Restoration of coastal ecosystems as an approach to the integrated mangrove ecosystem management and mitigation and adaptation to climate changes in north coast of East Java

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Abstract
Climate change is very basic and appears on earth. Climate change has become an issue that must be faced by humans today and in the future. One of the impacts of climate change can be found in coastal areas. Tsunamis and tidal floods repeatedly occur in coastal areas. One of the efforts to overcome sea level rise that causes tsunamis, erosion, and tidal flooding is mangrove forests. This study aims to determine public awareness of the occurrence of tidal flooding and tsunami and to find an easy and inexpensive way to overcome it. This research is integrated using the partial least square (PLS) approach and the coastal vulnerability index (CVI) approach to mangrove forests. The results showed that the awareness and assessment of the community to carry out mangrove forest restoration to overcome disasters caused by climate change must be managed and handled with a co-management approach.

Keywords Climate Changes · Mangrove Restoration · PLS · CVI · Mitigation · Adaptation

Introduction
Climate changes due to global warming have changed rain intensity and duration, temperature fluctuations, wind, and tropical storm frequency, and other climatic phenomena (Seneviratne et al. 2012; Sofian and Nahib 2010; Trenberth 2011). Climate change has altered nature, and the future risks for humans are prolonged suffer (Otto et al. 2017; McMichael 2012). Therefore, we need immediate, quick, and large-scale actions to reduce emissions because the average global temperatures are predicted to reach or pass the warming threshold to 1.5 Celsius degrees within 20 years (Frölicher et al. 2018; King and Karoly 2017). The impacts of global warming on human life are increasing and expanding drought, widespread diseases like malaria, increasing the frequency of storms, sea level rise, effects on agricultural production, heat waves, forest fires, destruction of marine ecosystems, and animal extinction (Ortiz-Bobea et al. 2021; Alig et al. 2011; Wents 2016).

The coastal region is a vulnerable region to sea level rise. Sea level rise potentially endangers coastal regions (Mcleod et al., 2010). This condition will bring social, economic, and cultural impacts (Stephens et al. 2018; Yan et al. 2016). Climate change affects manufactured infrastructures and coastal ecosystems in coastal areas and causes catastrophes, such as coastline erosions, coastal flooding, and water pollution.

These issues have become a concern in many countries. Coping with additional pressures of climate change may require a new approach to manage land, water, waste, and coastal ecosystems (Mandal et al. 2021; Toimil et al. 2020). Therefore, many countries create innovations to cope with
the impacts of climate change in coastal areas (Hsin-Ning et al. 2017; Kaspersen et al. 2016).

The ICCSR (2010) reports that Indonesia’s sea level will increase by 10 to 50 cm with an average increase of 25 to 30 cm by 2050. Meanwhile, the IPCC (2019) reports that the height above sea levels increases by an average of 0.86 cm per year. The leading causes of rising sea levels are thermal expansion of the ocean and iceberg melting in polar regions (ICCSR 2010).

Oceans absorb 90% of greenhouse gases trapped in the atmosphere, and this condition increases and expands seawater temperature. Consequently, seawater volumes increase. Greenhouse gases will melt the glaciers and ice sheets in the arctic; thus, the amount of water in oceans will increase (Lindsey 2021). Sea level rise (SLR) escalates and worsens the frequency of extreme sea levels (ESLs), leading to beach flooding. The global mean surface level (GMSL) is a function of the global mean surface temperature (GMST). Therefore, targets of temperature stabilization have essential implications for the risks of coastal flooding; for example, 1.5 C and 2.0 C of warming above pre-industrial level as mentioned in the Paris Agreement (Rasmussen et al. 2018). To date, few studies have investigated the impacts of climate change on shoreline change. First, the shoreline data is inadequate or cannot be solved temporally to analyze the dynamics of coastlines. Second, relative sea levels along the coastlines are generally known in an area that has a tide gauge. These two challenges can be solved due to the increasing number of mutually complementing observations of shoreline change and geodetic engineering. Different interpretations regarding the sea level rise in the coastline change recently highlight the need to conduct specific studies that rely on local observations and applicable models in the local geomorphology context. Cozanneta et al. (2014) state that understanding the dynamics of coastlines requires shoreline data that are frequently insufficient or cannot be solved temporally. Besides, data of sea levels along the coast is generally unknown because there are only a few tide gauges. Moreover, this problem can be solved because the observations of shoreline changes have increased; thus, they mutually complement.

Various interpretations regarding the sea level rise in the coastline change recently highlight the need to conduct specific studies that rely on local observations and applicable models in the local geomorphology context. Zacharioudaki and Reeve (2011) state that the current climate scenario and future projections report there statistically significant changes to wave climate conditions. For the scenario of future emissions, the most notable change occurs during the late summer from medium to high fluctuations and during the late winter from medium to low fluctuations. Finally, the critical points to manage coastal are observing the significant shoreline changes in the future wave direction and comparing them with wave height fluctuations.

Soefian (2010) explain that the increasing sea surface temperature (SST) in the Indonesian sea varies from -0.01°C/year to +0.04°C/year, and the highest increase trend occurs in the north coast of Papua Island and the lowest occurs in the south coast of Java Island. The decrease of SST on the south coast of Java Island does not happen in the long term. This decline is probably caused by growing upwelling in the southern coast of Java Island due to the increasing frequency of El Nino (Soefian 2010). The sea level rise changes current patterns, increases erosion, changes shorelines, and reduces wetland areas along the coast. In the end, wetland ecosystems in coastal areas may be damaged if the sea level rise and the sea surface temperature exceed the maximum limit of the adaptation capacity of marine biotas.

The SST is predicted to increase from 0.6°C to 0.7°C by 2030, and will reach 1°C to 1.2°C by 2050; these numbers are relative to the average SST in 2000. Meanwhile, the SST will rise from 1.6°C to 1.8°C by 2080 and will reach 2°C to 2.3°C by 2100. Compared to the data of SST paleoclimate in the Western Pacific Ocean, this phenomenon indicates that the SST will reach the highest rise in 2050 since 150,000 years ago. In addition, the sea level rise increased along with the increasing SST due to thermal processes and the increasing water from melted ice glaciers in Greenland or Antarctica. The potential increase in SST follows the expanding temperature and the melted ice (Soefian 2010).

Climate change brings impacts to Indonesian cities and potentially sinks coastal areas due to the declining land surface. Land subsidence or land subsidence often occurs in the coastal lowlands of Indonesia. The Road Map research (2019) revealed that 21 provinces and 132 districts or cities in Indonesia are indicated to encounter subsidence, particularly in coastal areas. Therefore, coastal lowlands need mitigation and adaptation subsidence. Dobben et al. (2012) state that the vegetation in coastal areas is expected to change due to sea level rise; these changes can be interpreted as the loss of diversity that will decline common species but increase rare species in extreme habitats. However, Dobben et al. (2012) did not discuss the existence of mangrove vegetation to prevent sea level rise towards the mainland. Mangrove vegetation is currently shrinking due to an anthropogenic process. In fact, the density of mangrove vegetation is necessarily improved to protect coastal areas from abrasion. Whidayanti et al. (2021) support this opinion and state that the more extensive and dense the mangrove vegetation in a region is, the lower the abrasion rate will be. However, if the region’s area and density levels are low, the abrasion will possibly become greater.

Xiaoxu et al. (2016) argues that community awareness and human vulnerability to potential health impacts due to climate change are active agents. Humans can control the effective use of technology and resources, community awareness, and health effects by adopting proactive measures,
including a better understanding of climate change patterns and their effects on health.

Based on research by Brown et al. (2020) stated that global mangrove forests have experienced fragmentation and Indonesia is one of the countries with high rates of deforestation due to land conversion. For this reason, Cinco-Castro and Herrera-Silveira (2020) states that well-conserved mangroves have low vulnerability and are in good health because of their high sensitivity. Meanwhile, mangroves that are affected by human activities are more vulnerable in terms of sensitivity and adaptive capacity. In the research area, the mangrove forest is degraded because it is heavily influenced by human activities. Thus, mangrove restoration is an option to improve a healthier coastal environment.

Research on mapping public awareness of disaster was conducted to more comprehensively observe public perception and appraisal of disasters and analyze shoreline change. Thus, the research could cope with the impacts of climate change by restoring coastal and mangrove forests as a “bodyguard” and integrated effort to manage coastal ecosystems, draft mitigation, and adapt to climate change. This study was conducted on the south coast of East Java Province, an area constantly inundated by water due to tidal flooding and tsunami. BMKG (2020) also reported a similar recurring condition and predicted that coastal flooding or rob would occur on May 27-28, 2020. Sea tides, high waves, and high rainfall can affect the dynamics of coastal regions in Indonesia, such as the south coastal region of East Java, and trigger coastal flooding (rob). BMKG explains that these conditions can disrupt transportation around the harbor and coastal, activities of salt farmers and inland fisheries, as well as loading and unloading activities in ports. The south coastal area of Java experiences a more severe impact of tidal waves and flooding. Hundreds of buildings, such as houses, gazebos, stalls, beach slopes, and buildings on the coast are damaged. In Lumajang, 300 children and women were displaced.

This study aimed to determine public awareness of disasters and map the vulnerability of coastal areas that required immediate, simple, and inexpensive management due to climate change. The results will be used to develop mitigation strategies and adaptation utilizing an approach of mangrove forest restoration.

Coastal ecosystem restoration is a comprehensive concept and approach to overcome the degradation of coastal ecosystems with interconnected ecosystems. This approach is the basis for restoring damaged (micro) mangrove forests. Integrated restoration of mangrove ecosystems is the method of restoring mangrove forests using the principles of scientific integration which include the PLS model, CVI model by assessing variables of geology, geomorphology, elevation/altitude, shoreline change, relative sea level rise, the average tidal wave, and significant wave height. While the results of the combination of the two models above produce a mitigation and adaptation model adapted to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.33/Menhk/Secretariat/Kum.1/3/2016 concerning the Guidelines for the Preparation of Climate Change Adaptation.

Therefore, this study necessarily composed mitigation and adaptation models using a co-management-based cooperation approach in coastal areas of Lamongan and Gresik Regencies with a coastal length of 187 Km. These areas are prone to tidal flooding and tsunami. CNN Indonesia (2021) and kompas.com (2020) report that flood frequently submerges coastal areas of Lamongan and Gresik, and flood puddles have increasingly widespread. Therefore, this study mapped public appraisal and awareness of disasters due to tidal flooding as well as classified and identified the susceptibility of coastal areas.

### Materials and methods

This research was conducted in coastal areas of Lamongan and Gresik Regencies, as shown in Fig. 1.

Central Bureau of Statistics of Lamongan Regency (2020) mentions that astronomically, Lamongan Regency is located 6° 51' 54" to 7° 23' 6" south latitude and between 112° 44' 41" to 112° 33' 12" east longitude. Geographically, Lamongan shares borders with other areas: the Java Sea in the north, Gresik Regency in the east, Jombang and Mojokerto regencies in the south, and Bojonegoro and Tuban Regencies in the west. Lamongan Regency covers 1,812.8 km2 or 3.78% of the area of East Java Province. Lamongan Regency consists of 47 miles of coastline and 902.4 km2 of marine area calculated 12 miles from the sea surface Tables 1 and 2.

The Central Bureau of Statistics of Gresik Regency (2020) describes that Gresik Regency is located between 112° 00' - 113° 00' East longitude and 7° 00' - 8° 00' South Latitude. It shares borders with several areas: the Java Sea in the north, Sidoarjo Regency in the south, Lamongan Regency in the west, and Madura Strait in the east. Almost one-third of Gresik's territory is coastal, consisting of along Kebomas District and some parts of Gresik, Manyar, Bungah, and Ujungpangkah Districts.

This study focused on excavating public opinions and judgment on coastal areas in Lamongan and Gresik Regencies. These areas are exposed to tidal flooding and inundation every year. Public opinion and appraisal were employed as the basis of cooperation among stakeholders. It is necessary to map vulnerable coastal areas using the coastal vulnerability index (CVI) to facilitate and direct stakeholders on areas requiring direct handling. This research interviewed several respondents in two regencies, as follows Table 3:
Fig. 1  Map of the research sites

Table 1  Flood in Lamongan in 2015–2020

| Year | Flooded areas                  | Number of families | Flooded agricultural land (Ha) | Flooded pond land (Ha) |
|------|--------------------------------|--------------------|-------------------------------|------------------------|
| 2015 | 6 Districts (39 Villages)      | 2,159              | 182                           | 3,790                  |
| 2016 | 11 Districts (83 Villages)     | 8,670              | 4,373                         | 1,522                  |
| 2017 | 12 Districts (88 Villages)     | 4,006              | -                             | 4,384                  |
| 2018 | 9 Districts (40 Villages)      | 3,921              | 1,710                         | 2,350                  |
| 2019 | 6 Districts (35 Villages)      | 3,391              | 100                           | 3,325                  |
| 2020 | 17 Districts (115 Villages)    | 9,610              | 1,120                         | 6,513                  |

Source: BPPD Lamongan in 2015–2020

Table 2  Flood in Gresik in 2015—2021

| Year | Flooded areas                  | Height of flood (Families) | Flooded settlements (Families) | Number of people dead |
|------|--------------------------------|-----------------------------|--------------------------------|------------------------|
| 2015 | Benjeng District               | 30 -100 cm                  | 1,245                          | 9,857                  |
|      | Cerme District                 |                             | 655                            |                        |
|      | Menagnti District              |                             | 581                            |                        |
| 2021 | Cerme District comprises of Gurang Anyar, Dungus, Morowudi, Iker-Iker, Cerme Kidul, Pandu, Jono, Tambak Beras, and Banjarsari Villages | 5 – 45 cm | 760 families | Not found |
The coastal vulnerability index (CVI) method was done by assessing variables of geology, geomorphology, elevation/altitude, shoreline change, relative sea level rise, the average tidal wave, and significant wave height. These variables strongly affected coastal region changes. Determining the CVI parameters was necessary to overcome threats of damaging coastal areas and formulate strategies and action plan mitigation to minimize the impacts of coastal damage (Pendleton et al., 2005), Thieler and Hammar-Klose (1999), Gornitz et al., (1994), Shah et al. (2013). Data to analyze CVI included CVI of Lamongan and Hammar-Klose (1999), Gornitz et al, (1994), Shah et al.

This study mapped 129 respondents' opinions and appraisal using the PLS method with a list of questions referring to five goals: the hazards or natural disaster assessment, vulnerability assessment, capacity assessment, resource management in a disaster situation, and risk analysis. Table 4 shows the list of questions answered by one respondent.

Based on the above questions, this research composed the PLS structural model of Lamongan and Gresik coastal areas, as presented in Fig. 2.

Structural model that emerged from the results of SEM modeling using SmartPLS 3.0. This is in accordance with the INNER MODEL which is a structural model used to predict causality relationships between latent variables or variables that cannot be measured directly. The structural model (inner model) describes the causal relationship between latent variables that has been built based on the substance of the theory.

The software used is SmartPLS 3.

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### Results and discussion

#### Results of the PLS analysis

The PLS software operation revealed that the construct correlation between the assessment of hazards or natural disasters and its indicators is higher than the correlation between assessment indicators of hazards/natural disasters and other indicators. The construct correlation between vulnerability assessment and its indicators is higher than that between vulnerability assessment indicators and other indicators. The construct correlation between source management in a disaster condition and its indicators is higher than that between vulnerability assessment indicators and other indicators. Similarly, the construct correlation between the risk analysis and its indicators is higher than the correlation between risk analysis indicators and the other indicators. These findings show that latent constructs predict that indicators on their blocks are better than those on other blocks.

Based on Table 7, this concludes several points.

1. The output results show the AVE value of each construct is greater than 0.5. The constructs of hazards/natural disaster assessment, vulnerability assessment, capacity assessment, risk analysis, and resource management in a disaster situation were good models. Therefore, it was estimated that all constructs in the model met the discriminant validity criteria.

2. Composite reliability is considered significant if its value is above 0.70. Table 7 signifies the composite reliability value of the risk analysis variable by 0.946, resource management in a disaster situation by 0.988, capacity assessment by 0.988, vulnerability assessment by 0.985, and hazards/natural disaster assessment by 0.976. The composite reliability values of the five constructs in the model are greater than 0.70. Therefore, the measurement or outer models with reflexive indicators show a very high validation rate. In other words, the indicators of the hazards/natural disaster assessment, vulnerability assessment, capacity assessment, risk analysis, and resource management in a disaster situation completely reinforced or could measure their latent variables. Moreover, the model in this research met the composite reliability.

3. The R-squared for the risk analysis variables was 0.413. This number denoted that the capacity assessment influenced the risk analysis by 41.3%. Meanwhile, other factors influenced the other 58.7%. The R-squared value of the resource management variable in a disaster situation was 0.801. This number denoted that the risk analysis and vulnerability assessment influenced the resource management in a disaster situation by 80.1%. Meanwhile, other factors influenced the other 19.9%. The R-squared value of the capacity assessment variable was 0.415. This number interpreted that the assessment of dangers or natural disasters influenced the capacity assessment by 41.5%. Meanwhile, other factors influenced the other 58.8%.

4. The R-squared value of the vulnerability assessment variable was 0.511. This number indicated that the assessment of dangers or natural disasters influenced the vulnerability assessment by 51.5%. Meanwhile, other

### Table 3 Location samples in two regencies in East Java

| No | Type of respondents | Coastal areas | Lamongan regency | Gresik regency |
|----|---------------------|---------------|------------------|----------------|
| 1  | Village government Local communities (including small employers) | 10 people | 10 people |
| 2  | 55 people | 54 people |
Table 4  List of questions referring to five goals

No  List of Questions

1.  A. Assessment Variables of Hazards or Natural Disasters
   A.1.1 Disasters occurring in these areas are combined effects between natural disasters (e.g., landslides of soil slopes due to heavy rains) and disasters due to human activities (e.g., logging of mangrove trees, reclamation, agricultural planting, and mining).
   A.1.2 Conflicts in these areas are due to human activities, such as pond development, mining excavation, and other activities destructing mangrove forests in coastal areas.
   A.1.3 Natural disasters in coastal areas, such as flood puddles, flash floods, or flooding, are due to heavy rainfall.
   A.1.4 Flood hazards cause many people to suffer from diarrhea, skin diseases, and other diseases.
   A.1.5 The local government institutions dealing with disasters have documented floods.
   A.1.6 The officers record the danger of floods and directly observe the field.
   A.1.7 The local authorities identify causes of floods by explaining the frequency, seasons, geographical regions of disasters, and cyclical or seasonal weather systems.
   A.1.8 Flood with the quick or slow flow will spoil any flooded objects.
   A.1.9 Flood in the past was more severe than that today.
   A.1.10 Recent floods have much greater physical impacts on infrastructures.
   A.1.11 It is necessary to create a trend to identify the occurrence of floods. Therefore, changes in frequency, season, location, and intensity patterns are identifiable and well-informed decisions on programming can be applied.
   A.1.12 Local government necessarily estimates the frequency and probability of rain and floods considering return periods.
   A.1.13 Flood in the past was more severe than that today.
   A.1.14 Earthquakes will probably increase due to releasing energy or climate change.

2.  B. Vulnerability Assessment Variables
   B.1.1 Individual or family vulnerability refers to a condition caused by inadequate basic necessities of life, such as basic needs, clean water, etc.
   B.1.2 the Impacts of floods will reduce the government's asset values.
   B.1.3 Intervention from the government or NGOs aimed to protect and enhance communities' assets and livelihoods affected by natural disasters.
   B.1.4 Society's economic vulnerability is caused by debt and the absence of savings, access to credit, and insurance.
   B.1.5 Natural disasters damage physical conditions and infrastructure in coastal areas.
   B.1.6 Society's social conditions do not guarantee security levels or access to education.
   B.1.7 The local government provides minimal access to assistance.
   B.1.8 The government still upholds human rights in addressing flood damage.
   B.1.9 When a disaster occurs, traditional values, such as cooperation, are still upheld as guidelines to overcome the vulnerable community.
   B.1.10 During the disaster, women in a family play an essential role in protecting children and the elderly and maintaining health, nutrition, and physically disabled family members.
   B.1.11 When a disaster occurs, people outside the disaster area assist.
   B.1.12 When a disaster occurs, each individual receives different impacts.
   B.1.13 When a disaster occurs, the poor usually are affected the most.
   B.1.14 Individual or family vulnerability refers to a condition caused by inadequate basic necessities of life, such as basic needs, clean water, etc.

3.  C. Assessment Capacity Variables
   C.1.1 Disasters do not cause significant damage to life or property because they occur in an area without inhabitants.
   C.1.2 Before a disaster occurs, the government informs the community to leave a disaster area.
   C.1.3 Before a disaster occurs, the community has taken actions to prevent or reduce the damaging impacts of disasters.
   C.1.4 When a disaster occurs, not all people in a disaster area have identical suffering.
   C.1.5 People who have known the emergence of disaster can immediately save themselves and their property.
   C.1.6 The local government has the policy to determine a community for the community during a disaster to reduce the damaging effects of dangers and secure sustainable livelihoods.
   C.1.7 The government could handle the previous disasters by counseling the community before a disaster occurs (the local government's reduction strategy).
   C.1.8 The local government is experienced in analyzing which resources will be affected by a disaster to reduce the risks.
   C.1.9 The local government anticipates a disaster by providing various needs required by the affected community and determining which institution will be responsible for delivering and controlling food.
   C.1.10 The local government has a policy and strategy to reduce disaster risks on the community and increase their ability to cope with disasters.
   C.1.11 The local government anticipates a disaster by training and providing counseling to the community. Therefore, the community can adjust themselves to disasters occurring in the future.
   C.1.12 The government trains the community by providing information about disaster prevention or mitigation.
   C.1.13 The local government gives aid, such as rice, social cash assistance, equipment, employment, etc.
   C.1.14 The community can handle or control all types of emerging threats, live normally, have adequate food and clean water, and receive better health services to prevent any disease.
   C.1.15 After the disaster, the community was assisted by the police, army, and local government officials to buy materials and equipment to rebuild their house destroyed by the disaster.
   C.1.16 Social organizations help communities confront, resist, and deal with possible threats in the future.
   C.1.17 Many social organizations or NGOs help the community during the disaster.
   C.1.18 Local social institutions that care about disaster provide much physical and non-physical assistance to the community.
   C.1.19 These social institutions support people affected by disasters to realize their abilities and have the self-confidence to deal with the crisis more significantly. Therefore, they can have control over an event and the power to change their conditions and become invulnerable to any threat.
factors influenced the other 48.9%. The variable of the danger or natural disaster assessment was an independent variable affecting the dependent variables. Therefore, it did not have an R-squared value.

The outer loading for the variable of the danger or natural disaster assessment confirmed that the 14 indicators had outer loading greater than 0.7 with P-values <0.05. This finding concluded that 14 indicators of the variable of the danger or natural disaster assessment met the convergent validity and significantly measured the variable of the danger or natural disaster assessment. Indicator A1.13 had an outer loading of 0.907, and indicator A1.2 had an outer loading of 0.803.

The outer loading for the vulnerability assessment variable confirmed that 14 indicators had outer loading greater than 0.7 with P-values <0.05. This finding concluded that 14 indicators of the vulnerability assessment variable met the convergent validity and significantly measured the vulnerability assessment variable. Indicator B1.8 had an outer loading of 0.935, and indicator B1.1 had an outer loading of 0.895 Table 8.

The above table summarizes several points of the respondents in Lamongan and Gresik.

1. The assessment of hazards or natural disasters was very high.
2. The vulnerability assessment was very high.
3. The capacity assessment was very high.
4. The resource management in a disaster situation was very high.
5. The risk analysis was very high.

Results of the CVI analysis

The results of the CVI analysis were divided into the CVI of Lamongan Regency and the CVI of Gresik Regency. This division aimed to determine the vulnerability of coastal areas in each regency. The grid was necessarily created to determine the CVI values of two districts. The grid was created with a size of 5x5 km; thus, 21 grids were formed in the two regencies. This step was done to simplify the analysis of vulnerability levels in coastal areas of Lamongan and Gresik Regencies. The following table summarizes vulnerability categories and the weight of scores of the CVI variable.

Based on the above table, the CVI map was compiled and shown in Fig. 4 with cell divisions of G1 – G7 for coastal regions of Lamongan and G8 – G21 for coastal regions of Gresik.

Figure 5 shows that each cell measured CVI based on six criteria following Table 9. These criteria included aspects of geomorphology, erosion/accretion, the average wave height, coastal slopes, tidal range, and sea level rise. The result is presented in maps shown in Figs. 6, 7, 8, 9, 10, and 11. The figures indicated that the results of calculating the CVI then grouped the regions into three vulnerability levels: vulnerable, moderate, and very vulnerable. The coastal areas of Lamongan and Gresik had a moderate vulnerability level. Meanwhile, the calculation results (Tables 8, 10) revealed that 16 coastal areas of Gresik had a high vulnerability level. Almost all coastlines of Gresik and Lamongan had a moderate vulnerability level. Although the majority of areas of
Gresik and Lamongan showed a moderate category, disasters occurred sporadically there.

**Adaptation and mitigation strategies**

The adaptation and mitigation strategies in the coastal areas of Lamongan and Gresik were prepared by considering local wisdom and referring to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.33/Menlhk/Secretariat/Kum.1/3/2016 concerning the Guidelines for the Preparation of Climate Change Adaptation. Article 9, point 2 of the Regulation of the Minister of Environment

Number P.33/Menlhk/Secretariat/Kum.1/3/2016 states that the determination of priority actions for climate change adaptation referring to paragraph (1) must consider the following points:

1. Coverage of regions and/or sectors associated with climate risks,
2. The area of regions and/or sectors affected by climate change,
3. Resources needed,
4. Potential constraints in implementing climate change adaptation,
5. Benefits from implementing climate change adaptation,
6. Period of the benefits of climate change adaptation,
7. Acquiring investment benefits of climate change adaptation, and
8. Institutional capacity to implement climate change adaptation.

Table 10 summarizes several occurrences in the coastal areas of Lamongan and Gresik. 1. The changing situation
Fig. 3 Coast line Lamongan Gresik

Table 5 Data of CVI measurement of Lamongan

| Cell  | Parameters               | Coastal slopes | Abrasion (-)/Accretion (+) | Tidal ranges | Significant wave height | Sea level rise |
|-------|--------------------------|----------------|-----------------------------|--------------|-------------------------|----------------|
| G1    | Mangroves, Coral Reefs, Muddy | 0.15           | 8.36                        | 0.4776       | 0.5846                  | 3.5853         |
| G2    | Mangrove, Muddy           | 0.11           | 9.66                        | 0.4938       | 0.5846                  | 3.5853         |
| G3    | Muddy                     | 0.06           | 3.31                        | 0.53         | 0.5846                  | 3.5853         |
| G4    | Muddy                     | 0.06           | 12.42                       | 0.56         | 0.5846                  | 3.5853         |
| G5    | Muddy                     | 0.15           | 2.70                        | 0.559        | 0.5846                  | 3.5853         |
| G6    | Muddy                     | 0.10           | 21.80                       | 0.6206       | 0.5846                  | 3.5853         |
| G7    | Muddy, Seagrass           | 0.12           | 26.06                       | 0.6374       | 0.6115                  | 3.5575         |

Table 6 Data of CVI measurement of Gresik Regency

| Cell  | Parameters               | Coastal slopes | Abrasion (-)/Accretion (+) | Tidal ranges | Significant wave height | Sea level rise |
|-------|--------------------------|----------------|-----------------------------|--------------|-------------------------|----------------|
| G8    | Muddy                    | 0.35           | 7.80                        | 0.7358       | 0.6115                  | 3.5575         |
| G9    | Muddy                    | 0.07           | 6.20                        | 0.8124       | 0.6115                  | 3.5575         |
| G10   | Brackish Marsh           | 0.01           | 26.48                       | 0.7962       | 0.6115                  | 3.5575         |
| G11   | Brackish Marsh           | 0.05           | 23.08                       | 0.698        | 0.6115                  | 3.5575         |
| G12   | Brackish Marsh           | 0.00           | 39.12                       | 0.8374       | 0.6115                  | 3.5575         |
| G13   | Muddy                    | 0.01           | 21.16                       | 1.043        | 0.6115                  | 3.5575         |
| G14   | Muddy                    | 0.03           | 15.61                       | 1.1232       | 0.6115                  | 3.5575         |
| G15   | Muddy                    | 0.06           | -9.32                       | 1.2398       | 0.6115                  | 3.5575         |
| G16   | Delta                    | 0.27           | -12.52                      | 1.3772       | 0.6115                  | 3.5575         |
| G17   | Delta                    | 0.27           | 23.81                       | 1.4852       | 0.6115                  | 3.5575         |
| G18   | Delta                    | 0.21           | 19.22                       | 1.6324       | 0.6115                  | 3.5575         |
| G19   | Muddy                    | 0.27           | 17.01                       | 1.6966       | 0.6115                  | 3.5575         |
| G20   | Muddy                    | 0.38           | -0.38                       | 1.8102       | 0.6115                  | 3.5575         |
| G21   | Muddy                    | 0.45           | 22.66                       | 1.9378       | 0.6115                  | 3.5575         |
Table 7  Values of AVE, composite reliability, Cronbachs Alpha, and R-square

| construct variables                        | Average variance extracted (AVE) | Composite reliability | Construct reliability (Cronbach’s Alpha) | R-squared |
|-------------------------------------------|----------------------------------|-----------------------|-----------------------------------------|-----------|
| Risk Analysis                             | 0.815                            | 0.946                 | 0.924                                   | 0.413     |
| Resource Management in a Disaster Situation | 0.837                            | 0.988                 | 0.987                                   | 0.801     |
| Capacity Assessment                       | 0.818                            | 0.988                 | 0.988                                   | 0.415     |
| Vulnerability Assessment                  | 0.829                            | 0.985                 | 0.984                                   | 0.415     |
| Assessment of Hazards or Natural Disasters | 0.741                            | 0.976                 | 0.973                                   | -         |

Table 8  The outer loading assessment

| No | Variables                          | Outer loading values > 0.7, p < 0.5 |
|----|------------------------------------|------------------------------------|
|    |                                    | The biggest indicators | The smallest indicators |
| 1  | Assessment of Hazards or Natural Disasters | A.1.13 (0.907) | A.1.2 (803) |
| 2  | Vulnerability Assessment            | B.1.8 (0.935) | B.1.1 (0.895) |
| 3  | Capacity Assessment                 | C.1.15 (0.933) | C.1.7 (0.864) |
| 4  | Resource Management in a Disaster Situation | D.1.14 (0.946) | D.1.4 (to 0.883) |
| 5  | Risk Analysis                       | E.1.1 (0.924) | E.1.3 (0.866) |

Fig. 4 Diagram of the Structural Equation Modeling (from Running PLS) with a Partial Least Square Approach Using the Smartpls Software (Measurement Model Specification)
**Table 9**  Categories and weight of scores of the CVI variable

| Score categories       | Very Low | Low       | Moderate  | High        | Very High   |
|------------------------|----------|-----------|-----------|-------------|-------------|
| Variables              | 1        | 2         | 3         | 4           | 5           |
| Coastal Geomorphology  | Craggy rocky beach | Medium-sized craggy and rocky beach | Lowly craggy and rocky beach with alluvial plains | Pebble, estuarine, and lagoon beach | Sandy beach with brackish marsh, mangrove, coral reef, delta, mud, and seagrass |
| Abrasion (-)/Accretion (+) (m/Yr) | > 2.00   | 1.00—2.00 | -1.00—1.00 | -2.00—1.00 | < -2.00    |
| The average wave height (m) | < 0.55   | 0.55—0.85 | 0.85—1.05 | 1.05—1.25 | > 1.25     |
| Coastal slopes (%)     | > 1.2    | 1.2—0.9  | 0.9—0.6  | 0.6—0.3    | < 0.3   |
| Tidal range (m/yr)     | < 1.00   | 1.00—1.90 | 2.00—4.00 | 4.10—6.00 | > 6.00  |
| Sea level rise (m/year) | < 1.8    | 1.8—2.5  | 2.5—3.0  | 3.0—3.4   | > 3.4    |

**Fig. 5**  The Map of G1—G21 Cell Lines of Lamongan and Gresik
Fig. 6  CVI map based on beach geomorphology

Fig. 7  CVI map based on coastal slope

Fig. 8  CVI map based on shoreline change

Fig. 9  CVI map based on tide range

Fig. 10 CVI map based on significant wave height

Fig. 11 CVI map based on sea level rise
### Table 10: Composing actions for climate change adaptation

| No | Parameters of determining action priorities | Climate change | Sea level rise | Increased incidence of extreme |
|----|---------------------------------------------|----------------|---------------|---------------------------------|
| 1  | Coverage of regions and/or sectors associated with climate risks | a) The climate systems in Lamongan and Gresik have changed and affected the quality and quantity of water, habitats, forests, health, agricultural land, and ecosystems of coastal regions  
   b) The climate has become hotter in Lamongan and Gresik | a) Inundation and flooding occur in Lamongan and Gresik and have lowered the quality of water sources  
   b) The temperature rise also increases chlorine levels in the water | Fish stock in Lamongan and Gresik has declined sharply, and this condition affected fishermen's daily income | a) Harvest is possibly failed due to drought  
   b) The dry season prolongs  
   c) The distance of fishermen catching fish gets further |
| 2  | The area of regions and/or sectors affected by climate change | a) The primary productivity rates are hampered  
   b) This condition affects the habitat and fauna life and | a) Sectors of food security and fisheries are disturbed  
   b) Drought has changed cropping patterns that result in crop failure | a) Changes in air pressure, temperature, wind speed, and wind direction alter the ocean currents. These phenomena can affect fish migration  
   b) Ocean acidification occurs | a) Seasons become unpredictable  
   b) Changes in habitat allow changes in the life resistance of larvae and their growth |
| 3  | Resources needed | a) The sea becomes warm due to the declining nutrient levels in the mesopelagic zone. Therefore, the growth of diatoms, not phytoplankton, is restricted  
   b) The above condition affects marine biodiversities and is very harmful to coral reefs | High rainfall results in a high inundation and possibly brings water directly to the sea without storing it in the basin used as a clean water source | a) Animal habitats change due to changes in temperature, humidity, and primary productivity. Therefore, several animals migrate to find a new and appropriate habitat  
   b) Bird migration will change because seasons, wind speed, wind direction, and ocean currents bringing nutrients and fish migration also change |
| 4  | Implementing the climate change adaptation potentially faces constraints | a) Increasing the capacity of carbon absorption  
   b) Reducing gas emissions of greenhouse  
   c) Maintaining sustainable forests  
   d) Exceeding climate change rates beyond the adaptation ability | a) The frequency and intensity of floods increase  
   b) The long rainy season raises the seawater and floods human settlements and ponds | a) Food production is affected  
   b) Tsunami and tidal flooding potentially occur | c) The agricultural sector and food security are disrupted  
   d) The land is fired  
   e) Coastal areas are damaged  
   f) The need for energy increases |
| 5  | Benefits from implementing climate change adaptation | a) Preventing the increasing microclimate heat  
   b) Preventing the decreasing water availability  
   c) Preventing the loss of biodiversity | a) Preventing the increasing tidal flood and tsunami  
   b) Preventing health impacts for the society  
   c) Preventing puddles in residential areas, offices, fields, and yards | a) Preventing the intrusion of seawater  
   b) Restoring mangrove  
   c) Building coastal protection structures  
   d) Elevating road constructions  
   e) Dumping the beach | a) Reducing social and economic vulnerability of the community  
   b) Reducing the declining fish and rice production |
| 6  | Period of the benefits of climate change adaptation | A long-term period (25 years) | A medium-term period (10 Years) | A medium-term period (5 Years) | A short-term period (1 year) |
will threaten human life and the survival of flora and fauna. 2. Public health is disturbed. 3. The seawater intrusion pollutes the quality and quantity of water supply for the community. 4. The micro-climate difficulty predicts climate change. 5. The quality and quantity of water supply for coastal communities decline due to seawater intrusion. 6. Coastal ecosystem Habitats on land and in the sea are endangered due to sea level rise. 7. Flooding and inundation frequently emerge due to high rainfall. 8. The coastal land subsidence occurs. 9. Fish stocks are impaired due to seawater acidification. 10. Ocean currents change due to changes in air pressure and an increase in temperature.

Therefore, public, local governments, and private parties must mutually cooperate to protect the beach naturally. The beach protection by building jetty, groin, breakwater, seawalls is necessarily reconsidered because their development and operation cost highly. Therefore, this study proposed a natural and cheap approach mutually performed by all parties, namely the restoration of mangrove ecosystems as a “bodyguard” to protect the beach from changing conditions due to climate change.

The results of research, mitigation, adaptation to climate change show that mangrove forests are essential coastal ecosystems and play a major role in human life. Mangrove forests maintain biodiversity and a nursery for many marine and coastal species and support fisheries. Mangrove forests play an important role in supporting coastal communities against extreme weather events, such as hurricanes, stabilizing the shoreline, and slowing down or reducing soil erosion.

Newton et al. (2011) discovered that the mangrove forest restoration could cope with climate change. Thus, mangrove ecosystems closely relate to climate change. Moreover, healthy mangroves in coastal areas can increase coastal communities’ resilience to climate change and minimize the impacts of natural disasters, such as tsunami, storms, and waves (adaptive function).

It is recommended that the restoration plan should initially examine potential pressures, such as blocked tidal waves to prevent secondary successions, and plan to eliminate the stress before trying the restoration (Hamilton and Snedaker 1984; Cintron-Molero 1992).

First, the government necessarily addresses mangrove forests in a damaged coastal village as a key of the coastal restoration. Second, the village government then forms a team consisting of society, government, and private sectors. Finally, stakeholders work using the co-management approach (Priyono et al. 2017). Thus, the village government forms institutional aspects by considering the village’s characters and using the co-management approach.
The CVI data signify that mangrove forests in the entire coastal areas in Lamongan- Gresik should be restored although these areas are currently categorized as lowly and highly vulnerable areas. The mangrove forest is absolutely restored as a solution to protect coastal and critical areas. Coastal land conservation is easily done by the society in cooperation with the local government and private sectors.

Conclusion

The impacts of climate change in the coastal areas of Lamongan and Gresik are solved by adaptation and mitigation efforts using mangrove forest restoration. The PLS analysis concluded several points. a) The assessment of hazards/natural disasters was classified very high. b) The vulnerability assessment was classified very high. c) The community's capacity assessment was very high. d) The management resource in a disaster situation was very high. The risk analysis was very high. This research implies that people living in the coastal areas of Lamongan and Gresik are highly aware of the dangers of disasters due to climate change. The awareness and assessment of communities and local government are pivotal to coping with disasters in the future. To date, society still "surrender" to emerging disasters. Moreover, the local government will act to overcome a disaster after it occurs. The local government's ability to anticipate and face a disaster is necessarily improved using the available data; priority areas require particular attention.

The CVI results discover that the coastal areas in Lamongan and Gresik that need attention are along with the 129 Ha, and a high priority of flooding is in cell 16 in Gresik. However, due to limited funds and personnel, this research did not investigate the next categories. Therefore, further research necessarily sharpens the utmost priority and priority categories based on the results of village discussion. The local government should initiate this discussion to prevent disaster areas.

The approach is applied as a solution to protect coastal areas, critical land, and land conservation by restoring mangrove forest ecosystems. Types, structures, and autecology of mangroves should consider their original vegetation adjusted with the coastal land structures and textures.

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