

## Impacts and Adaptation to Climate Change: A Case Study of Coastal Inundation at Proboliunggo, East-Java

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### Abstract

The vulnerability of communities in coastal areas continues to increase in the face of climate change. The increasing rainfall in one place and droughts elsewhere, high waves and strong ocean winds are real phenomena indicative of climate change. Increasing symptoms of climate change at the same time as a high tide can cause widespread coastal inundation. This can interfere with food security, livelihoods and environmental sustainability (including bio-diversity), and threaten coastal infrastructure. The purpose of this study was to study the impact of climate change and the adaptation and mitigation done by coastal communities in the face of it. The method of this study is the analysis of satellite imagery data, interviews and analysis of the productive land. The results of this study show the occurrence of irregularities such as increased rainfall in 2010, during the period 2002-2011; how flood tides in coastal areas can damage productive land (fish ponds), and submerge residences, public facilities and infrastructure. In Kalibuntu there was flooding to an average water depth of 110 cm over 87.84 Ha for 4-4.5 hours. Coastal communities adapted by raising the ground floor of their houses about 0.5-1 meters and switching to other kinds of job. Flood mitigation involved building a seawall of stacked stone in a trapezoidal shape with groins extending in to the sea. This design has strong resistance and has proven durable. In addition to physical prevention efforts, biological precautions, especially mangrove reforestation, are necessary.

**Keywords:** Symptoms of climate change; Impacts Adaptation/mitigation; Kalibuntu village

### Introduction

#### Symptoms of climate change

Coastal areas are highly dynamic and geo-morphologically complex systems which respond in various ways to extreme weather events [1]. More than one-third of the world's human population lives in coastal areas and on small islands [2]. Considering the fact that 21 % of the world's population lives within coastal zones [1], the potential impacts of sea-level-rise are significant for the wider coastal ecosystem [3]. Climate change is expected to cause accelerated rises in sea-level with elevated tidal inundation, increased flood frequency, accelerated erosion, increased saltwater intrusion, increasing storm surge and increasing frequency of cyclones [4]. The vulnerability of communities living in coastal areas continues to increase in the face of climate change [5-7]. The long-term sustainability of these populations is dependent on the coastal ecosystems and the services they provide, such as storm buffering, fisheries production and enhanced water quality [8].

The increasing rainfall in one place and droughts elsewhere, high waves and a change in strong ocean winds are real phenomena indicative of climate change. Increasing symptoms of climate change, along with high tides, can cause widespread tidal flooding in coastal areas. This can interfere with food security, livelihoods and environmental sustainability (including bio-diversity), and coastal infrastructure was also threatened. The vulnerability of coastal communities and economic sectors to coastal flooding is expected to increase in the coming decades due to both environmental and social-economic changes [6,7]. Coastal floods are regarded as among the most dangerous and harmful of natural disasters [1].

Climate change is expected to cause accelerated sea-level rise with elevated tidal inundation, increased flood frequency, accelerated erosion, rising water tables, increased saltwater intrusion, increasing storm surges and increasing frequency of cyclones [4]. If the frequency of coastal flooding, population growth, development activity and

environmental degradation in coastal areas continue increasing, this suggests that coastal communities should to plan to adapt to such changes. Adaptation is an important strategy in the face of the risk of change. The identification of sections of shoreline susceptible to sea-level-rise is necessary to more effectively manage coastal areas, in order to increase resilience and to help reduce the impacts of climate change on both infrastructure and human beings [9].

The initial concept in the study of climate change in this paper is referring to 'any change in climate over time, whether due to natural variability or human activity' [6]. This concept emphasizes that the causes of climate change involve natural and human factors. The main indicators of the occurrence of climate change are the increasing concentration of carbon dioxide, rising temperature of earth's surface, the melting polar ice caps and sea level rise. Global emissions of greenhouse gases (carbon dioxide, methane, nitrogen oxide,) caused by human activity have increased since the start of the industrial revolution. The increase in emissions makes global warming inevitable: the surface temperature between 1970 and 2004 increased by 0.6°C (the decade of 1990s recorded the highest temperatures), rainfall patterns also change spatially and temporally and global sea levels rose by 0.1-0.2 m [6]. The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period 1901 to 2010 global mean sea level rose by 0.19 (0.17 to 0.21)

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m [10]. Conditions indicate significant symptoms of climate change such as an increase in sea level of about 17 cm in the last century at a rate of 3.3 mm per year, and rising global temperatures are causing ocean warming, decay of ice in the polar regions, the increase in CO<sub>2</sub> concentration, change in salinity, alkalinity and ocean circulation [11,12]. Indications suggest that increased CO<sub>2</sub> in the atmosphere is a major cause of global warming and global climate change [13].

## Method

### Study area

Sub-district Kraksaan by virtue of government regulation No. 2 of 2010 dated January 5, 2010 is the capital District-Province of Probolinggo, East Java. Kraksaan is situated on the north coast of East Java, about 100 km east of Surabaya. The Kraksaan sub-district consists of 13 villages and five urban villages. Kalibuntu village is one of the five coastal villages that is close to the sea along with Asem Bokor, Kebon Agung, Patokan and Asembagus villages (Figure 1) and was 3 km from Kraksaan city.

Kalibuntu village has a total areas of around 100.01 ha that consisting of rice fields (0.3 ha), yards (26.72 ha), fish/shrimp ponds (67.57 ha), a graveyard (2.22 ha) and other uses (3.20 ha) [14]. The population of the Kalibuntu village is about 7,222 people which consist of 3,585 males and 3,637 females. In the village of Kalibuntu, about 1,916 people are fishermen or farmers and about 1,594 are traders [14]. In communities where people depend on marine resources for their livelihood, all activities are strongly influenced by weather conditions making each type of fishing activity seasonal.

### Height of sea level

The data used for the simulation of flood inundation were the average tides in East Java waters and the significant wave heights calculated on the basis of the prevailing winds. The height of significant waves is an important parameter related to inundation areas on the coast [15]. The tide levels in the territorial waters of East Java are as follows (Table 1).

### Calculating the height of sea level

Significant wave height can be determined based on wind data taking into account the length of the fetch in each wind direction. The

Elevation of sea level (m)	
Highest Astronomical Tide (HAT)	1.56
Mean Highest High Water Spring (MHHWS)	0.73
Mean Highest High Water Neap (MHHWN)	0.15
Mean Sea Level (MSL)	0.000192
Mean Lowest Low Water Neap (MLLWN)	-0.45
Mean Lowest Low Water Spring (MLLWS)	-1.03
Lowest Astronomical Tide (LAT)	-1.74

Table 1: Tide heights in East Java.

fetch length is determined by the equation [16].

$$\frac{gHm_o}{Ua^2} = 1.6 \times 10^{-3} \left( \frac{gF}{Ua^2} \right)$$

F<sub>ef</sub> = Average effective Fetch (m)

X<sub>i</sub> = Fetch length measured from the wave observation point to the end of fetch (m)

α = Deviation on both sides of the wind direction by using the increment 6° until 42° on both sides the wind direction.

The height and period of a significant wave can be calculated using the Sverdrup, Munk and Bretschneider (SMB) after the value of the effective fetch was obtained by the following equation [17],

$$\frac{gHm_o}{Ua^2} = 1.6 \times 10^{-3} \left( \frac{gF}{Ua^2} \right)$$

$$\frac{gTm}{Ua^2} = 2.857 \times 10^{-1} \left( \frac{gF}{Ua^2} \right)$$

g = 9,8 m/s<sup>2</sup>

H<sub>m<sub>0</sub></sub> = Height of significant wave (m)

T<sub>m</sub> = Peak wave period (s)

F = Length of Fetch (m)

The height of the tide and waves was then used as input data for the maximum sea level for a simulation of inundation in Probolinggo. The scenario analysis of inundation used "Global Mapper 12" software following [18].

1. If, height of sea level Mean Highest High Water Spring (MHHWS) and average wave height
2. If, height of sea level Mean Highest High Water Neap (MHHWN) and average wave height
3. If, height of sea level Mean Sea Level (MSL) and average wave height
4. If, height of sea level Highest High Water Level (HHWL) and highest wave height

### Shoreline changes

Analysis and detection of long-term changes in the shoreline position of sand beaches was based on the interpretation of remote sensing data and used Landsat7 sensor ETM+ data images from 2000 and 2006. The interpretation of remote sensing data is a common method for the study of continental coastlines and large islands [19].

### Economic valuation

Cost-benefit analysis is one method used in the management of

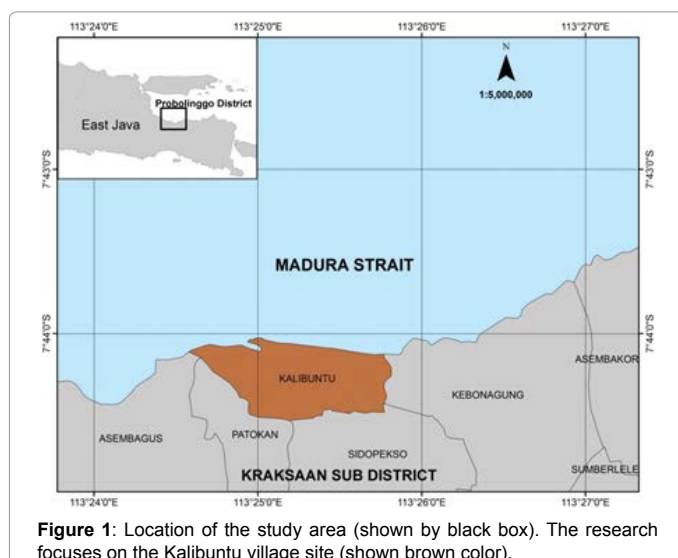


Figure 1: Location of the study area (shown by black box). The research focuses on the Kalibuntu village site (shown brown color).

coastal areas with various forms of Environmental Impact Assessment. However, the weakness of this analysis is that the only aspects that can be measured are those that can be assessed in terms of monetary value. The purpose of this analysis is to compare the cost, or disadvantages, with the benefits or advantages [20]. Cost-benefit analysis was used to calculate the economic value of the natural resources in coastal areas. Cost was something that reduces to an object, whereas benefits the something added to an object.

### Community adaptation

To obtain accurate information about the effects of climate change and the effort of coastal communities to adapt to it, interviews and group discussions were conducted with community leaders and fisherman.

## Results and Discussion

### Symptoms of climate change

Based on an analysis of rainfall data from the Agency for Meteorology, Climatology and Geophysics (BMKG) in Juanda Airport Surabaya-East Java in 2002-2011, the Probolinggo district has its highest

rainfall in February (525.5mm). Relatively high precipitation occurs in December (366.9 mm), January (459.6 mm), and March (401.9 mm), commonly referred to as the west monsoon or rainy season. Conversely the east monsoon or dry season begins in June and decreases until August (4.1 mm). During 2010 there were anomalies in rainfall patterns that continued to increase compared to the average rainfall per month between 2002 to 2011 (Table 2). Based on the observed data for 30 years (1971-2000) in East Java, there has been a shift in the rainy and dry seasons [21].

Based on the analysis meteorology data, there has been a change of wind speed in the rainy season (December-March) on the Probolinggo coast in the period 2004-2010 (Table 3). It is important for fisherman to be careful especially with wind speeds of 10.3 m/s, although they occurrence only momentarily. During the rainy season the wind direction was from the north, but at the certain moments the wind direction was from south (Figure 2). In the dry season the wind direction was from the northeast and occasionally from the southwest (Figure 3). Fisherman should be especially aware of wind speed between 5.5-8.5 m/s which tend to last longer than wind speed 8.5-10 m/s which tend to occur only for short periods of time.

Years	Changes in rainfall (mm) patterns (↗ increased) and (↘ decreasing) Probolinggo and surrounding region 2002-2011											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	↘	↗	↘	↗	↘	0	0	0	0	0	↗	↘
2003	↘	↗	↘	↘	↗	↗	↘	0	0	0	↗	↗
2004	↘	↗	↗	↘	↘	0	↗	0	0	0	↗	↗
2005	0	↘	↗	↗	0	↗	↗	0	0	↘	↘	↗
2006	↗	↘	↘	↘	↘	0	0	0	0	0	0	↗
2007	↘	↘	↗	↗	↘	↗	0	0	0	0	↗	↘
2008	↗	↗	↘	↘	↘	0	0	0	0	0	0	↘
2009	↗	↗	↘	↗	↗	↘	0	0	0	0	0	↘
<b>2010</b>	↗	↘	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗
2011	↗	↘	↗	↘	↗	0	0	0	0	0	↗	↘
Average rainfall	459.6	525.5	401.9	200.7	146.6	34.8	42.7	4.1	25.5	29.2	119.7	366.9

Table 2: Rainfall pattern during 2002-2011 in Probolinggo and surrounding region.

No.	Month	2005	2007	2008
1.	January	8.0 m/s	9.9 m/s	-
2.	December	8.1 m/s	10.3 m/s	-
3.	February	8.0 m/s	-	8.9 m/s

Table 3: Changes in wind speed 2004-2010 at Probolinggo Coast.

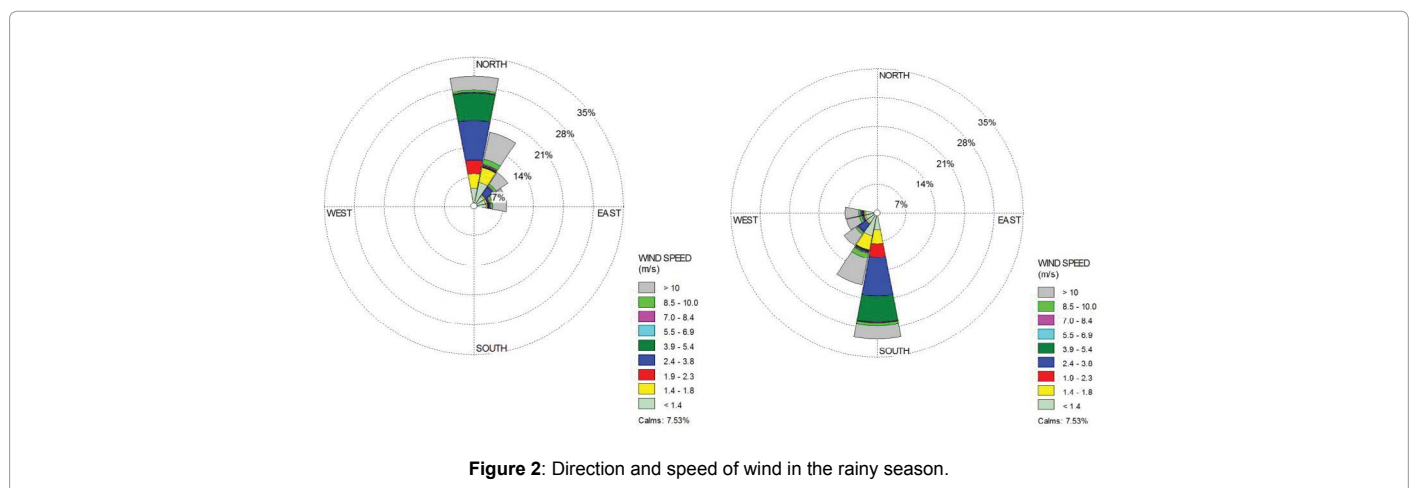


Figure 2: Direction and speed of wind in the rainy season.

### Inundation scenarios

In the rainy season, especially in November-December and in the dry season from June to July, the highest tides occur and coastal inundation tends to be more widespread. At the same time there was a change of wave height and wind speed so that inundation impacts on some coastal areas such as milkfish ponds, salt ponds, crab cultivation areas, rice fields, settlements and infrastructure in coastal environments. Direct measurements during the inundation, show that Kalibuntu village was more affected than other villages (Table 4). An indication of the increase in the level of sea water was that some people have made efforts to raise the level of the ground floor of their houses.

In the first scenario, if the tide height at the Mean High Water Neap (MHHWN) was 0.15 meter and the average wave height is 0.15 meter, the sea level height will be 0.3 meter (Figure 4a). Secondly, if the height of sea at the Mean High Water Spring (MHHWS) 0.73 meter and the average wave height is 0.15 meter, the sea level was 0.88 meter (Figure 4b). In the third scenario, the highest tide of 1.6 meter with an average wave height of 0.15 meter, so that the sea level was 1.75 meter (Figure 4c). In extreme conditions of a 1.6 meter tide and an average significant wave height of 0.7 meter, the sea level height would be 2.3 meter (Figure 4d). The results of the four scenarios show that Kalibuntu was more vulnerable to flood inundation than Randutatah or Gending villages. Inundation scenarios on the coast, assuming the waves and sea level continue to increase, still require further study and the available data for more than 30 years to predict the occurrence of inundation. In addition, the occurrence of inundation needs to be brought to the attention of various stakeholders such as the government, coastal communities and NGOs.

Based on the measurements of the increased inundation at Kalibuntu in July 2012 the widespread impacts of inundation on land use in coastal area can be calculated (Table 5). The areas most extensively affected were the fish ponds (54.44 ha) and the settlement (33.054 ha).

### Shore line change

This study was not based on continuous observation of the changes

in sea level, but based on the assumption that the continuous increase in wave size and rainfall will contribute to shore line changes. Based on the results of the interpretation of Landsat 7 ETM data recorded in 2000 and 2006, shoreline changes can be calculated. Erosion that occurred in Kalibuntu was -4.99 meter/year, which was faster than Gending -1.42 meter/year, whereas accretion of +1.3 meter/year occurred in Randutatah (Table 6). Coastal communities used stone rubble buildings and bamboo in their erosion prevention efforts, though the latter was less effective for slowing it down.

### Economic valuation

Calculation of the economic impact of rising flood tides, predict a total loss of Rp. 158.2 billion (Table 7). The calculation only covers a few types of land uses such as rice fields, milkfish, crab fattening, salt ponds and settlements. Studies are not yet available for use in policy making by local government about the use of coastal resources in an efficient and sustainable manner, both economically and socially, in coastal areas that are vulnerable to inundation. Because of this, the government often does not recognize the significance of the effect of environmental damage on economic activity [22].

### Strategy of adaptation

The community has made efforts to adapt in anticipation of flooding as result of climate change in coastal areas as follows:

#### Increase of ground floor

In general, the most common adaptation done in coastal communities was to increase the height of the ground floor of the house by between 0.5-1.0 meters (Figure 5). Coastal community members that formerly lived near the beach have already left since their settlements were inundated in the 1970-1980's. Based on field studies during the flood tides, there were 15 homes that were inundated for 30-75 minutes. Many people moved on their own initiative, but some of them moved under the direction of the local government. Some other people moved to another residence or village that was more convenient. A Kalibuntu village monograph in 2012 recorded that 49 families that had moved

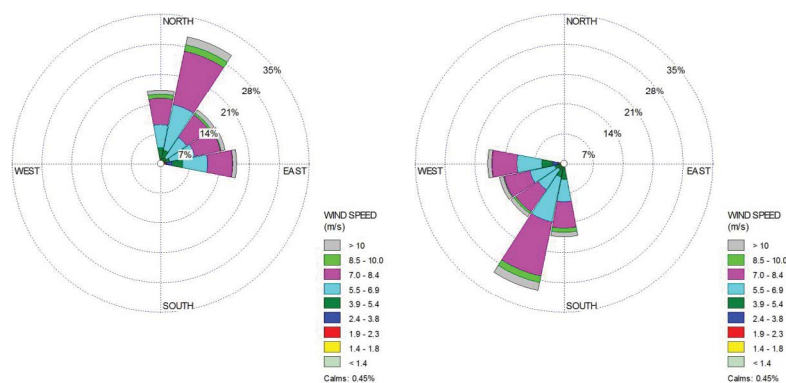


Figure 3: Direction and speed of wind in the dry season.

No.	Locations	Longitude	Latitude	Depth (m)
1.	Kalibuntu village	113.417307	-7.737197	0.110
2.	Gending-1 village	113.312262	-7.769192	0.86
3.	Gending-2 village	113.311814	-7.769567	0.98

Table 4: The depth of water during inundation at Kalibuntu Village.

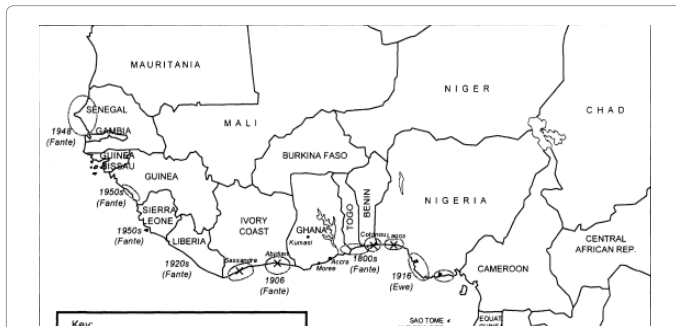


Figure 4a: First scenario.

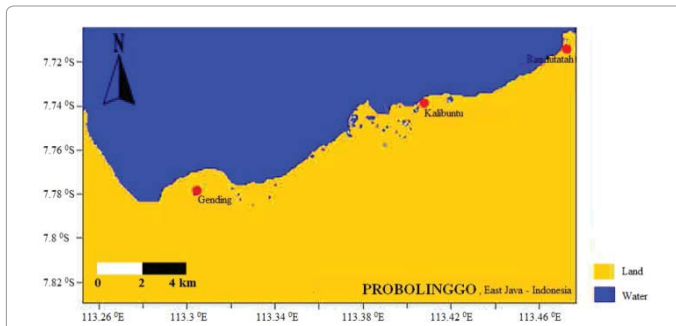


Figure 4b: Second scenario.

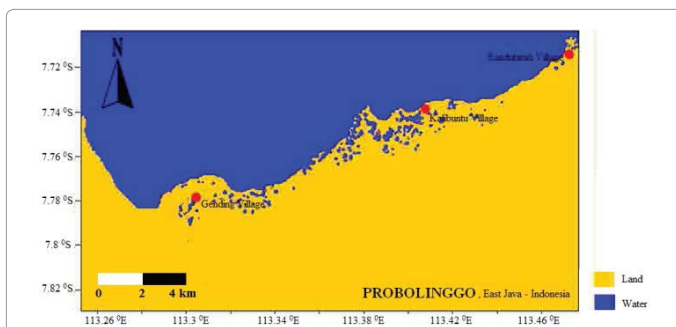


Figure 4c: Third scenario.

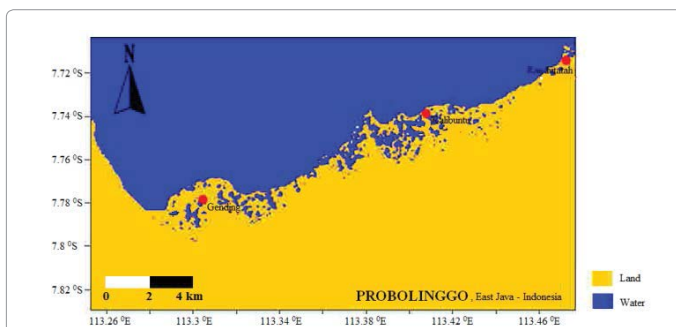


Figure 4d: Extreme condition.

residence. If this displacement was one of the ways the community adapts in anticipation of the impact of tidal flooding, it needs to be studied more deeply.

### Coastal embankments or sea-wall

Another effort for the prevention of damage and loss of land was the

construction of a seawall. The new seawall has a total length of 1225.3 meters along the shoreline of 2147 meters, so the remaining 921.77 meters was still prone to erosion. The estimated cost of construction was around 13.8 billion. The cost of construction of coastal embankments was high, so of course this will be an obstacle for local governments. The construction of seawalls was the responsibility of many parties, involving both local and central government, and in the absence of

No.	Villages	Inundation Land (ha)			Total (ha)
		Rice field	Fish Ponds	Settlement	
1.	Gending	0.46	14.14	-	14.59
2.	Kalibuntu	0.35	54.44	33.05	87.84
3.	Randutatah	-	32.20	-	32.20
	Total	0.81	102.78	33.05	136.64
		(0.59 %)	(75.22 %)	24.19 %	(100 %)

Table 5: Land flooded during high tide.

Villages	Shore line change (m)		
	Erosion	Accretion	Trend (m/year)
Randutatah	10.89	19.67	+ 1.3
Kalibuntu	70.96	40.98	- 4.99
Gending	50.00	41.47	- 1.42

Table 6: The average of Shore line change at Kraksaan Sub-district.

No.	Villages/Land use	Inundation (ha)	Value (Rp/ha)	Economic Loss Rp (000)
1.	Gending:			
	-Rice field	0.456	11,775,000	5,369,400
	-Milkfish Pond	14.139	4,450,000	62,918,500
			I	68,287,900
2.	Kalibuntu:			
	-Rice field	0.35	11,775,000	4,121,250
	-Milkfish pond	54.436	4,450,000	242,240,200
	-Settlement	33.054	50,000,000/105 m <sup>2</sup>	157,400,000,000
	-Mud crab	0.474	11,560,000	739,440
			II	157,647,100,890
3.	Randutatah:			
	-Salt ponds	34.2	12,967,800	443,498,760
	-Rice field	4.0	11,775,000	47,100,000
			III	490,598,760
			I+II+III	158,205,987,550

Table 7: Economic valuation on coastal flood.



Figure 5: Increase of ground floor level to adapt to higher tides.

cooperation between central and local governments, the communities who live in coastal areas will be increasingly vulnerable.

Observations of seawall protection in the villages of Randutatah, Kalibuntu and Gending have the found three different models of coastal embankments (Figure 6a-6c). The type shown in photo 2c proved to be more robust and durable in comparison with the other types of embankments 2a or 2b. Type 2c has stone crevices that can reduce wave energy.

### Fishing communities

The process of salt production is highly dependent on the weather. The problem faced is that it was difficult to predict changes in precipitation. There has been a shift in the timing of rainy and dry seasons [21]. Based on observation for 30 years (1971-2000) the seasons have shifted and occur 10-20 days later. In general, the period of the rainy season ranges from November to May and the dry season from June to October. Extreme weather phenomena occurred in 2010 across the Indonesian region during the rainy season. These extreme conditions disrupted salt production which can usually be done 2-4 times/month for 6 months but which could only be done for 2-3 months.

An effort to increase the production of salt has been promoted by the Ministry of Marine Affairs and Fisheries, through the empowerment program for the development of salt producers (Pemberdayaan Usaha Garam Rakyat: PUGAR). The goal of this program is to increase the production of salt with regular flow of sea water through the ponds allowing the salinity to increase gradually through evaporation. Other community efforts in the face of climate irregularity include

communities: delaying the processing of salt, switching to fishing, providing agricultural labor in other villages and saving their abundant salt production, especially at the peak of production in September (Figure 7a and 7b).

### Mangrove plantation

A possible short-term community activity that can be performed in the coastal area of Kalibuntu was planting mangroves. The mangrove species that can be developed, among other types, include *Rhizophoraspp* that grows in muddy environments around the mouth of the river, *Avicennia marina* that can grow in the muddy sand on the beach and *Bruguiera spp.* that grows on coarse sand substrate very close to the mainland. The mangrove planting can be done gradually, step by step, starting in the more protected areas (Figure 8). Planting starts from a relatively safe location of the waves of the sea (sea wall) or away from the beach (A). Selection of mangrove seedlings adapted to the substrate types and the planted with the group. If this manner can grow and develop properly, then the next step at the location near the beach (B).

### Conclusions

1. Indications of climate change are generally perceived by all the coastal communities in Kalibuntu. It has not been fully realized by the public, that these are actually symptoms of a long process of climate change, rather than just uncertain and changing seasons.



Figure 6a: Embankments and groin with stone cement, b. Embankment without groin and stone cement, c. Embankments and groin with stone crevices.

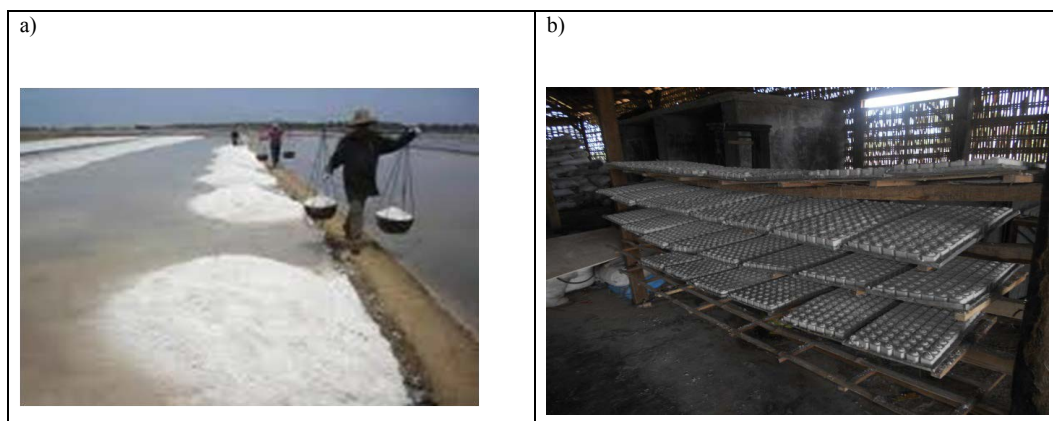


Figure 7a: Peak salt production, b. Salt production management.



Figure 8: Strategic of mangrove rehabilitation.

2. The impact of climate change was already disturbing regular activities and the productivity of land, aquaculture ponds and the livelihoods of fishermen. Flood tides are increasing and becoming more widespread from year to year, resulting in high economic losses for productive land.
3. Community adaptation strategies in the face of changes that occur in the coastal environment include: increasing the height of the floor of homes to anticipate flood tides, making embankments to dampen and reduce the rate of abrasion, and, some people are permanently moving to another village.

## Recommendations

1. To plant mangroves such as *Rhizophora* sp., *Bruguiera* sp., *Aveicennia* sp. in selected locations safe from the influence of the wave.
2. To study and develop potential adaptations and forms of flood mitigation so that the government was better able to coordinate stakeholder programs for integrated coastal zone management.

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