.

Study methods

Field survey and community consultation: in order to support the assessment of SLR impacts on mangroves, the research team conducted a field survey to adjust the SLR impact map of the Giao Thuy district. At the same time, questionnaires for field survey and community consultation were developed, which involved households participating in livelihood activities related to planting and harvesting mangrove forests.

Delphi method: in order to determine mangroves' use value groups that are likely to be affected by SLR and to select the level of damage, the Delphi method was applied with two rounds to consult experts who are officers of state management agencies at all levels and scientists and experts from agencies such as managers of the Department of Agriculture and Rural Development; Department of Natural Resources and Environment of Nam Dinh and Division of Agriculture and Rural Development of Giao Thuy district, Nam Dinh province; lecturers at Hanoi University of Natural Resources and Environment, and experts from the Institute of Meteorology, Hydrology and Climate Change.

Method of SLR impact mapping: in this study, the research team inherited the method of developing flooding risk maps according to climate change and SLR scenarios for Vietnam by MONRE (2016) to map the impact of SLR on the Giao Thuy district in 2050. The map was also adjusted according to the field survey findings. Because only the map of "Land Use Planning to 2020" is of the most practical significance, this study assumes that land use in the Nam Dinh province would follow the Land Use Planning and Land Use Status in 2050, which doesn't show much change compared to 2020. Therefore, the land use status in 2050 in the Nam Dinh province in this calculation is determined according to "Land use planning for Nam Dinh province until 2020" [6] combined with field survey data.

In the context of increasing SLR and saline intrusion in coastal districts of Nam Dinh province and in order to make a plan for medium and long-term SLRs, our study selected the 2050 SLR scenario of 32 cm for Nam Dinh province corresponding to the high average scenario RCP6.0 to determine the area of affected mangroves.

Method of valuation of economic values: using statistics yearbook data, research works related to the affected subjects to estimate the average value in 2010 of the specific subjects is given in Table 1. The total economic value (TEV) formula by Bolt [7] (2005), Pearce (1990), and Barbier's, et al. methodologies [8] for calculating losses due to SLR were used.

Table 1. Method of valuing economic values of mangroves

Affected subjects	Valuation method	Used data
Direct use values		
Mangrove area with ecotourism value	Travel Cost Method - TCM	Findings in the thesis of Dinh Duc Truong (2010) "Assessing the economic value for wetland management - applied in the wetlands of Ba Lat river mouth, Nam Dinh province" show the value was determined to be 2.4 billion VND/year [9].
Mangrove area with value of bee-keeping for honey	Market price method	Study findings of Dinh Duc Truong (2010): 0.6 million VND/ha/ year [9].
Indirect use value		
Mangrove area with value of ecological support for aquaculture activities	Use production function model (Cobb-Douglas function) to determine the optimal effectiveness of the objective function.	Study findings of Dinh Duc Truong: 16.5 million/ha/year [9].
Mangrove area with value of carbon accumulation/absorption	Use market price method	Research by Tateda (2005), in which the estimation of carbon absorption value of mangroves was carried out in some mangrove areas of Southeast Asia including Xuan Thuy area showed a cumulative capacity of 2.5 tons/ha/year of the mangroves in this area [10].
Mangrove area with value of natural disaster impact mitigation (storms, SLR)	Use method of Avoided Cost - AC	Results of the "Study on seadyke protection value of mangrove forest in Xuan Thuy - Nam Dinh" by Tan Phuong Vu, Thi Thu Ha Tran: the value of mangroves in impact mitigation is estimated to be 633,000 VND/ha/year for seadyke repair and maintenance [11].
Non-use values		
The loss of mangrove area results in non-use values such as biodiversity conservation	Use Contingent Valuation Method - CVM	The results from the thesis "Assessing the economic value for wetland management - applied in the wetlands of Ba Lat river mouth, Nam Dinh province" Giao Thuy district: the value is 399 million VND/year [9].

Study results

Process for valuation of economic losses of mangroves due to climate change and SLR

A database has been built, expert opinions have been collected, and field surveys and community consultations have been conducted to develop a process of assessing the economic losses of mangrove forests under the impacts of climate change and SLR. There are seven main steps shown in Fig. 1 and outlined below [12]:

(1) Select an appropriate SLR scenario

(2) Develop flood risk maps according to different SLRs

under the scenario

(3) Develop a map of climate change and SLR impacts on mangrove forests

(4) Adjust the map of climate change and SLR impacts on mangrove forests

(5) Determine the area of affected mangroves and the use values of mangroves

(6) Calculate and determine the damage value of mangroves

(7) Demonstrate damage assessment results on the map of climate change and SLR impacts.

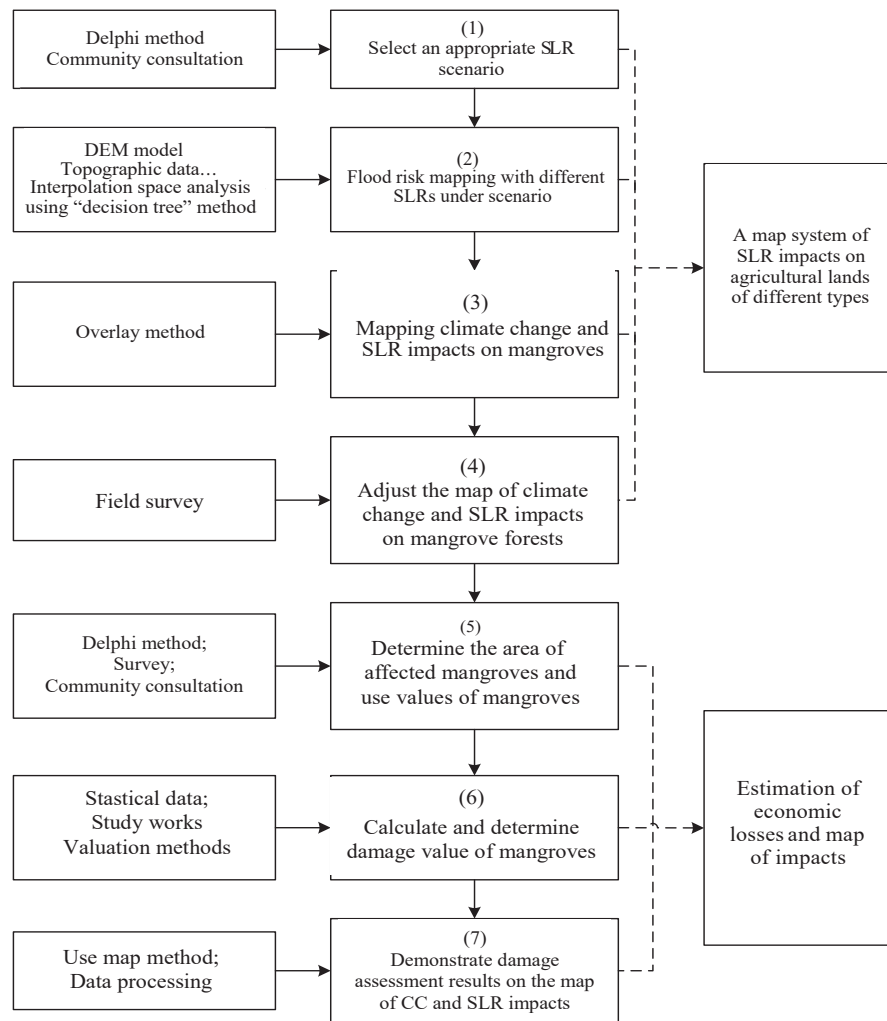**Fig. 1. Study process of economic loss valuation of mangroves under the impacts of climate change and SLR.**

Building the map of climate change and SLR impacts on mangrove forests

Using the map "Land use planning for Nam Dinh province to 2020" along with the timelines for calculation under the flood risk scenario of SLRs, the research team built a map of flood risk impact on mangrove forests due to climate change and SLRs for the Giao Thuy district.

The map of the SLR-induced flood risk impact on mangroves based on the map "Nam Dinh land use planning to 2020" for years with corresponding SLRs of 12, 18, 24, and 32 cm (2020-2050) was used to map the flood risk impacts caused by SLRs on mangroves in Giao Thuy district. The area of mangroves affected by SLRs is shown in Table 1.

There are two typical maps below based on the "Land use planning till 2020" map for the year 2030 (Fig. 2) and 2050 (Fig. 3) with the affected mangrove forest area.
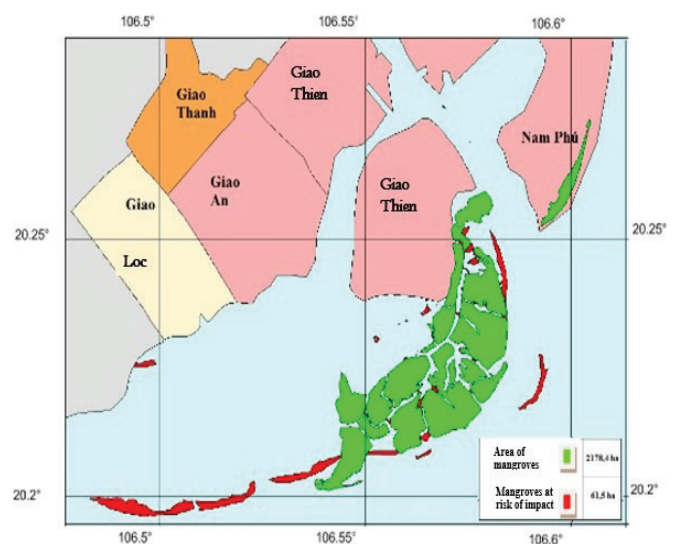

Fig. 2. Predicted mangrove area change in Ba Lat river mouth, Giao Thuy district under the impact of climate change in 2030.

From the forecast map of the affected mangrove ecosystem at Ba Lat mouth, Giao Thuy district, the change in the area of mangroves has been determined as shown in Table 2.

Table 2. Area of mangroves affected by climate change and SLR in Giao Thuy from 2020 to 2050 according to the map of land use planning 2020.

Mangroves at risk of impact	Map based total area of mangroves (ha)	Mangrove area affected by SLR over time (ha)			
		2020 (12 cm)	*2030* (18 cm)	*2040* (24 cm)	*2050* (32 cm)
Based on the planning map 2020	2,178.4	22.1	61.5	104.1	176.1

Table 2 lists the area of mangroves affected by SLR in the Giao Thuy district from 2020-2050 (based on the map titled "Nam Dinh land use planning to 2020"). Also shown in Table 2 is the gradual increase in the total area of mangroves affected by SLR from 2020 to 2050, ranging from 1.3% to 9.3% of the district's natural land area.

Fig. 2 shows the map of the SLR impacts on the use of agricultural land in 2030 with an inundation level of 18 cm according to map "Nam Dinh land use planning to 2020". Figure 3 shows the map of the mangrove area in Xuan Thuy area at risk of impact in 2050 with a SLR of 32 cm.
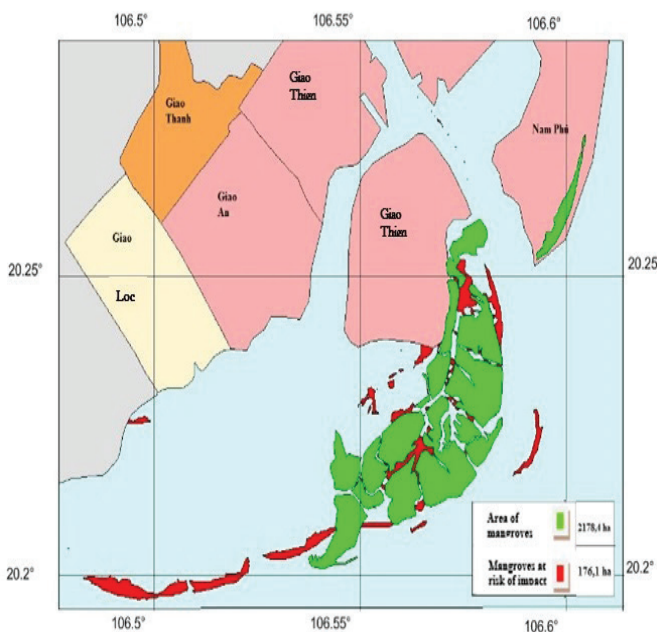
Fig. 3. Mangrove area in Ba Lat mouth, Giao Thuy district affected by climate change in 2050.

Valuation of economic losses of mangroves in Giao Thuy district

The establishment of the formula for calculating economic losses of mangroves in Giao Thuy district, Nam Dinh province is based on the formula system of Bolt (2005) and Pearce (1990). From the process shown in Fig. 1, the following equation, Eq. (1), was developed to evaluate economic losses of the studied mangroves caused by climate change and SLR:

$$TEV = UV + NUV = DUV + IUV + OV + EV + BV \quad (1)$$

where TEV is the total economic value; UV is the use value; NUV is the non-use value; DUV is the direct use value; IUV is the indirect use value; OV is the option value; EV is the existence value; and BV is the bequest value. Further, $DUV = (\sum Q_i \times P_i)$/year, where Q_i is annual average quantity of product i and P_i is the price of product i, and IUV = ($\sum$replacement cost)/year = ($\sum$preventive cost)/year = ($\sum$travel cost)/year.

The formula system for valuation from Barbier [1] was used as well.

The level of loss, K, according to joint Circular No 43/2015/TTLT- BNNPTNT-BKHDT, was determined using the same expert method for the period of 2020-2040 and 2040-2050:

$$TH_{RNM} = \sum(S \times G) \times K \quad (2)$$

where TH_{RNM} is the economic loss of mangrove caused by SLR in one area; S is the area of mangroves affected by climate change and SLR; G is the mean economic value of one area unit of mangroves; and K is the level of loss.

Applying Eq. (2):

- S: was determined based on the impact map, Table 2, and especially the study of the map "Land use planning till 2020".

- G: was calculated by processing the data collected from statistic yearbooks and research works published in Nam Dinh, as shown in Table 3.

The survey method was used to determine the average economic value of the subjects that are affected by climate

change and SLR. Collected data regarding the temperature, rainfall, humidity, etc, according to the Nam Dinh statistical yearbook was used, and reference to the valuation works related to the affected subjects including group of wetlands, dike systems, and salt prevention facilities.

The selection of the discount factor (r) that makes the value similar to that of 2010 was carefully considered because in Vietnam the comparative price is a statistic that is widely used to estimate the average economic value of the mangrove forest.

Based on community and expert consultation results combined with the Delphi method with 2 rounds to identify those affected by SLR, the study has identified the losses due to SLR with the use value of mangrove forests as follows:

Table 3. Average economic value of mangroves affected by climate change and SLR in Giao Thuy district.

Affected subjects	Economic value loss according to the price of 2010 (million VND)
Loss in mangrove area with direct, indirect use and non-use values	+ Ecotourism: 2.4 billion VND/year=2,400 (million/ha) + Bee keeping for honey: 0.6 million VND/ha/year + Ecological support for aquaculture activities: 16.51 million VND/year (at the time of the year 2008)→ converted equivalent to the price of 2010: $16.51x(1+0.08)^2 = 19.3$ million/ha + carbon absorption/accumulation: 2.5 tons/ha/year→ equivalent to: 2.5x5x20,000=250,000 VND/ha/year= 0.25 million/ha + Natural disaster impact mitigation (storms, SLR): 633,000 VND/ha/year = 0.633 million/ha + Biodiversity conservation: 399 million VND/ha/year => Total value: 2,400+0.6+19.3 +0.25+0.633+399=2,819.7 (million VND)

- K: estimated following Circular 43 and Delphi method with different levels of loss [13].

+ Mangrove ecosystem loss in the phase 2020-2040: K = 0.2

+ Mangrove ecosystem loss in the phase 2040-2050: K = 0.4

Based on the area of agricultural land affected by SLR on maps of land use such as the map of planning to 2020, from Table 2, it can be seen that there is an increased risk to the mangrove forest area in the Giao Thuy district being affected by climate change and SLR. For instance, in 2020, at an inundation level of 12 cm, the flooded area will be about 22.1 ha. In 2050, the respective figures will be 32 cm and 176.1 ha. Table 4 is formed based on the Eq. (2) above and Table 2 on the area of mangroves affected by climate change and SLR. Table 3 is formed based on the average economic value of the mangrove forests in the Giao Thuy district. Table 4 shows economic loss of the mangroves in the Giao Thuy district due to the impacts of climate change and SLR from 2020 to 2050 according to different land use approaches.

The results show that the affected mangrove forest area will be proportional to the economic losses and both will continuously increase from 2020 to 2050. With the two coefficients of K in the period 2020-2030 and 2040-2050 being 0.2 and 0.4, respectively, the results are as follows:

With the approach of no-intervention, if land use is as planned in the 2020 planning map, and if the SLR is 12 cm, the economic loss value in 2020 will be 12,463.1 million VND, increasing to 34,682.3 million VND in 2030 and the maximum value of losses in 2050 will be 198,619.7 million VND, equivalent to 176.1 ha of forest lost when the SLRs to 32 cm.

Table 4. Economic loss of mangroves in Giao Thuy district under impacts of climate change and SLR from 2020 to 2050.

Mangroves in Xuan Thuy affected by climate change and SLR	Mangrove area (S) affected by SLR over time (ha)				Average value (G) per 1 ha (million VND comparative price of 2010)	Loss level K		Estimated economic loss over years (million VND)			
	2020	2030	2040	2050				2020	2030	2040	2050
	(12 cm)	(18 cm)	(24 cm)	(32 cm)							
Based on planning map of 2020	22.1	61.5	104.1	176.1	2,819.7	0.2	0.4	12,463.1	34,682.3	117,412.3	198,619.7

Source: Land use planning for Nam Dinh province till 2020.

Conclusions

This study has assessed the economic loss of mangrove forests due to SLR in the Giao Thuy district, Nam Dinh province, from 2020 to 2050. The results show that the impacts of SLR on the mangroves is increasing over time, even with no human intervention.

In addition to the assessment of the damage of climate change and SLR in the Giao Thuy district, this study also showed the risk of impacts on agricultural land use in Nghia Hung and Hai Hau, which are also coastal districts of Nam Dinh province.

This study's results also warns of the damage of SLR to dike systems and irrigation systems in the coastal districts including Xuan Truong, Giao Thuy, Hai Hau, and Nghia Hung.

Valuation of economic loss caused by climate change and SLR in the mangrove area in the Giao Thuy district of Nam Dinh is aimed to limit the damage of SLR. The locality should assign importance to the maintenance and restoration of the coastal mangrove forests, especially in Xuan Thuy National Park. The district also needs to pay attention to the spontaneous conversion of the aquaculture model to limit the impacts on mangrove forests. There should be projects and research topics on conservation and development of mangroves, with sustainable models of aquaculture combined with mangrove planting or new planting and supplementary planting in the areas where mangrove forests are being degraded.

The authors declare that there is no conflict of interest regarding the publication of this article.

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