湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences）

第 50 卷 第 10 期
2 0 2 3 年 10 月

Available online at http://jonuns.com/index.php/journal/index

Vol. 50 No. 10
October 2023

Open Access Article https://doi.org/10.55463/issn.1674-2974.50.10.21

Shoreline Management Innovation with Mangrove Ecosystem Restoration Approach: A Case Study, Tanjung Widoro Village, Bungah Sub-District, Gresik Regency

Rudianto Rudianto[1,2]*, Very Dermawan[3], Ismu Rini Dwi Ari[4], Seftiawan Samsu Rijal[1], Mega Amelia[5], Cecilia Mia Clarina[5], Luluk Anggin Nindiana Dewi[5], Achmat Soleh Hudin[5]

[1] Department of Fisheries and Marine Resources Utilization, Brawijaya University, Indonesia

[2] Head of the Integrated Coastal Ecosystem Restoration and Sustainable Development (ICESSMENT) Study Group, Brawijaya University, Indonesia

[3] Department of Civil Engineering, Brawijaya University, Indonesia

[4] Department of Urban and Regional Planning, Brawijaya University, Indonesia

[5] Students of the Department of Fisheries and Marine Resource Utilization, Brawijaya University, Indonesia

* Corresponding author: rudiantoita@gmail.com

Received: July 18, 2023 / Revised: August 13, 2023 / Accepted: September 10, 2023 / Published: October 31, 2023

Abstract: This research originated from basic research conducted in 2015 on coastal ecosystem restoration in Malang Regency and Gresik Regency, East Java Province. The results showed that coastal areas in Gresik Regency are very vulnerable to flood disasters and the intensification of anthropogenic processes. In 2022, it continued with applied research related to disasters in the coastal areas of the Gresik and Lamongan Regencies. The results showed that the highest level of vulnerability along the Gresik Regency coastline was the coastline in Tanjung Widoro Village, Bungah District of the Gresik Regency. Problems that occur are that tidal flooding annually affects the coastal area of Tanjung Widoro. This disaster washed away hundreds of hectares of milkfish ponds ready for harvesting. This research aims to commercialize the results of the 2022 research by developing shoreline management innovations using mangrove forest ecosystem restoration to prevent coastal flooding disasters. The research method uses spatial analysis with remote sensing images and generalized structured component analysis to determine community attitudes and perceptions of disaster, Driver-Pressure-State-Impact-Response (DPSIR) framework, and analytical hierarchy process analysis. The results showed that, according to the prediction results, changing shoreline from 2023 to 2033 can reach more than 145 submerged ponds or about 158.4 ha. To prevent it, restoring mangrove forests along the 11-km coastline is necessary to withstand tidal floods.
Keywords: shoreline, tidal flooding, ecosystem restoration, flood management, Gresik Regency.

红树林生态系统恢复方法的海岸线管理创新：以格雷西克摄政区文雅分区丹绒维多罗村为例

摘要：這項研究源自於2015年在東爪哇省瑪琅縣和格雷西克縣進行的沿海生態系復育基礎研究。結果表明，格雷西克縣沿海地區非常容易遭受洪水災害和人為活動的加劇。2022年，它繼續進行與格雷西克和拉蒙乾地區沿海地區災害相關的應用研究。結果顯示，格雷西克

攝政區海岸線脆弱性最高的是格雷西克攝政區文雅區丹绒维多罗村的海岸線。出現的問題是每年潮汐洪水都會影響丹絨維多羅沿海地區。這場災難沖毀了數百公頃準備收穫的遮目魚池。該研究旨在透過利用紅樹林生態系統復原來開發海岸線管理創新來預防沿海洪水災害，從而將2022年研究成果商業化。研究方法使用遙感影像空間分析和廣義結構化成分分析來確定社區對災害的態度和感知、駕駛員壓力狀態影響反應框架和分析層次過程分析。結果顯示，根據預測結果，2023年至2033年海岸線的變化可達超過145個淹沒池塘或約158.4公頃。為了防止這種情況發生，有必要恢復11公里海岸線上的紅樹林以抵禦潮汐洪水。

关键词：海岸線、潮汐洪水、生態系統復育、洪水管理、格雷西克攝政。

1. Introduction

The research background starts from the base research results [1], which showed that coastal areas in the Gresik Regency are very vulnerable to flood disasters and anthropogenic processes. Applied research [2] showed that the level of vulnerability along the coastline of Gresik Regency that was most vulnerable to flooding was the coastline of the coastal village of Tanjung Widoro, Bungah District, Gresik Regency because the coastline is experiencing abrasion. According to [3], coastal areas are vulnerable to sea level rise. Sea level rise can endanger the coast. The increase in sea level reason is the increasing global temperature of the Earth, commonly referred to as global warming. This sea level rise causes the land area to shrink, threatening human life. This phenomenon must consider that the water area in Indonesia is greater than the existing land area [4]. Today, sea level rise is a serious challenge worldwide, including Indonesia [5]. This condition will have social, economic, and cultural impacts [6, 7].

The problem of sea level rise occurs in many countries, so there are various efforts to create innovations to overcome the effects of climate change in coastal areas [8, 9]. Meanwhile, [10] reported that Indonesia's sea level will increase by 10 to 50 cm, with an average increase of 25 to 30 cm by 2050. Meanwhile, [11] also reported that sea level rise at heights above sea level increased by an average of 0.86 cm per year. The primary causes of sea level rise are the thermal expansion of the oceans and the melting of icebergs in the polar regions [12]. This disaster event also occurred in the coastal village of Tanjung Widoro, Bungah District. Floods in 2022 inundated up to a height of 20–40 cm, and hundreds of hectares of fish ponds were submerged in water [13]. Many fish that were ready to harvest were flooded and lost. The losses that the fishermen have to bear are running into hundreds of millions of rupees. This research aims to study mangrove restoration along the coastline affected by abrasion by an innovative coastal ecosystem restoration approach to control tidal flooding.

Fig. 1 Coastal village, Tanjung Widoro Bungah Subdistrict, Gresik Regency, flooded in 2022

The specific objective of this research is to consolidate previous basic and applied research results. The results of this research, which have obtained intellectual property rights, must be able to provide actual benefits to coastal communities. The downstream process takes the form of innovation in planning security for coastlines vulnerable to sea level rise. Therefore, a feasibility study is needed to convince various parties, especially decision-makers, namely the Gresik Regency government, of the model that will be an answer to the problems faced by the community. Therefore, the downstream process still refers to the Brawijaya University Research Master Plan stated in 2021–2025.

2. Materials and Methods

Tanjung Widoro Village is located in the Bungah sub-district with an area of 7.38 square kilometers or 9.29% of the total Bungah sub-district area of 7946.44 square kilometers. Based on data, the area of ponds in this village is 715.29 ha [14]. The research method used spatial analysis with remote sensing images, generalized structured component analysis (GSCA) to determine community attitudes and perceptions of disaster, and the DPSIR framework based on the concept that drivers (both natural and human-induced) exert pressures (direct factors) on the environment that cause changes in environmental conditions (state). The analytical hierarchy process (AHP) method is a decision-making tool that determines the best alternative from many elements of choice, using pairwise comparison.

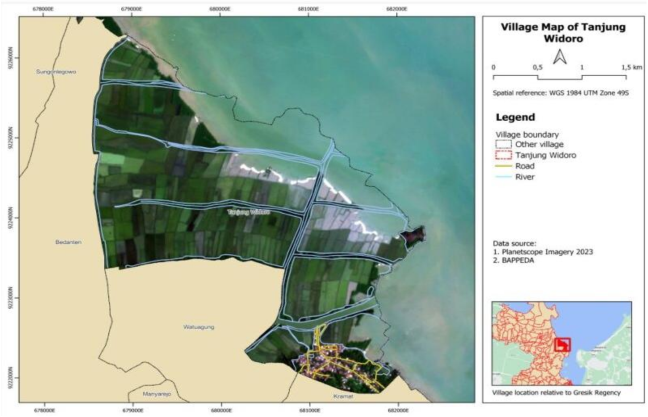

Fig. 2 Location map of Tanjung Widoro village

This research used four methods in stages, with each result providing input for the next method. The research stages used 10 steps as follows:

– First, identify the problem. This research focused on solutions to overcome the increasingly critical area of Banyu Urip village due to the vulnerability of the area to tidal flooding; mangrove vegetation as a coastal "body guard" continues to shrink. To answer the hypothesis, a literature study on various studies related to innovations to overcome coastal damage whose coastline is continuously exposed to abrasion was required.

– Second, identify and name the variables. The variables to be observed/measured in this study include the variables of Perna viridis shells that become waste and scattered in coastal areas. In addition, the variables of the community around the beach are related to people's perceptions and attitudes toward the presence of Perna viridis shells and the variables of coastal spatial aspects.

– Third, make operational definitions. Researching the hardness of Perna viridis shells tested in the laboratory in the form of a mixture as an alternative to coarse aggregate. Hardening of a mixture of cement, water, fine aggregate (sand), and coarse aggregate (crushed stone or gravel) plus Perna viridis shells was attempted.

– Fourth, manipulate and control variables. The independent variable was the quality of Perna viridis shells in the aquatic ecosystem. This is intended to determine its impact on the variables it affects, such as its effect on the prototype mix as an alternative aggregate to be used for wave protection. The other variables used were the attitudes and perceptions of the community toward wave protection using Perna viridis shells.

– Fifth, develop a research design. The process of determining data collection instruments for both primary and secondary data was based on this study, which used quantitative and qualitative data. Spatial data use remote sensing data, and quantitative data use statistical and mathematical calculations. Determination of research samples using green mussel shell prototypes.

– Sixth, identify and arrange observation and measurement tools. At this stage, the research was carried out experimentally in the laboratory of the Faculty of Fisheries and Marine Science, Brawijaya University.

– Seventh, prepare questionnaires and interview schedules. The questionnaires to be prepared include community responses to the use of green mussel shells scattered everywhere as a mixture for making concrete, the effect of shells on the income level of the community, and the socioeconomic conditions of the community, including the influence of culture that changes due to the use of green mussel shells.

– Eighth, conduct laboratory and statistical analyses. Conducting material inspection, including fine and coarse aggregate inspection and Perna viridis shell inspection, making cylindrical samples, stirring the mixture, and testing the samples [15].

– Ninth, using computers for data analysis. Data analysis requires computer assistance. One of the software that has been developed is the SPSS program.

2.1. Spatial Analysis Model

The spatial analysis model uses remote sensing image data and field survey data. Remote sensing image data are preprocessed, including geometric and radiometric corrections. The image is then processed with a vegetation index to determine the condition of vegetation cover, especially mangroves at the research location. Vegetation index processing displays temporary results validated by field surveys. Validation includes above-ground biomass (AGB) measurement and mangrove density measurement. The results of field validation are processed using a statistical approach, namely regression analysis, to determine the magnitude of the influence value (R2) between the results of field validation and image processing results. The R2 value is then calculated against the image processing results and becomes the final result of the search for mangrove biomass and density values at the study site.

2.2. Generalized Structured Component Analysis (GSCA)

The GSCA model in the following table shows that variables are described in the form of variables, dimensions, and indicators. Table 1 contains three variables, three dimensions, and three indicators that will form a structural model.

Table 1 Variables, dimensions, and indicators

Components	Content
Variable 1	Spatial analysis to identify areas with high vulnerability, medium vulnerability, and low vulnerability
Dimension 1	Spatial distribution: topography, geomorgology, geological landforms, and seascapes

Continuation of Table 1

Indicator 1	Spatial typology, spatial structure, topographic form, and geomorphological and geological processes
Dimension 2	Landscape inventory: sediments, land use, hills, vegetation types, and species.
Indicator 2	Vegetation structure and density, coast, sediments, hills, lowlands, and coastal shape
Dimension 3	Seascape inventory: sediment, seascape use, sea hills, vegetation types and species, and biota
Indicator 3	Structure and density of mangroves, coral reefs, seagrasses, gastropods, bivalves, and macrobenthos
Variable 2	Analysis of local people's perceptions behavior influence on the environment and influence of the environment on the community
Dimension 2	Perceptions, views, behaviors, and responses to disasters
Indicator 2	Ways of thinking, paradigms, responses, responses, problem solutions, rescue efforts, and reactions
Variable 3	Analysis of rescue policy options in terms of spatial planning
Dimension 3	a) Policies to be achieved, b) Rational policies or realistic, c) Clear policy; d) Policies that are clearly orientated
Indicator 3	Demand, impact, means, effectiveness, economy, sufficiency, fairness, and accuracy

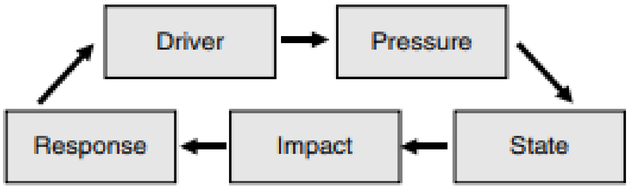

Fig. 3 DPSIR model

The Driver-Pressure-State-Impact-Response (DPSIR) framework is used to analyze environmental problems. DPSIR facilitates the investigation of all possible cause–effect relationships and plans an appropriate technological response. This study demonstrates the application of DPSIR to a mangrove restoration innovation model in Tanjung Widoro. Based on the logical scheme of DPSIR, the results can analyze how the response or outcome of the innovation will affect the driver, pressure, and state.

2.3. Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) method is one of several methods used to solve Multiatibute Decision Making (MADM) problems. AHP is a functional hierarchy with its main input from human perception. AHP has many advantages in explaining the decision-making process. One of them is that it can be described graphically to ease understanding by all parties involved in decision making.

3. Results

3.1. Spatial Analysis Using Remote Sensing Images

The spatial analysis produced an image bathymetry map with an average depth of 6–10 m. On this map, if observed in the estuary area, the average depth is between 4 and 10 m. This map is used as a base map for planning mangrove ecosystem restoration. The length of the planned beach is 11 kilometers.

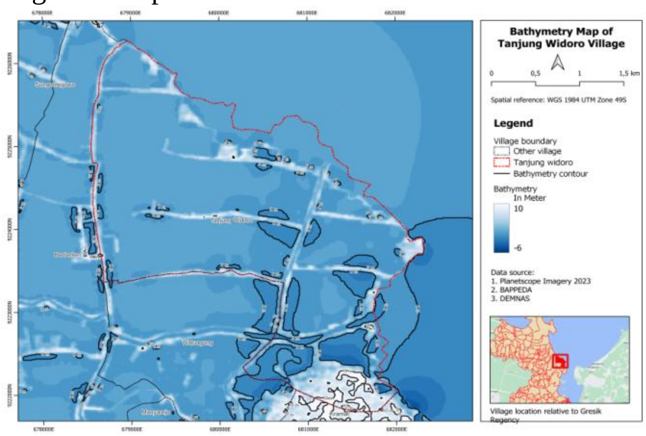

Fig. 4 Bathymetry map

The slope of Tanjung Widoro Village varies from 0% to 10%. This means that Tanjung Widoro, with an area of 7.38 km^2, is a flat slope class. Thus, in the research area, if there is a rise in sea level and river water cannot flow to the river due to constrained water level rise, then Tanjung Widoro village is vulnerable to tidal flooding. Fig. 5 shows the slope map.

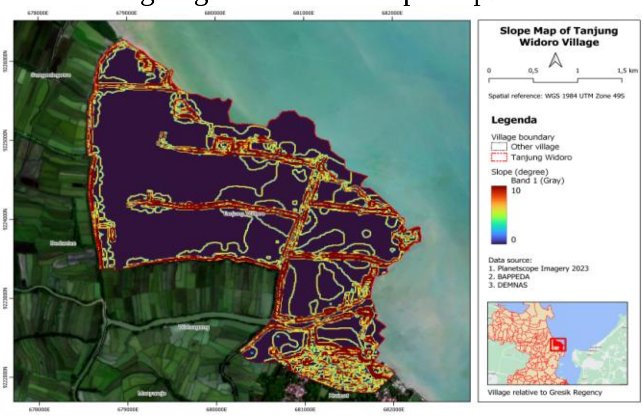

Fig. 5 Slope map

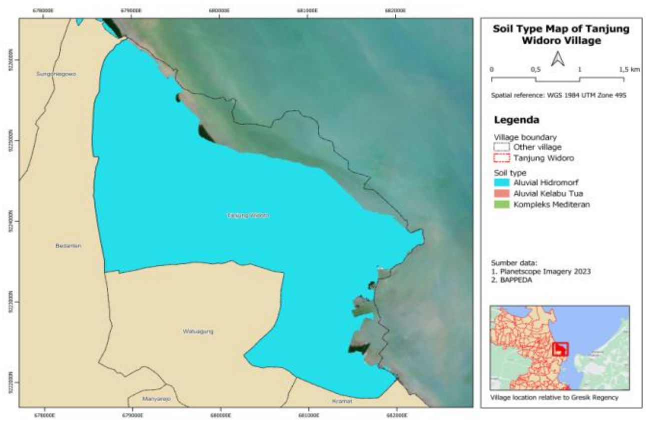

Fig. 6 Soil type map

Tanjung Widoro Village is a low-lying area located around the mouth of a river. The location of this area is also between major rivers. The hydromorphic alluvial soil type dominates the soil type. Alluvial soil types are land and sea sediments formed by sand plates and coral fragments. The characteristics of this soil type are gray with a slightly loose structure and are sensitive to erosion. Each of the above soil types has a different texture; generally, the soil texture in the study area is classified as fine (very high clay content). Fig. 6 shows the distribution of soil at the research location.

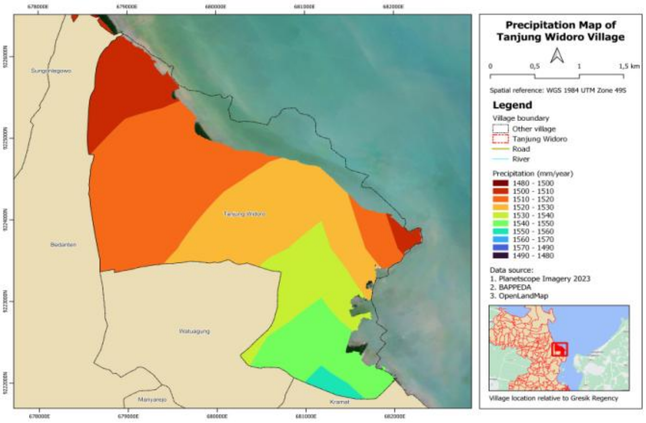

Fig. 7 Precipitation map

Rainfall in the study area based on data from BMKG, Planetscope images in 2023, and Bappeda Gresik Regency ranges from 1480 to 1500 mm/year (Table 2). Fig. 7 shows the rainfall map in Tajung Widoro Village. According to the Kompas daily newspaper (2022), tidal floods spread across 4 sub-districts in Gresik, one of which hit the coastal village of Tanjung Widoro. This flood submerged approximately 145 ponds containing milkfish readily for harvest. The losses suffered by farmers reached hundreds of millions of rupiahs.

Table 2 Precipitations on Tanjung Widoro

Rainfall (mm/year)	Extensive (Ha)	Percentage
1510 - 1520	86	11,89 %
1520 -1530	270	37,34 %
1530 -1540	186	25,73 %
1540 - 1550	84	11,62 %
1550 - 1560	86	11,89 %
1560 - 1570	11	1,52

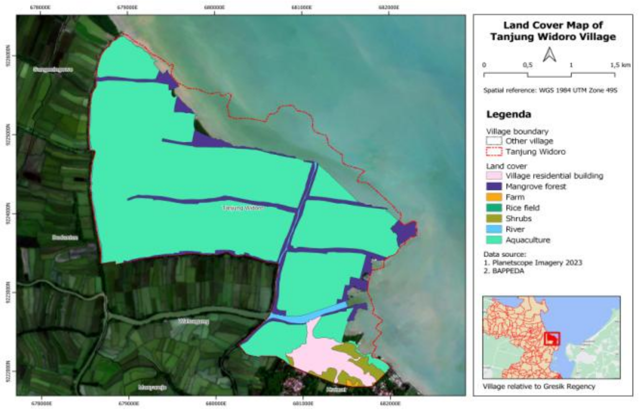

Fig. 8 Land cover map of Tanjung Widoro

Table 3 shows the results of the observation of the percentage of land use in Tanjung Widoro Village, Gresik. Land use in Tanjung Widoro Village includes plantations, ponds, shrubs, mangrove forests, residential buildings, rice fields, and rivers. The largest land use is used as a pond, which is 598.194 ha or 82.51% and the smallest is rice fields covering 0.001 ha or 0.00%.

Table 3 Land use in Tanjung Widoro

Land use	Extension (Ha)	Percentage
Plantation	0.774	0.11%
Pond	598.194	82.51%
Shrubs	14.682	2.03%
Mangrove forest	68.096	9.39%
Village settlement building	31.115	4.29%
Rice field	0.001	0.00%
River	12.131	1.67%

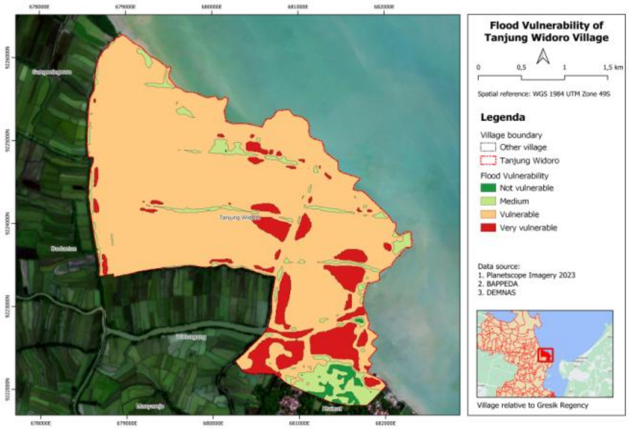

Fig. 9 Flood vulnerability map

Results of spatial data processing using bathymetry data, slope, land cover, rainfall, rivers, roads, soil types, and administrative boundaries. Fig. 9 shows the flood vulnerability map in Tanjung Widoro Village. The level of flood vulnerability on the map is divided into four categories: not vulnerable (dark green), moderate (light green), vulnerable (yellow), and very range (red). Meanwhile, Table 4 shows the percentage value of flood vulnerability. The highest percentage of flood vulnerability in Tanjung Widoro Village in the vulnerable category is 81.12% or an area of 695.28 Ha and the lowest in the not vulnerable category is 1, 12% or an area of 9.63 Ha.

Table 4 Category of flood vulnerability

Flood vulnerability		
Category	**Extensive (Ha)**	**Precentage**
Highly Vulnerable	92.95	10.84%
Vulnerable	695.28	81.12%
Medium Vulnerable	59.28	6.92%
Not Vulnerable	9.63	1.12%

Table 4 shows that the Tanjung Widoro area has high vulnerability of 81.12%. Thus, this area requires protection along the coastline of ± 11 km.

3.2. Generalized Structured Component Analyzed (GSCA) Analysis to Determine Community Attitudes and Perceptions of Disaster

The number of respondents interviewed was 55 people, and based on the interviews, 58.2% of respondents agreed that coastal damage was caused more by human activities by changing land use, and 18.2% of respondents disagreed that coastal damage was caused more by human activities by changing land use. An average of 3.51 respondents agreed that coastal damage is caused more by human activities by changing land use. While 49.1% of respondents strongly agreed that repairing damaged coastal environments is done with a restoration approach, 47.3% strongly agreed that the community expected coastal damage to be addressed by the village government through the preparation of a clear program with a master plan, and 43.6% agreed that the community expected coastal damage to be addressed by the village government. Based on the interview results, 58.2% of respondents strongly agreed that the community hopes that the provincial government will encourage district and village governments to perform coastal restoration through assistance funds, and 41.8% of respondents agreed that the community hopes that the provincial government will encourage district and village governments to perform coastal restoration through assistance funds. Regarding the importance of provincial government assistance, 58.2% of respondents strongly agreed that the community expects the provincial government to provide encouragement to district and village governments to carry out coastal restoration through assistance funds, and 41.8% of respondents agreed that the community expects the provincial government to provide encouragement to district and village governments to perform coastal restoration through assistance funds. In relation to suffering from flooding, 52.7% of respondents strongly agreed that the community suffered considerable losses due to flooding, and 43.6% of respondents agreed that the community suffered considerable losses due to flooding. In relation to suffering from flooding, 52.7% of respondents strongly agreed that the community suffered considerable losses due to flooding, and 43.6% of respondents agreed that the community suffered considerable losses due to flooding.

Based on the evaluation of the measurement model, which includes convergent validity, discriminant validity, and reliability testing, which includes criterion testing with Cronbach's alpha and composite reliability (Dillon-Goldstein's Rho), all indicators are declared reliable in measuring their latent variables.

Table 5 Reliability testing

Variable	Alpha	Rho
Mangrove ecosystem damage	0.683	0.825
Sea level rise	0.728	0.831
Causes and victims of flooding in Tanjung Widoro	0.855	0.890
Collective awareness of flood threats	0.778	0.844
Joint prevention to tackle floods	0.696	0.815

The reliability test above indicates that the variables of mangrove ecosystem damage, sea level rise, causes and victims of flooding in Tanjung Widoro, joint awareness of flood threats, and joint prevention of flooding produced Cronbach's alpha values greater than 0.6. Thus, based on Cronbach's alpha index, the indicators that measure these variables are declared reliable.

3.3. DPSIR Framework

The results of the DPSIR analysis are presented in the following tidal flood management structure status (Fig. 10). The increasing population growth driver in the Tanjung Widoro area shows that the dynamics of the research area are very fast; therefore, it is estimated that the need for land, especially for settlements and business premises, is also increasing rapidly. The limited land available for business is getting narrower so that land conflicts are likely to occur in the future. In addition, the intensification of milkfish ponds cultivated by pond farmers and inundated by water will decrease pond productivity. Pressure due to tidal flood inundation results in land use change, which will decrease land functioning. Tidal floods that occur almost every year cause damage to ponds, irrigation networks, and embankments, resulting in crop failure in pond farmers. Coupled with the absence of mangrove vegetation along the coastline, there is no barrier to tidal floods that will enter residential areas and ponds. The state of ecological crisis due to excessive utilization by the community has caused several problems to emerge in the environment, such as in the economic, social and cultural fields. Because of the wider tidal floods toward land, the wider the land that will be inundated and pond farmers will experience the more losses. Impact of economic losses for aquaculture farmers inundated by tidal floods, the economic situation of aquaculture farmers will experience a poverty crisis. The broader impact is a decrease in the Regional Original Revenue (PAD) of Gresik Regency. Inundation by tidal floods also causes much "idle" land (which cannot be utilized). Thus, the pond land will gradually become narrower or even disappear due to tidal flooding. Responses to tidal flooding require mangrove restoration along the coast as a "body guard" to prevent tidal flooding. Community participation in flood management is needed, especially in emergency flood management activities. The impact of tidal flood inundation has left much land unutilized Therefore, for the land to be utilized economically, ecotourism development is needed. Ecotourism is used as an element of education, understanding, and support for nature conservation efforts. Ecotourism can be in the form of opening mangrove areas in areas affected by abrasion and ex-mining land that can be used for geotourism. Ecotourism is very important because its development pays attention to sustainable conservation and is closely related to social and economic aspects so that it becomes an interconnected dimension.

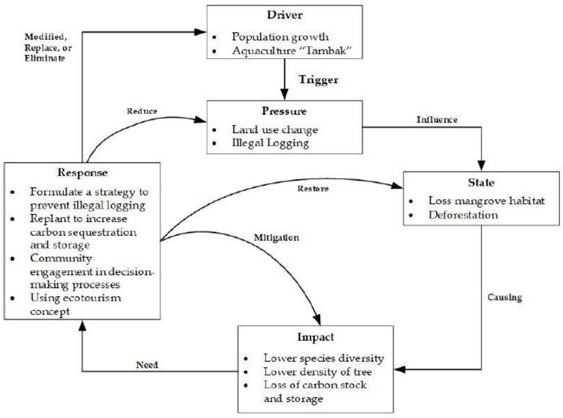

Fig. 10 DPSIR framework

3.4. Analytical Hierarchy Process (AHP) Method

Determination of alternatives, namely joint prevention strategies for tidal flood management use the analytical hierarchy process (AHP) method. The AHP method helps solve complex problems through the determination of criteria arranged in a hierarchy and then gives a numerical weight value as a substitute for the views or perceptions of experts or stakeholders in the field. By providing a synthesis, the priority scale will be known.

The AHP model in this study is has two levels:

– Level 1, which is the criteria of the factors considered consisting of 3 criteria (flood management by the government, mutual cooperation to preserve the ecosystem, flood management education).

– Level 2 is an alternative strategy for joint prevention of tidal flood management consisting of five alternatives: budget for tidal flood management every year, community cooperation to overcome tidal floods, planning mangrove restoration along the coastline, community awareness of mangrove restoration, and socialization of tidal flood disaster management).

Fig. 11 describes the hierarchical model of these factors and alternatives.

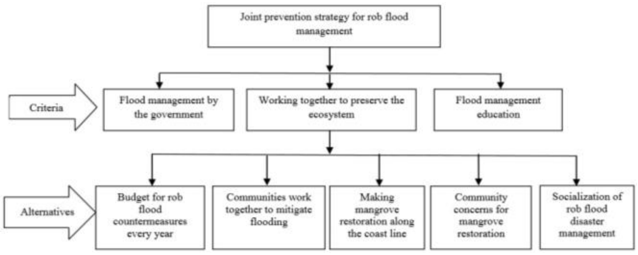

Fig. 11 AHP graph

The results of the DPISR analysis are presented in the following tidal flood management structure status (Fig. 11). The increasing population growth driver in the Tanjung Widoro area shows that the dynamics of the research area are very fast; therefore, it is estimated that the need for land, especially for settlements and business premises, is also increasing rapidly. The limited land available for business is getting narrower so that land conflicts are likely to occur in the future. In addition, the intensification of milkfish ponds cultivated by pond farmers and inundated by water will decrease pond productivity. Pressure due to tidal flood inundation results in land use change will decrease land function. Tidal floods that occur almost every year cause damage to ponds, irrigation networks, and embankments, resulting in crop failure in pond farmers. Coupled with the absence of mangrove vegetation along the coastline, there is no barrier to tidal floods that will enter residential areas and ponds. The state of ecological crisis due to excessive utilization by the community has caused several problems to emerge in the environment, such as in the economic, social and cultural fields. Because of the wider tidal floods toward land, the wider the land that will be inundated and the pond farmers will experience more losses. Impact of economic losses for aquaculture farmers inundated by tidal floods, the economic situation of aquaculture farmers will experience a poverty crisis. The broader impact is a decrease in the Regional Original Revenue (PAD) of Gresik Regency. Inundation by tidal floods also causes much "idle" land (which cannot be utilized). Thus, the pond land will gradually become narrower or even disappear due to tidal flooding. Responses to tidal flooding require mangrove restoration along the coast as a "body guard" to prevent tidal flooding. Community participation in flood management is needed, especially in emergency flood management activities. The impact of tidal flood inundation has left much land unutilized Therefore, for the land to be utilized economically, ecotourism development is needed. Ecotourism is used as an element of education, understanding, and support for nature conservation efforts. Ecotourism can be in the form of opening mangrove areas in areas affected by abrasion and ex-mining land that can be used for geotourism. Ecotourism is very important because its development pays attention to sustainable conservation and is closely related to social and economic aspects so that it becomes an interconnected dimension.

4. Discussion

4.1. Shoreline Changes

Based on spatial analysis that produces several maps related to bathymetry maps, slope maps, soil maps, rainfall maps, land cover maps, and flood vulnerability maps, it can be concluded that the source of tidal flooding that occurs in the research area is that river water cannot flow to the sea due to sea level rise, which causes river water to flow back to land. The main problem is that the 11-km coastline does not have a protective mangrove forest. As a result of no shoreline protection from 2017 to 2023, the average value of the distance of shoreline change in Tanjung Widoro Village is -103.85 m, with the highest change distance value being 304 m and the lowest change distance value being 616 m. Negative value on the average value of the shoreline change distance in Tanjung Widoro Village. The negative value on the average value of the distance of shoreline change indicates that the research location tends to experience abrasion or regression of the coastline. The results of data processing show that abrasion that occurs in the pond area resulted in a land reduction of 95 ha. The accretion events generally occur in mangrove areas located in the eastern part of the village. The additional land area is estimated to be around 7 ha from 2017 to 2023.

4.2. Hydroseanography

Changes to the coastline are mainly due to the lack of protection and because the hydroceanographic elements in this area have quite large waves. In addition, the soil elements in the form of texture and structure are quite crunchy, causing deterioration of the coastline.

4.3. Waves

Wave forecasting from wind data is performed using two methods, namely the numerical method and the fisher tipped method. Gresik waters in general have a fetch distance that is not too far because they are directly opposite Madura Island and Kalimantan Island (Fig. 12). The average effective fetch distance in Gresik waters is 277.1 km (Table 6). This value will be used in forecasting waves from wind data using both numerical and fisher-tipped methods.

Table 6 Effective fetch

Effective fetch		
Main direction	**F_{eff} (km)**	**F_{eff} (m)**
North	298.32	298323.46
Northeast	484.30	484301.55
East	485.79	485791.17
Southeast	24.88	24876.28
South	29.94	29938.82
Southwest	26.19	26185.10
West	192.50	192501.87
Northwest	674.87	674865.33
Average	277.10	277097.95

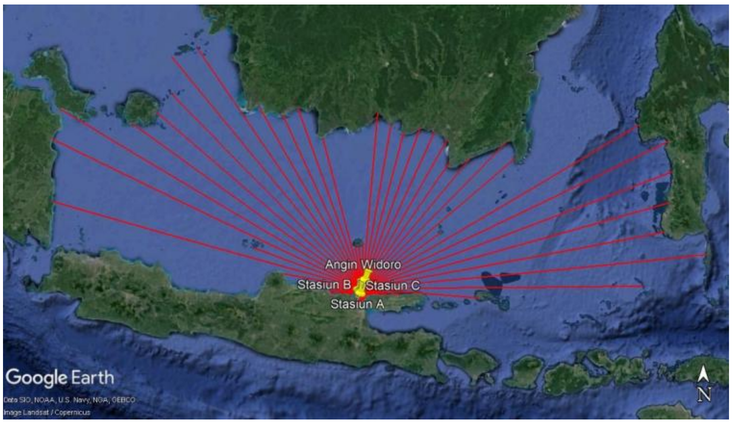

Fig. 12 Fetch

4.4. Numerical Methods

Waves in Gresik waters are known in the west season to obtain the maximum height seen from the trend in each west season, which has a high trend value (Fig.13). The highest wave height occurred in the western season of 2018, with a height of 1.43 m. The lowest value occurred in transitional season 2 of 2022 with a height of 0.23 m. The lowest value occurs in transitional season 2 in 2022 with a height of 0.23 m.

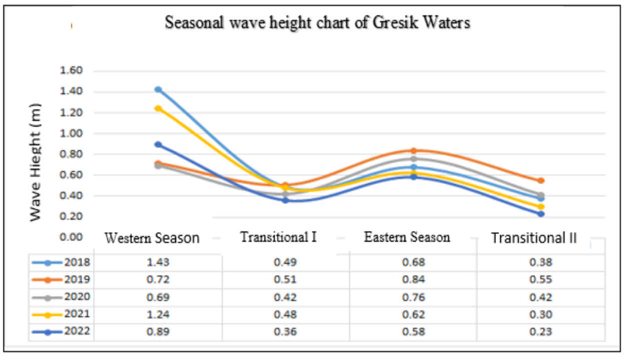

Fig. 13 Per-season Gresik coastal wave height chart 2018–2022

The highest wave period is in the west wind season, with a value of 5.65 s. The lowest wave period value is in transitional season 2 in 2022 with a value of 2.20 s.

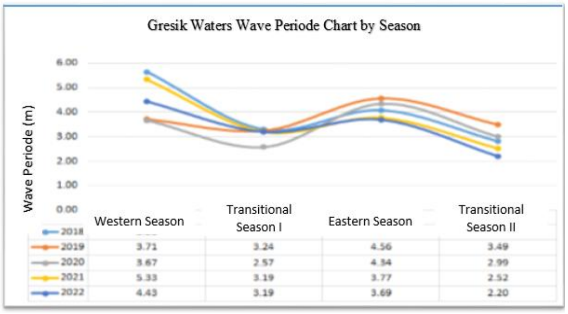

Fig. 14 Per-season wave period chart of Gresik waters 2018-2022

4.5. Fisher-Tipped Method

The return period extreme wave height using the Fisher Tipped Type I method in Gresik waters can be determined by sorting the maximum wave height data for 10 seasons (2018-2022) from highest to lowest. The highest estimated maximum wave height (H_{max}) is 1.24 m with a probability of 0.35%. Meanwhile, the lowest estimated maximum wave height (H_{max}) is 0.58 m with a probability of 0.06% (Table 7).

Table 7 Calculation of the 10-season return wave period

10-season return period wave calculation								
No. order m	**H_{max}**	**P**	**Ym**	**Hsm. Ym**	**Y²m**	**(Hsm-¯Hsm)²**	**ˆHsm**	**Hsm-ˆHsm**
1	1.43	0.94	2.87	4.10	8.21	2.04	38.66	-37.23
2	0.68	0.85	1.79	1.22	3.19	0.46	18.87	-18.19
3	0.72	0.75	1.23	0.89	1.52	0.52	12.32	-11.60
4	0.84	0.65	0.84	0.70	0.70	0.71	18.36	-17.52
5	0.69	0.55	0.51	0.35	0.26	0.48	15.13	-14.44
6	0.76	0.45	0.23	0.17	0.05	0.58	3.27	-2.51
7	1.24	0.35	-0.04	-0.05	0.00	1.54	-0.44	1.68
8	0.62	0.25	-0.32	-0.20	0.10	0.38	-2.54	3.16
9	0.89	0.15	-0.63	-0.56	0.39	0.79	2.74	-1.85
10	0.58	0.06	-1.06	-0.62	1.13	0.34	-9.88	10.46
Total	8.45	5.00	5.41	6.00	15.56	7.84		

Forecasting the extreme wave height (Hsr) of the Fisher Tippet Type I method with a longer temporal scale yielded results that continue to increase. There are several return periods, namely, 2, 5, 10, 25, 50, and 100 years, which successively obtained results of 2.91 m, 5.0 m, 6.81 m, 9.08 m, 10.80 m, and 12.51 m (Table 8). The improvement in extreme wave height forecasting can be used as a consideration when planning the construction of coastal protection buildings to strengthen the building structure and estimate the height of the building to be safe from extreme waves.

Table 8 Extreme wave height (Hsr) forecasting

Return period (season)	**S (Season)**	**Hsr (m)**	**Ơnr**	**Ơr**	**Hs-1.28Ơr**	**Hs+1.28Ơr**
2	0.3665	1.37	1.2964	1.21	-0.18	2.91
5	1.4999	2.50	2.1620	2.02	-0.08	5.08
10	2.2504	3.25	2.9792	2.78	-0.31	6.81
25	3.1985	4.20	4.0881	3.81	-0.68	9.08
50	3.9019	4.90	4.9346	4.60	-0.99	10.80
100	4.6001	5.60	5.7852	5.40	-1.31	12.51

4.6. Shoreline Cross Section

Before mapping the transverse profile of the existing coastline (2023), the village map was first displayed to provide a description of the landscape and seascape of Tanjung Widoro Village. The largest land use is for milkfish ponds. Tanjung Widoro Village has a fish auction place (TPI) specializing in milkfish with excellent quality compared to milkfish products in other areas. According to the Head of Tajung Widoro Village, there are 5 tons of milkfish every day at Tanjung Widoro TPI. If, on average, 1 kg of milkfish costs Rp20 thousand, then there is a minimum turnover of Rp100 million/day in Tanjung Widoro Village. Since there are two TPIs, this means that the amount of money that rotates is at least Rp200 million/day. Almost all fish are sold outside the region with marketing areas including Sidoarjo, Lamongan, Madura, Juwana, and Central Java. Such huge economic potential will be lost or disappear if it is inundated by tidal floods. A solution is to minimize the losses caused by tidal floods by planning shoreline protection with an approach of mangrove forest ecosystem restoration. The planning started with three stations along the coastline of Tanjung Widoro Village with an approximate length of 11 km (Fig. 15). The red line on the map shows the planned ±11 Km coastline that will be planted with mangroves.

Fig. 15 Map of the mangrove restoration plan at Stations A, B, and C

The average value of the rate of shoreline change in Tanjung Widoro village is -17 m/year. The highest value of the shoreline change rate is 51 m/year, and the lowest value of the shoreline change rate is -103 m/year. Based on data on the rate of shoreline change that occurred during 2017–2023 (Table 9).

Table 1 Predicted changes in the shoreline of Tanjung Widoro

Value	Max (m)	Min (m)	Average (m)
Change distance	304.43	-616.32	-103.85
Rate of change	51.51	-104.29	-17.77
Predicted change	515.10	-1042.90	-175.74

Tanjung Widoro Village is predicted to experience deterioration of the coastline in the next 10 years with an average change distance of 175 m, as shown in Fig. 16. The highest predicted value of the change distance is 515 m, while the lowest predicted value of the change distance is -1042 m. Predictions of shoreline changes indicate that in the next decade, a reduction in land area of 158 ha is expected. The Tanjung Widoro village pond area is prone to impacts due to shoreline changes because it is directly adjacent to the sea.

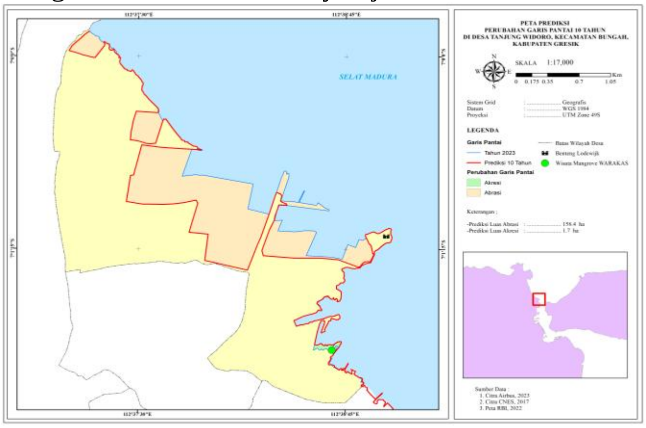

Fig. 16 Predicted shoreline change in the next 10 years

Based on the results of the AHP analysis as a whole, the priority of alternative choices of strategies for joint prevention of tidal flood management is as follows:

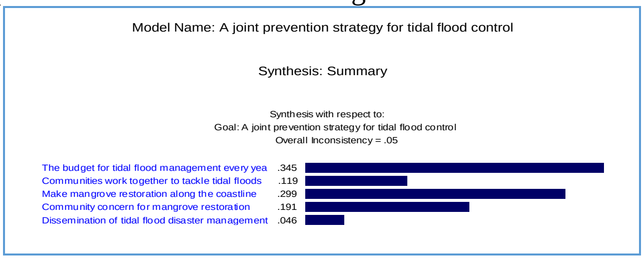

Fig. 17 Prioritization of alternatives

Fig. 17 shows that the prioritization of alternatives is as follows:

– *1st priority:* budget for tidal flood management every year (0.345);

– *2nd priority:* mangrove restoration along the coastline (0.299);

– *3rd priority:* community awareness of mangrove restoration (0.191);

– *4th priority:* communities work together to overcome tidal flooding (0.119);

– *5th priority:* socialization of tidal flood disaster management (0.046).

Communities working together to overcome tidal floods (0.107), making mangrove restoration along the coastline (0.246), community concern for mangrove restoration (0.231), and socialization of tidal flood disaster management (0.046). The first alternative that can be used is the tidal flood management fund budget every year with a weight of 34.5%. Furthermore, the second priority alternative is mangrove restoration along the coastline with a weight of 29.5%, followed by community concern for mangrove restoration (0.191), community mutual cooperation to overcome tidal floods (0.119), and finally socialization of tidal flood disaster management (0.046). Overall, the priority order of criteria and alternatives used can be presented in the following dynamic sensitivity diagram (Fig. 18).

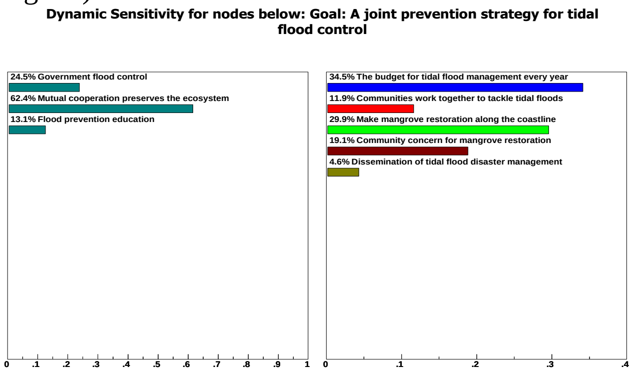

Fig. 18 Summary of priority criteria and alternatives

4.7. Restoration Mangrove Forest Analysis

The mangrove forest restoration analysis includes a watchtower design plan and a mangrove restoration plan. The watchtowers are planned at 3 locations, while the mangrove restoration plan is implemented along the $\pm$11 km coast by planting Rhizophora stylosa mangroves on the basis that this mangrove is more resistant and tolerant to pollution. Its support roots are stronger, and its growing zone is generally in the fore zone.

The mangrove restoration plan involves the following planting stages:

1. One mangrove seedling was taken from the bed.
2. Open the polybag that covers the sediment and roots of the seedling. Do not dispose of the polybag carelessly, but place it on top of the stakes.
3. Plant the mangrove seedling directly into the soil by punching a hole in the soil with a pick so that the hole is deep enough for the roots to be planted properly.
4. Next, tie the mangrove seedlings to the stakes using the raffia rope provided.
5. Pile up with soil. Do not put too much pressure

on the soil so that oxygen can freely escape and enter the soil.

6. Take the polybags that are located on top of the stakes and collect them together in a basket/plastic. Furthermore, the polybags can be recycled into various recycled plastic items.

7. The mangrove planting plan for protecting 11-km Tanjung Widoro coastline requires 3,000 Rhizophora stylosa mangrove seedlings. The planting pattern is as follows (Fig. 19).

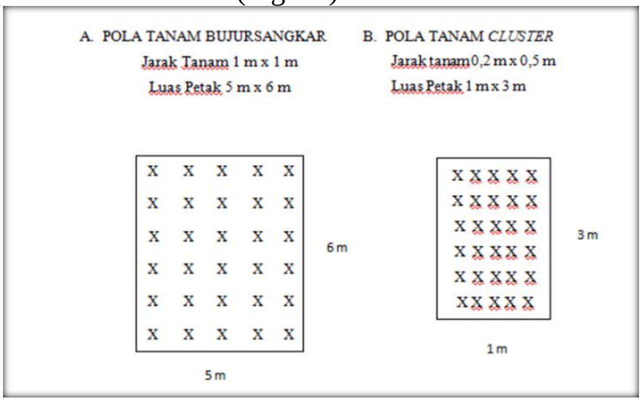

Fig. 1 Mangrove planting pattern

5. Conclusion

The research downstreamed the study results of 2022 in the form of mangrove forest planting along 11 kilometers of Tanjung Widoro Beach. The intermediate result is the planting of mangrove forests. For this reason, top-down innovations are:

a. Protecting the existence of the Tanjung Widoro coastline, where water rises, and the flow of river water does not enter the land, causing tidal floods. In July 2022, Tanjung Widoro Village was inundated with water, which resulted in 145 milkfish ponds that were about to be harvested drowning.

b. The main finding of this research is the prediction results of shoreline changes in the next ten years starting in 2023–2033, estimated that tidal floods will reach more than 145 ponds drowned or around 158.4 Ha if the government does not immediately try to save the coastline, meaning that the local economy to produce milkfish is declining.

c. The results of this study compared with [5] are very different. The findings show that the inundation of tidal floods to the west is widespread and impacts reducing the productivity of milkfish grown by fishermen. The study [5] only examined the causes of tidal floods caused by hydroseanographic variables, whereas their impact on the population's economic aspects was unstudied.

d. The implications of the results of this study indicate that policy formulation by the East Java provincial government is very strategic to perform coastal ecosystem restoration efforts along 11 km of beaches in Tanjung Widoro. The Gresik Regency Government encourages community participation in planting and maintaining mangrove forests as a "bodyguard" of the coastline. Thus, there is mutually beneficial cooperation between the local government and the community.

e. Recommendations for the provincial and Gresik district government and future research are to collaborate with universities to monitor and evaluate mangrove restoration plants to be planted by the community. Universities are also expected to supply base data to predict the level of coastline abrasion, and efforts are needed to prevent widespread tidal floods.

References

[1] RUDIANTO I., and YAMINDAGO. Restoring coastal ecosystems – a case study Malang and Gresik regency, Indonesia. Journal of Coastal Conservation, 2015, 19: 119-130.

[2] RUDIANTO, DARMAWAN V., ISDIANTO A., and BINTORO G. 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. Journal of Coastal Conservation, 2022, 26(4): 26-37.

[3] MCLEOD E., POULTER B., HINKEL J., REYES E., and SALM R. Sea-level rise impact models and environmental conservation: a review of models and their applications. Ocean Coastal Management, 2010, 53: 507-517. https://doi.org/10.1016/j.ocecoaman.2010.06.009

[4] KHASANAH U.N., and MARZUKI M.I. Sea Level Rise Analysis Using Altimetry Dataset for Climate Change Mitigation Application in Fisheries Management Zone (WPP) 573. National Institute of Aeronautics and Space, Jakarta, 2017.

[5] KRESTEVA G.D., ROCHADDI B., and SATRIADI A. Study of Sea Level Rise in Kendal Waters. Journal of Oceanography, 2014, 3(4): 535-539.

[6] STEPHENS M., JOHNSON M., and MARSHALL L.A. Implications of future climate change for event-based hydrologic models. Advances in Water Resources, 2018, 119: 95-110.

[7] WANG Z., OCHIRKHUYAG E., UKHNAA M., and GAUDEL S. A New Era of Economic Globalization: An Opinion on Opportunities, Riskd and Challenges of One Belt One Road. International Journal of Research in Commerce, Economic and Management, 2019, 9(6).

[8] SU H.N., and MOANIBA I.M. Does innovation respond to climate change? Empirical evidence from patents and greenhouse gas emissions. Technological Forecasting and Social Change, 2017, 122: 49-62. https://doi.org/10.1016/j.techfore.2017.04.017.

[9] KASPERSEN B.S., CHRISTENSEN T.B., FREDENSLUND A.M., MØLLER H.B., BUTTS M.B., JENSEN N.H., and KJAER. Linking climate change mitigation and coastal eutrophication management through biogas technology: Evidence from a new Danish bioenergy concept. Science of the Total Environment, 2016, 541: 1124-1131. DOI: 10.1016/j.scitotenv.2015.10.015.

[10] TRIANA K., and WAHYUDI A. Sea Level Rise in Indonesia: The Drivers and the Combined Impacts from Land Subsidence. ASEAN Journal on Science and Technology for Development, 2020, 37. DOI: 10.29037/ajstd.627

[11] NURHIDAYAH L., DAVIES P., ALAM S., SAINTILAN N., and TRIYANTI A. Responding to sea level rise: challenges and opportunities to govern coastal

adaptation strategies in Indonesia. Maritime Studies, 2022, 21: 339-352. https://doi.org/10.1007/s40152-022-00274-1

[12] INDONESIA CLIMATE CHANGE SECTORAL ROADMAP (ICCSR). Scientific Basis: Analysis and Projection of Sea Level Rise and Extreme Weather Event. Jakarta: Ministry of National Development Planning or National Development Planning Agency, Republic of Indonesia, 2010.

[13] HABIB. Rob Flood Submerges Hundreds of Ponds in Gresik: Thousands of Tons of Fish Lost. Tim TV One Reports. Sunday, June 19, 2022.

[14] CENTRAL BUREAU OF STATISTICS. Bungah District in Figures. Catalog No. 1102001.3525120, 2020.

[15] HEWAWASAM UDUMULLAGE ERANGI IMASHA. Extraction and Identification of Microplastics in Green Mussels in Thailand. Master of Science Thesis (Engineering and Technology). Sirindhorn International Institute of Technology, Thammasat University, Thailand, 2021. http://ethesisarchive.library.tu.ac.th/thesis/2021/TU_2021_6322041077_15014_17301.pdf

参考文:

[1] RUDIANTO I. 和 YAMINDAGO。恢復沿海生態系 - 以印尼瑪琊和格雷西克縣為例。海岸保護雜誌，2015，19：119-130。

[2] RUDIANTO、DARMAWAN V.、ISDIANTO A. 和 BINTORO G. 沿海生態系統恢復作為東爪哇北海岸紅樹林生態系統綜合管理以及減緩和適應氣候變遷的一種方法。海岸保護雜誌, 2022, 26(4): 26-37.

[3] MCLEOD E.、POULTER B.、HINKEL J.、REYES E. 和 SALM R。海平面上升影響模型和環境保護：模型及其應用綜述。海洋海岸管理，2010，53：507-517。https://doi.org/10.1016/j.ocecoaman.2010.06.009

[4] KHASANAH U.N. 和 MARZUKI M.I. 使用測高資料集進行海平面上升分析，用於漁業管理區氣候變遷減緩應用573。國家航空航天研究所，雅加達，2017年。

[5] KRESTEVA G.D.、ROCHADDI B. 和 SATRIADI A. 肯德爾水域海平面上升研究。海洋學報, 2014, 3(4): 535-539.

[6] STEPHENS M.、JOHNSON M. 和 MARSHALL L.A. 未來氣候變遷對基於事件的水文模型的影響。水資源進展，2018，119：95-110。

[7] WANG Z.，OCHIRKHUYAG E.，UKHNAA M. 和 GAUDEL S. 經濟全球化新時代：對「一帶一路」機會、風險與挑戰的看法。國際商業、經濟與管理研究雜誌，2019，9（6）。

[8] SU H.N. 和 MOANIBA I.M. 創新是否應對氣候變遷？來自專利和溫室氣體排放的經驗證據。技術預測與社會變革，2017，122：49-62。https://doi.org/10.1016/j.techfore.2017.04.017。

[9] KASPERSEN B.S.、CHRISTENSEN T.B.、FREDENSLUND A.M.、MØLLER H.B.、BUTTS M.B.、JENSEN N.H. 與 KJAER。透過沼氣技術將氣候變遷減緩和沿海富營養化管理聯繫起來：來自丹麥新生物能源概念的證據。全環境科學，2016，541：1124-1131。DOI：10.1016/j.scitotenv.2015.10.015。

[10] TRIANA K. 和 WAHYUDI A. 印尼海平面上升：地面沉降的驅動因素和綜合影響。東協科學技術促進發展期刊，2020年，37。DOI：10.29037/ajstd.627

[11] NURHIDAYAH L.、DAVIES P.、ALAM S.、SAINTILAN N. 和 TRIYANTI A. 應對海平面上升：管理印尼沿海適應策略的挑戰和機會。海事研究，2022年，21：339-352。https://doi.org/10.1007/s40152-022-00274-1

[12]印尼氣候變遷部門路線圖。科學依據：海平面上升和極端天氣事件的分析和預測。雅加達：印度尼西亞共和國國家發展規劃部或國家發展規劃局，2010年。

[13] HABIB。羅布洪水淹沒了格雷西克的數百個池塘：數千噸魚消失。提姆第一電視台報道。2022年6月19日，星期日。

[14]中央統計局。武雅區的數字。目錄號1102001.3525120，2020年。

[15] HEWAWASAM UDUMULLAGE ERANGI IMASHA。泰國青口貝中微塑膠的萃取與鑑定。理學碩士論文（工程與技術）。泰國法政大學詩琳通國際理工學院，2021。http://ethesisarchive.library.tu.ac.th/thesis/2021/TU_2021_6322041077_15014_17301.pdf