Rural Coastal People are at Risk of Seawater Inundation in the Future: A Case Study in Chanthaburi Province, Thailand

Puvadol Doydee and *Jirawat Panpeng*

Rural coastal areas in Laemsing District, Chanthaburi Province, Thailand have been experiencing tidal flooding, and most communities are settled in the District's areas with geographical characteristics susceptible to sea level rise. In line with the efforts of the Government of Thailand to raise awareness on the impacts of climate change and understand climate change vulnerability, this study was conducted to link the impacts of sea level rise and its consequences with the lives of rural coastal people, and affirm that this particular District has the highest risk of sea level-relevant events in the future. Scientific tools and techniques including climate models, GIS and remote sensing as well as simple techniques for inundation mapping were applied to pursue the objectives of the study. Results of the analysis based on A1B, csiro_mk30 and best estimates suggested that the total sea level rise in the study area from 2000 to 2045 would be 43.69 cm leading to land loss of around 19,507.50 rais and affecting 2881 persons. The District's aquaculture areas would be most affected, especially in Bangkachai Sub-district with its land and people bearing the brunt of seawater inundation. Reducing the utilization of artesian well water, integrating climate change adaptation into the integrated coastal management (ICM) approach, and implementing the ICM approach in all coastal areas are among the possible solutions that could mitigate the impacts of seawater inundation on the concerned rural coastal people.

Coastal areas importantly link the complexity of environmental systems with people's livelihoods. Many countries worldwide, including Thailand are now being confronted with coastal degradation and its severity is attributed to the influence of climate change. In fact, climate change which is now a severe global problem leads to rising land and sea surface temperatures, and sea level among others. The event is obviously now occurring on Earth, creating adverse impacts that seriously affect coastal systems (Snoussi *et al*., 2008). A climate-relevant phenomenon, sea level rise creates important stress on the coastal areas of Thailand mostly distressing the quality of life for many people living along the country's coastline of approximately 2600 km, in 23 provinces of the Andaman Sea and Gulf of Thailand. Records have shown that the sea level of these two seacoasts had significantly risen at an average rate of 3.00-6.00 mm per year from 1981 to 2006 (Neelasri, 2008), and was anticipated to be worse in the near future (NREPP, 2011). Southeast Asia START (2010) also reported that the average increase of sea level in 2030-2049 relative to that of 1980-2000 would be 13.26 and 10.89 cm for the southeastern coast and southern coast of the Gulf of Thailand, respectively. Many economic sources, particularly shrimp farms in the proximity of the coastline are also susceptible to inundation due to the yearly expected sea level rise of 1.00 cm (START, 2008). Coastal areas in Thailand are therefore vulnerable to and are at risk of the impacts of sea level rise, and are also expected to experience increasing coastal degradation. One of the several coastal provinces in Thailand, Chanthaburi Province has been experiencing frequent tidal flooding that threatens the coastal lands and affects the local people's livelihoods. More particularly, Laemsing District which is one of the four districts of Chanthaburi Province had been confronted with temporary sea level floods that negatively affected its people's livelihoods. The geographical conditions of most of the areas in this District are flat and low-lying, making these areas vulnerable to sea level rise.

The Case Study

Climate change and its consequences which had created significant burdens on peoples around the world including those in Thailand, had been taken into account in the Third Sub-guideline of the Second Guideline on "Upgrading the capacity of climate change coping and adaptation to immune society", specifically in the Sixth Strategy of the Eleventh National Economic and Social Development Plan (NESDB, 2011). In order to develop adequate climate adaptation plans and public policy interventions, understanding about the nexus of the impacts of climate change and its consequences, as well as the risks of people is necessary.

This study has the main objective of promoting enhanced understanding of the relationship among the status of potential sea level change, physical degradation and the people affected which could be represented in terms of accuracy. Sufficient data and information is necessary for decision makers in all levels, as they could help the vulnerable people survive in the midst of possible severity of sea level rise. In addition, this study is aimed at affirming the results of the previous studies on vulnerability assessment to climate-relevant phenomena which indicated that Laemsing District is highly vulnerable to potential sea level change.

Box 1. Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)
The SRES scenarios are grouped into four scenario families (**A1, A2, B1 and B2**) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions.
A1. The A1 scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (**A1B**) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).
A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Source: Adapted from IPCC (2007)

This case study was conducted with the application of scientific tools in order to specifically attain its goal of clarifying sea level change in the future; identifying possible inundated areas and affected people; and charting precise solutions for affected people to cope with the severity of the impacts of sea level rise. The case study made use of scientific models based on two emissions scenarios, namely: A1B and B2 **(Box 1)** as these were considered appropriate for the study area. In modeling for projected future climate change, the Special Report on Emissions Scenarios (SRES) should be used, where the SRES refers to the scenarios described in the IPCC Special Report on Emissions Scenarios (IPCC, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that could be used to explore alternative development pathways that cover a wide range of demographic, economic and technological driving forces that result in greenhouse gas (GHG) emissions (IPCC, 2007). Any of the four emissions scenarios could be used in projecting future climate change and its impacts to the socio-economic and demographic conditions of an area under study, which in this case is Laemsing District in Chanthaburi Province, Thailand. The results could also be used as inputs in assessing the climate change vulnerability of a particular area.

The study area and data gathering

Laemsing District in Chanthaburi Province was considered for the case study as it is the most vulnerable area having frequently experienced sea level rise and its adverse consequences. While most of its areas are geographically vulnerable, so are most people living in the District's coastline and dependent on the natural resources for their livelihoods.

Chanthaburi Province is one of the 17 coastal provinces in the Gulf of Thailand with coordinates at 12.6084 (North) and 102.2706 (East) on the east coast. Situated in a tropical monsoon climate area, this Province can be divided into three areas based on geographical conditions, *i.e.* mountainous area, plateau and low-lying flat land adjacent to a river and coastal zone (Chanthaburi Office, 2013). One of the four districts of Chanthaburi Province is Laemsing District which has a coastline and accounted for the aforesaid third geographical condition. As a matter of fact, most of its areas have elevation of below 10.00 m

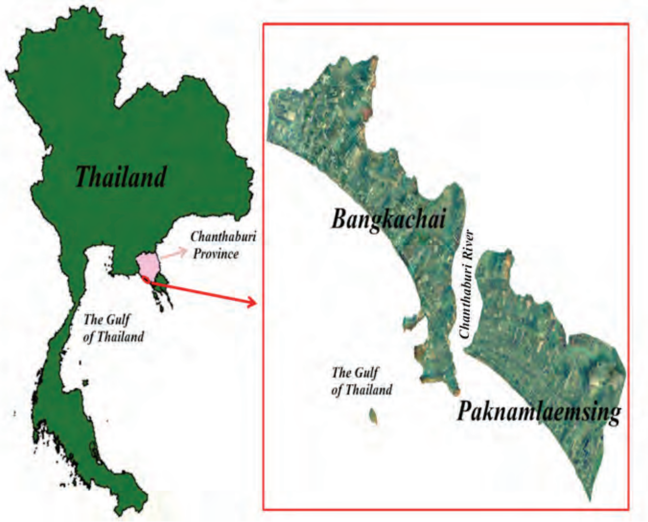

Fig. 1. Map of Thailand showing Chanthaburi Province and the two sub-districts that comprised the entire study area

Table 1. Categories of land use in the entire study area (areas in rais: 1.0 rai = 0.16 ha)

Study Sites	Aquaculture area	Agriculture area	Community area	Infrastructure area	Vegetation area	Water area	General area	TOTAL
Bangkachai	11,444.72	184.95	1,031.26	19.27	4,564.18	2,426.40	**70.81**	**19,741.59**
Paknamlaemsing	8,559.21	1,608.18	2,529.29	116.13	797.73	1,555.66	**235.12**	**15,401.33**
TOTAL	**20,003.93**	**1,793.13**	**3,560.55**	**135.41**	**5,361.91**	**3,982.06**	**305.93**	**35,142.91**

Source: Calculations from land use shape file provided by Thai LDD (2010)

above the mean sea level and connected to the shoreline (Mcgranahan *et al*., 2007), making Laemsing District at high risk of sea level rise. This District has seven Sub-districts, of which Bangkachai and Paknamlaemsing had been selected as the study area for this case study (**Fig. 1**).

These two Sub-districts as the study area have coastlines that are connected to the Gulf of Thailand and located close to Chanthaburi River, and also host a network of brackishwater canals. Most areas in these Sub-districts have very low elevations and mostly occupied by aquaculture farms while the people are mostly involved in exploiting the natural resources. Altogether, aquaculture occupies about 57% of land in the entire study area, of which approximately 57% of the land in Bangkachai Sub-district alone is used for aquaculture. Both aquaculture and water areas cover about 68% of the entire study area (**Table 1**), thereby the entire study area is not only in vulnerable geographical locations but is also having high risk of land inundations.

In order to identify the potential sea level change as hazard, and the land loss and numbers of people affected from the adverse impacts of inundation due to rising sea water, the study adopted the risk-hazard approach described in Eakin and Luers (2006). The collaboration of various stakeholders had been sought for the study which availed of various scientific tools, such as climate models, satellite imageries, Digital Elevation Model (DEM), and Geographic Information System (GIS). A mixed descriptive and explanatory research was applied to illustrate the risk of rural coastal communities to sea water change and its impacts, and on how it could be alleviated. The data collected from primary and secondary sources had been analyzed and assessed from every view point to achieve the research objectives. The data in the form of both qualitative and quantitative have created a wide and deep knowledge of the situation which is crucial for the study. Daily, weekly, monthly and yearly reports and other documents were reviewed and extracted as secondary data as well as those from the focus group discussions adopting some techniques from Daze *et al*. (2009), while inputs from key informants' interviews, questionnaires, and field measurements served as primary data that play important role in explicitly characterizing the entire study area (**Fig. 2**).

Potential sea level change as climate-relevant stressor or hazard in the entire study area

For this study, future sea level change was assessed using SimCLIM Software, a commercial package and an open-framework computer model system which is user-friendly and allows users to import their own data and examine or customize their climate-proposed study based

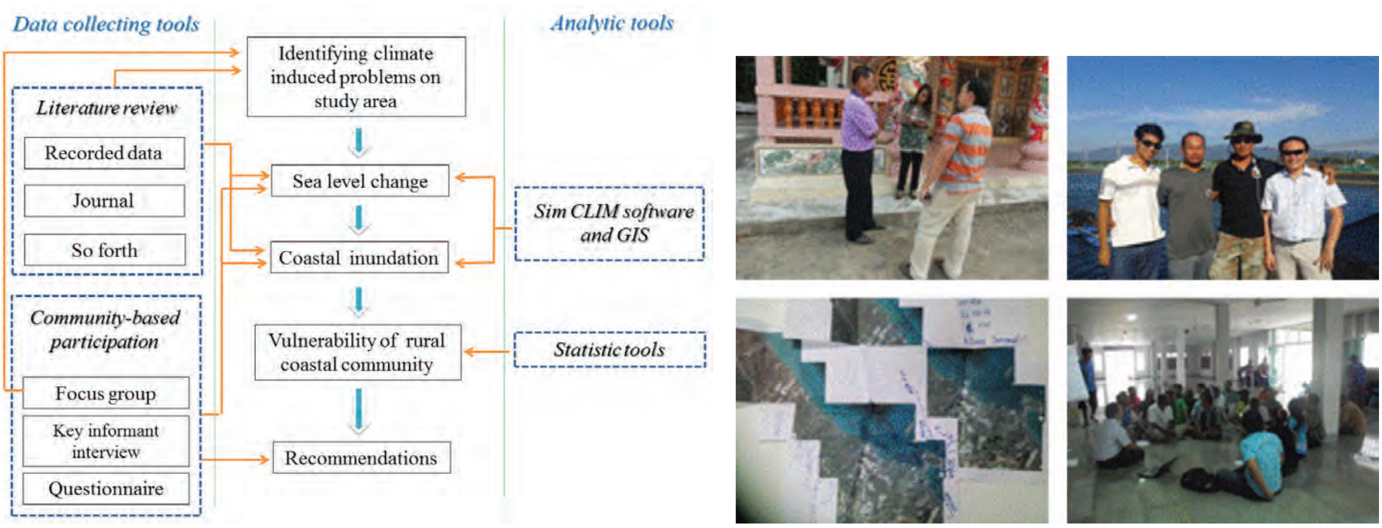

Fig. 2. Data collection for the case study: data collecting and analytical tools used *(left)*; and key informants' interview, questionnaire surveys and field measurements *(right)*

on specific greenhouse gas emissions scenarios (Special Report on Emissions Scenarios in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (AR4)), General Circulation Model (GCM), times and areas (Iglesias-Campos *et al*., 2010). The study therefore simulated the potential sea level change in three years of interest, such as that of 2025, 2035 and 2045, based on a combination A1B and B2 Scenarios accounted in AR4 and GCM of csiro_mk30 in the Coupled Model Inter-comparison Project Phase 3. Two assumptions of man-induced GHG emissions scenarios, *i.e.* A1B and B2 were used and the important inputs were incorporated for the simulation of potential sea level change in the entire study area.

Csiro_mk30 which is a selective GCM was used considering its accuracy in analyzing the observed and simulated data. Moreover, two statistical tools, *i.e.* sample correlation coefficient and standard deviation were used to measure the accuracy (Smith and Hulme, 1998).

Mapping sea level inundations in years of interest and quantifying its negative impacts

Assessment of the inundation was carried out using mostly the techniques provided by the Coastal Service Center of NOAA (2012), with several data inputted such as the volume of potential sea level change in the three years of interest and the DEM which were provided by Land Development Department of Thailand (Thai LDD). These data were necessary to be able to create the inundation map for quantifying the inundated land and the people affected in the years of interest. The inundation-mapping approach and interpretation of the inundated areas were processed by Arc Map 10.1 and illustrated in **Fig. 3**.

In order to evaluate the number of people affected by sea water inundation in each Sub-district under each year of interest, the study firstly calculated the rate of community-inundated areas and quantified the affected households by multiplying the above calculated rate with the entire number of households in each Sub-district. Finally, the affected people were quantified by multiplying the affected households of each Sub-district with the household size.

Results and Discussion

Relative sea level or total sea level which is an accumulation of global and regional sea levels as well as the local conditions has been projected year by year within the 21st century. The total sea level change was measured in terms of different sea levels in 2025, 2035 and 2045 relative to 2000, and presented as cm in three sensitivities: low, medium and high. For simulating the total sea level change, the study made use of the GCM, two GHG emissions scenarios and an observed volume of local sea level change, the latter of which was measured at 10.50 mm/year from the Laemsing Tide-gauge Measuring Station (coordinates: 102.07, 12.4654) during 1993 to 2004. The potential total sea level change was quantified at the same coordinates of the Laemsing Tide-gauge Station and positioned on the same line along the seafront areas in the entire study area. Projection of the volumes of sea level rise made use of the said potential sea level change in the entire study area and calculated using the same position as that of the Laemsing Tide-gauge Station.

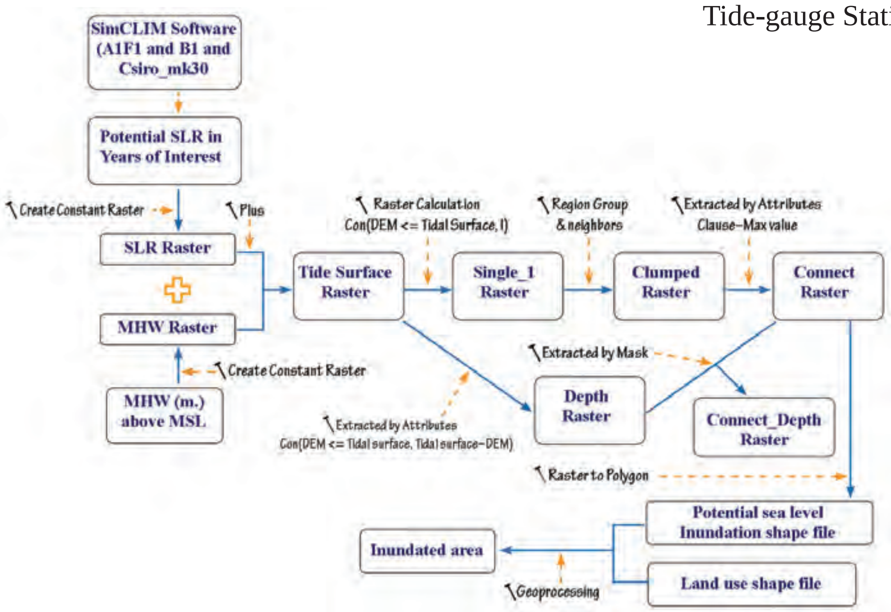

Fig. 3. Approach used to map sea level inundations *(Adapted from approach of NOAA)*

Table 2. Simulated volumes of potential total sea level change (cm) based on combination of csiro_mk30 and both emission scenarios at Laemsing District

Year	Low Sensitivity		Medium Sensitivity		High Sensitivity	
	A1B	B2	A1B	B2	A1B	B2
2000	00.00	00.00	00.00	00.00	00.00	00.00
2025	20.72	20.88	23.22	22.71	25.71	24.54
2035	29.14	29.27	33.28	32.42	37.39	35.56
2045	37.58	37.70	43.69	42.45	49.79	47.19

Increase of sea level in Laemsing District is not skeptical in both GHG emissions scenarios, potentially and inevitably affecting the people in such areas. Over the first 45 years of the 21st century (from 2000 to 2045), based on A1B Scenario and best estimates, Laemsing District will experience 11.00 mm/year sea level rise which is higher than that of B2 at the same estimate, and 12-year rate of observed sea level rise by about 1.54 and 0.50 mm/year, respectively. The total sea level in the whole District would continuously increase and creep from 2000 to 2025, 2035 and 2045 by 23.22+1.97, 33.28+4.13 and 43.69+6.11 cm, respectively.

Likewise, based on the B2 Scenario, the total sea level would also continuously rise in line with the sea level simulation based on the A1B Scenario. The rising volumes of the total sea level could be anticipated at 22.71+1.83, 32.43+3.15 and 42.45+4.75 cm by 2025, 2035 and 2045, respectively (**Table 2**).

In the 21st century, the simulated changing volume of total sea level in Laemsing District, based on A1B Scenario is higher than that of B2 Scenario by about 3.43%. Considering the first 45 years of this century, the total sea level based on A1B is not significantly different from B2 Scenario by 2.92% while a higher difference of about 3.62% during the last 45 years of the century (**Fig. 4**) could occur. In determining the coastal inundation-relevant impacts, the inundated areas and affected people in each aforementioned year of interest were considered based on the above anticipated volumes of total sea level change, the DEM and land use shape file provided by Thai LDD. Overall, the entire study area will continuously face the

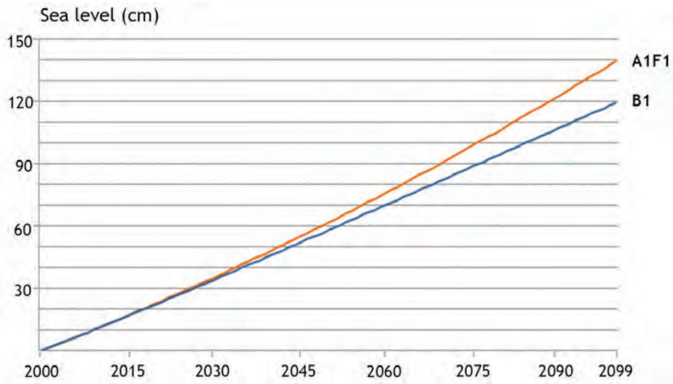

Fig. 4. Trend of the total sea level change in Laemsing District based on csiro_mk30 and both A1B and B2 Emissions Scenarios, in medium sensitivity

severity of inundation associated with increasing total sea level in each year of interest (**Table 3** and **Fig. 5**).

Specifically, aquaculture lands in the study areas are anticipated to be mostly inundated by about 65% (**Fig. 6**) affecting about 12,513.62 rais during 2000-2045 with most of the land loss and affected people occurring in Bangkachai Sub-district. However, the inundation-relevant impacts associated with A1B Scenario are expected to be slightly severe than that of the B2 Scenario.

Based on A1B Scenario, 65% of the total area of Bangkachai Sub-district will be submerged by 2045 while sea level will envelop 44% of the land area in Paknamlaemsing Sub-district. Thus, people in the study areas would be continuously confronted with the worse impacts of potential inundation in line with the inundated lands (**Table 3**).

Table 3. Areas and people affected by seawater inundation in the two Sub-districts in all years of interest

Year	A1B emission scenario						B2 emissions scenario					
	Inundated areas (rais)			Affected people (individuals)			Inundated areas (rais)			Affected people (individuals)		
	2025	2035	2045	2025	2035	2045	2025	2035	2045	2025	2035	2045
Bangkachai	11,752.34	12,439.06	12,787.91	1,220	1,358	1,497	10,933.61	12,415.60	12,722.73	1,185	1,351	1,455
Paknamlaemsing	6,101.13	6,459.56	6,719.59	1,063	1,231	1,384	6,079.49	6,405.69	6,678.06	1,044	1,211	1,357
Entire study area	17,853.47	18,898.62	19,507.50	2,283	2,589	2,881	17,013.10	18,821.29	19,400.79	2,229	2,562	2,812

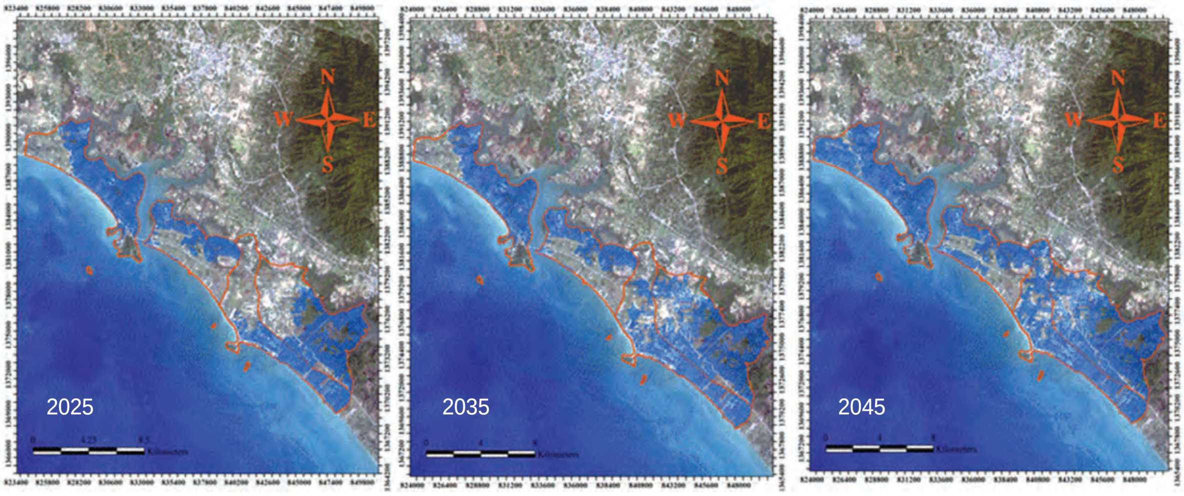

Fig. 5. Inundation maps of the study areas in all years of interest based on csiro_mk30 and A1B Scenario

Over the first 45 years of the century, the number of affected people in Bangkachai Sub-district will be higher than that of Paknamlaemsing Sub-district. During this period, the total sea level which was simulated based on the A1B Scenario will engulf many community areas and affect around 1,497 individuals in Bangkachai Sub-district or about 37% of its total population. In other words, during 2000-2045, around 11 households or 33 individuals will annually bear the brunt of the impacts of inundation. Meanwhile, 1,384 individuals in Paknamlaemsing Sub-district (16% of its total population) will experience sea water inundation or around 31 individuals per year, during the same period.

Conclusion, Recommendations and Lessons Learned

Although preliminary, the study was able to link the potential sea level change and its consequences with the biophysical impacts on people in Laemsing District which has demonstrated the high risk from sea water-relevant events, especially inundation. Using a combination of quantitative and qualitative data and information in regional and local scales, and scientific tools and techniques in climate modeling, GIS and remote sensing and simple techniques for inundation mapping, the study indicated that increase of the total sea level in Laemsing District would be quite inevitable over the 21st century, as simulated using a combination of the GHG emissions scenarios A1B and B2, and csiro_mk30. Based on B2 scenario, the total sea level was anticipated to rise by 42.45 cm and increasing up to 43.49 cm considering the A1B scenario. The continuing and gradually increasing sea level will create creeping impacts to and threaten the rural coastal people in Laemsing District in the future. Based on A1B scenario, approximately 19,507.50 rais or 56% of its entire area will be affected by sea water inundation while about 2881 persons will also affected within 2045. Aquaculture farms which comprise the largest land utilization in the study areas will be largely inundated especially that these

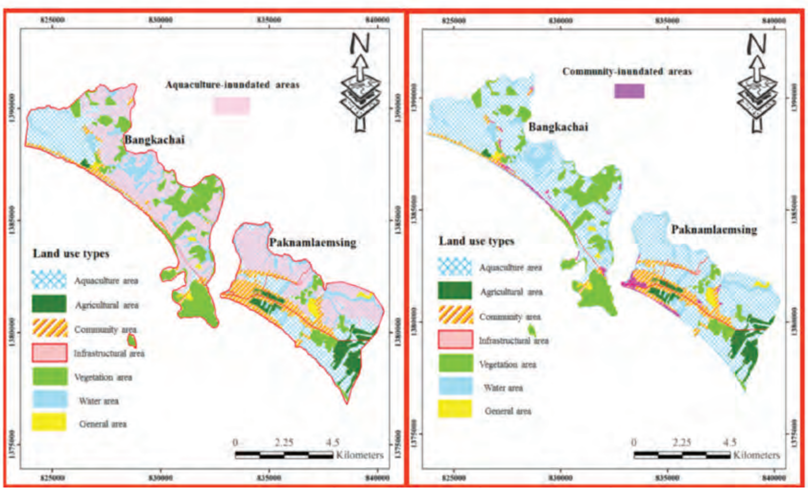

Fig. 6. Inundation maps of aquaculture areas *(left)* and communities *(right)* based on estimates of sea level change from 2000 to 2045

are located in low elevation areas and close to the sea and brackish canals. Bangkachai Sub-district will mostly bear the risk of the potential impacts of sea level change based on both measuring factors, where around 12,787.91 rais will be submerged within 2045 affecting about 1497 individuals. As suggested from the results of the analysis, the impacts of sea level change taking into consideration the A1B scenario would be slightly higher than that of the B2 scenario.

The results therefore indicate that the entire study area is susceptible to sea water inundation. Based on the inputs from the questionnaire survey and key informants' interview, there are several possible solutions that could reduce the risk of sea level change and its impacts. These could include: promoting reduced utilization of artesian well water; enforcing strictly the town's development plans; regular monitoring and maintenance of existing coastal protectors; creating evacuation plans and provisions of resettlement areas; conducting studies on integration of climate adaptation into the integrated coastal management (ICM) approach; and implementing the ICM approach in all coastal area. From the experience obtained from the case study, the application of simple tools and techniques to assess sea level impacts, as well as sophisticated scientific techniques, modeling tools and adequate techniques could provide the insights for developing prioritized options as means of mitigating the impacts of sea level change.

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About the Authors

Dr. Puvadol Doydee is from the Department of Agro-Bio Resources, Faculty of Natural Resources and Agricultural Industry, Kasetsart University, Chalermphrakiat Sakon Nakhon Province 47000 Thailand (email: *pdoydee@yahoo.com*).

Mr. Jirawat Panpeng is from the Office of Natural Economic and Social Development Board (Central Regional Office), 88/38 Moo 4 Talad Khun, Nonthaburi, Nonthaburi Province 11000 Thailand (email: *Jirawat_p@nesdb.go.th; jpanpeng54@gmail.com*).