eISSN: 2721-5717; pISSN: 2747-2124 https://journal.unhas.ac.id/index.php/zonalaut

ZONA LAUT

JOURNAL OF OCEAN SCIENCE AND TECHNOLOGY INNOVATION

Projection of Sea Level Rise Due to Climate Change in Panimbang District Using CMIP6 Model

Nabila Sukma Mardeny 1), Luthfi Anzani 2), Ayang Armelita Rosalia 3) dan M. Arief Rahman 4)
1) Marine Information Systems Study Program, Indonesian Education University Serang Campus
2) Meteorology Climatology and Geophysics Agency
email: luthfi_anzani@upi.edu

Abstrct

Global climate change, including sea level rise due to global warming, has become a significant threat to coastal areas, especially in Panimbang District, Pandeglang Regency, Banten. This study uses the Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model, specifically the Model for Interdisciplinary Research on Climate (MIROC6), with the Shared Socioeconomic Pathways (SSP) 585 climate scenario to evaluate sea level rise projections and their impacts on the area until 2100. The limitation of this study is that it does not analyze land subsidence. The analysis shows a sea level rise rate of 3.5 mm per year, slightly higher than the global average projected by the Intergovernmental Panel on Climate Change (IPCC) of 3–4 mm per year in a high emission scenario. The cumulative increase projection of 394 mm by the end of this century has the potential to submerge up to 95,804 km² of coastal areas in Panimbang District. Factors that influence sea level rise will result in impacts such as land subsidence due to excessive groundwater extraction. The land subsidence will add new problems such as tidal flooding in Panimbang District. The impact can be mitigated and adapted such as raising the floor of the house or building embankments and also utilizing mangrove conservation in Lembur Mangrove Patikang located in Citeureup Village, Panimbang District.

Keyword: Coupled Model Intercomparison Project Phase 6 (CMIP6) Projection Model, Sea level rise, Climate Projections.

1. INTRODUCTION

Climate change is the biggest challenge faced by humans in the 21st century, which has an impact on human activities that produce large amounts of greenhouse gas emissions, which causes global warming [1]. Some of the consequences that arise due to global warming are the loss of glaciers, the extinction of animals [2]. To overcome this, the UNFCCC (United Nations Framework Convention on Climate Change) was formed as an international convention that regulates global climate change mitigation. Based on the UNFCCC, international regulations such as the Kyoto Protocol were born, which regulates developed countries (Annex I) and developing countries in reducing greenhouse gas emissions. The Paris Agreement became a regulation agreed upon in 2015 by 196 countries in Le Bourget, France, which is an important step in the global commitment to reducing emissions and limiting the increase in the earth's temperature. The Paris Agreement, adopted by 196 countries in 2015, encourages countries to contribute to climate change mitigation and adaptation. This agreement involves almost all countries, with the main goal of suppressing the increase in the earth's average temperature below 2°C, with an ideal target of 1.5°C [3].

As many as 195 countries have ratified the Paris Agreement until July 2021. Projections of global climate change show that the average global temperature is expected to continue to increase due to high concentrations of greenhouse gases (GHG) in the atmosphere. According to the latest projections suggested by the Intergovernmental Panel on Climate Change (IPCC), global temperatures could increase between 1.5°C and 5°C by the end of the 21st century, depending on the emission scenario taken. Greenhouse gas emissions continue to increase at the same rate as Representative Concentration Pathways 8.5 (RCP 8.5), then global temperatures could increase by more than 4°C by 2100, which could cause more extreme and irreversible climate change [4,5]. Based on IPCC projections, if global temperatures increase by 2°C by 2100, global sea levels could rise by about 0.5 meters, which will submerge densely populated coastal areas [4]. This sea level rise can cause loss of coastal habitats, land subsidence, coastal erosion, and increase the risk of annual flooding that threatens large cities around the world [4, 6]. Sea level rise projections generated from the study (Sung et al., 2021) indicate that sea level rise will continue throughout the 21st century, and could have a very large impact on densely populated coastal areas. The study used CMIP6 for the Paris climate target, as is the case around the Korean Peninsula.

Significant sea level rise, expected to occur along with global warming, will drastically affect coastal areas, increasing the risk of flooding and changing ecosystems. Similar things can be expected to happen in Indonesia, where rising sea levels are predicted to submerge coastal areas and worsen the damage that has occurred due to climate change [7]. Based on the SLR projections and their impacts on coastal areas suggested [7]. Indonesia needs to strengthen its commitment to implementing climate change adaptation policies that focus more on mitigating risks due to significant sea level rise, this is also in accordance with global efforts that have been initiated through the Paris Agreement, which aims to limit global temperatures and reduce the impacts that may arise from global warming. The following phenomena occur, so to study the projection of sea level rise below the Paris climate target (1.5, 2.0, 3.0 °C) can use CMIP6.

The CMIP6 model can integrate improvements in climate processes that interact between the atmosphere, ocean, ice, and the earth's surface. Changes that occur in climate increase the model's ability to simulate climate phenomena more realistically, including projections of changes in sea level. The use of Global Climate Models (GCM) and Coupled Model Intercomparison Project Phase 6 (CMIP6) modeling can also provide an accurate picture of the impact of global climate change including Indonesia itself, where most of its territory is ocean, such as in the Banten province, especially on the coast of Panimbang District [8]. Several factors from the sea level rise projection need special attention because of their multidimensional impacts, including land subsidence, tidal flooding. Overall, these impacts can increase the risk of environmental damage in coastal areas [9]. Land subsidence caused by sea level rise will add new problems such as flooding.

rob flood, the expansion of the area due to rob flood shows the continuity between land subsidence [9]. The benefits of this study are to provide a strong scientific basis as a projection of sea level rise against climate change, as well as to assist related parties in developing strategies for the impacts of sea level rise for natural resource management and protection policies, especially in maintaining the sustainability of mangrove ecosystems which have an important role in reducing abrasion and also binding the soil that can offset sea level rise [10]. The results of this study are expected to be a reference for more effective policies to reduce the negative impacts of climate change on people's lives and ecosystems in the coastal areas of Panimbang District. Analyzing climate change on sea level rise in Panimbang District can be done by utilizing the CMIP6 model to predict the impact of climate change with the Shared Socioeconomic Pathways (SSP) 585 scenario which covers various levels of greenhouse gas emissions and socio-economic changes until 2100 can provide a strong scientific basis for disaster mitigation planning and climate change adaptation, as well as assisting related parties in developing natural resource management strategies and protection policies, especially in maintaining the sustainability of the mangrove ecosystem which plays an important role as a wave breaker and carbon absorption in Panimbang District. The results of this study are expected to be a reference for more effective policies in reducing the negative impacts of climate change on people's lives and ecosystems in the coastal areas of Panimbang District.

2. METHODS

2.1 Location and Time of Research

The research location is in Panimbang District, Pandeglang Regency, Banten Province, which is located at 06°29‟00”- 06°36‟00” South Latitude and 105°38‟00”- 105°50‟00” East Longitude. This research was conducted in 2020, 2040, 2060, 2080 and 2100.

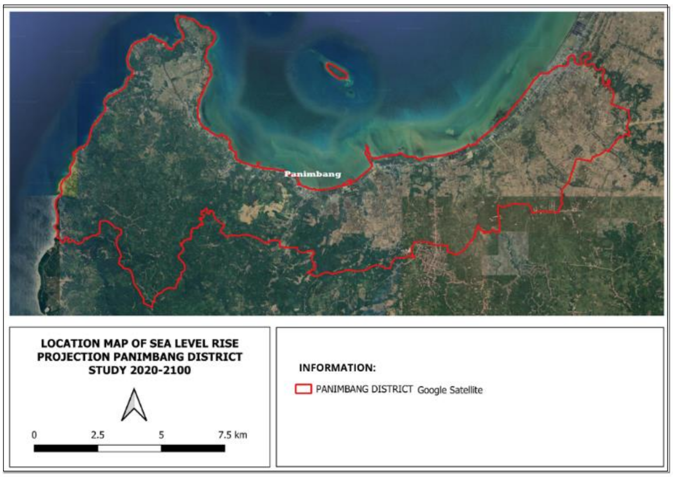


Figure 1. Map of projected sea level rise locations
Panimbang sub-district study 2020-2100

2.2 Data analysis

Climate change is the biggest challenge faced by humans in the 21st century, which has an impact on human activities that produce large amounts of greenhouse gas emissions, which causes global warming [1]. Some of the consequences that arise due to global warming are the loss of glaciers, the extinction of animals [2]. To overcome this, the UNFCCC (United Nations Framework Convention on Climate Change) was formed as an international convention that regulates global climate change mitigation. Based on the UNFCCC, international regulations such as the Kyoto Protocol were born, which regulates developed countries (Annex I) and developing countries in reducing greenhouse gas emissions. The Paris Agreement became a regulation agreed upon in 2015 by 196 countries in Le Bourget, France, which is an important step in the global commitment to reducing emissions and limiting the increase in the earth's temperature. The Paris Agreement, adopted by 196 countries in 2015, encourages countries to contribute to climate change mitigation and adaptation. This agreement involves almost all countries, with the main goal of suppressing the increase in the earth's average temperature below 2°C, with an ideal target of 1.5°C [3].

As many as 195 countries have ratified the Paris Agreement until July 2021. Projections of global climate change show that the average global temperature is expected to continue to increase due to high concentrations of greenhouse gases (GHG) in the atmosphere. According to the latest projections suggested by the Intergovernmental Panel on Climate Change (IPCC), global temperatures could increase between 1.5°C and 5°C by the end of the 21st century, depending on the emission scenario taken. Greenhouse gas emissions continue to increase at the same rate as Representative Concentration Pathways 8.5 (RCP 8.5), then global temperatures could increase by more than 4°C by 2100, which could cause more extreme and irreversible climate change [4,5]. Based on IPCC projections, if global temperatures increase by 2°C by 2100, global sea levels could rise by about 0.5 meters, which will submerge densely populated coastal areas [4]. This sea level rise can cause loss of coastal habitats, land subsidence, coastal erosion, and increase the risk of annual flooding that threatens large cities around the world [4,6]. Sea level rise projections generated from the study (Sung et al., 2021) indicate that sea level rise will continue throughout the 21st century, and could have a very large impact on densely populated coastal areas. The study used CMIP6 for the Paris climate target, as is the case around the Korean Peninsula.

Significant sea level rise, expected to occur along with global warming, will drastically affect coastal areas, increasing the risk of flooding and changing ecosystems [7]. Similar things can be expected to happen in Indonesia, where rising sea levels are predicted to submerge coastal areas and worsen the damage that has occurred due to climate change [7]. Based on the SLR projections and their impacts on coastal areas suggested [7]. Indonesia needs to strengthen its commitment to implementing climate change adaptation policies that focus more on mitigating risks due to significant sea level rise, this is also in accordance with global efforts that have been initiated through the Paris Agreement, which aims to limit global temperatures and reduce the impacts that may arise from global warming. The following phenomena occur, so to study the projection of sea level rise below the Paris climate target (1.5, 2.0, 3.0 °C) can use CMIP6.

The CMIP6 model can integrate improvements in climate processes that interact between the atmosphere, ocean, ice, and the earth's surface. Changes that occur in climate increase the model's ability to simulate climate phenomena more realistically, including projections of changes in sea level. The use of Global

Climate Models (GCM) and Coupled Model Intercomparison Project Phase 6 (CMIP6) modeling can also provide an accurate picture of the impact of global climate change including Indonesia itself, where most of its territory is ocean, such as in the Banten province, especially on the coast of Panimbang District [8]. Several factors from the sea level rise projection need special attention because of their multidimensional impacts, including land subsidence, tidal flooding. Overall, these impacts can increase the risk of environmental damage in coastal areas [9]. Land subsidence caused by sea level rise will add new problems such as flooding.

The use of global climate models Global Climate Models (GCM) and CMIP6 modeling can provide a more accurate picture of the impacts of climate change in various regions, including coastal areas. CMIP6 (Coupled Model Intercomparison Project Phase 6) is a global initiative that aims to coordinate the development and comparison of various climate models used to predict the impacts of future climate change. CMIP6 involves many research institutions around the world, each developing different climate models with the aim of providing more accurate projections of climate change based on various greenhouse gas emission scenarios. One of the models used in CMIP6 is MIROC6 (Model for Interdisciplinary Research on Climate 6) version 6, which was developed by a team of researchers from Japan, including the University of Tokyo and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). MIROC6 is designed to simulate the complex interactions between the atmosphere, ocean, ice, and biosphere, and predict future climate change using various different greenhouse gas emission scenarios. The MIROC6 model used in this study has quite detailed specifications. The Source ID of this model is MIROC-ES2L, and the Institution ID is MIROC. The experiment used in this study, this model follows ssp585, which is a scenario with a high greenhouse gas emission pathway that describes the possibility of greater global warming in the 21st century. The variant label of this model is r1i1p1f2, which refers to the first model variation, with the first configuration and experiment. The grid used in this model is latitude-longitude based with the label gn, and the model output results are obtained with a monthly frequency (mon), with the main focus on simulating ocean conditions that are relevant for sea level rise (SLR) analysis.

FABDEM (Forest And Buildings removed Copernicus DEM) data is used as elevation data. FABDEM is a digital elevation model that has removed vegetation and building elements to provide a more accurate picture of the earth's surface. This data is then adjusted to the administrative area of Panimbang District to obtain results that are more specific and relevant to the observation area. Using the MIROC6 model prepared for CMIP6 and FABDEM elevation data, sea level rise (SLR) projections can be calculated as a function of time (t), providing a more accurate picture of the impacts of climate change, especially those related to sea level rise in the coastal area of Panimbang District. This projection is very important for planning climate change adaptation policies and mitigating risks against coastal damage in the future.

Based on a journal [7], this equation combines several components that contribute to sea level changes, as follows.

$$SLR(t) = SLR(t)_{ocean} + SLR(t)_{glaciers} + SLR(t)_{ice\ sheets} + SLR(t)_{ground\ water} + SLR(t)_{GIA} \quad (1)$$

SLR(t)ocean measures the contribution of ocean thermal expansion to sea level rise, calculated using data from climate models such as CMIP6. When ocean temperatures increase, the volume of seawater also increases according to the thermal expansion coefficient. The slr_ocean data, generated by the MIROC6 model in CMIP6, describes changes in ocean volume due to global warming. Slr_ocean provides information on the contribution of ocean thermal expansion to projected sea level rise, which is important for planning climate change mitigation and adaptation in coastal areas. SLR(t)glaciers is calculated using a volume-area model that estimates changes in glacier mass based on projected temperature and precipitation. Global climate models allow for estimates of glacier volume loss due to melting due to global warming. Data from climate models are used to calculate changes in the volume of melting glaciers, which are then converted into contributions to sea level rise. SLR(t)ice sheets are calculated through two main components, namely, Surface Mass Balance (SMB) and Dynamical Contribution (DYN). SMB reflects the surface mass balance, which is calculated based on snow accumulation and ice melting due to changes in atmospheric temperature. For example, for the Antarctic ice sheet, the SMB change is calculated by the formula:

$$\Delta SMB_{Antarctic} = -0.0105 - 0.01759 \times \delta T_{atm} - 0.0412 \quad (2)$$

This formula relates the change in atmospheric temperature (δTatm\delta T_{atm}δTatm) to the loss of ice mass. The same process can be applied to Greenland using the relevant formula for that region. Dynamical Contribution (DYN) includes factors such as ice movement (calving) and other changes in ice sheet dynamics. This dynamical contribution is calculated by relating ΔSMB\Delta SMBΔSMB to additional factors.

An example of the dynamic contribution to Antarctica can be calculated using the formula:

$$\Delta DYN_{Antarctic} = \Delta SMB_{Antarctic} \times 0.95 + 32 \times r \quad (3)$$

It can be seen that r is a factor determined from previous studies, reflecting the influence of certain dynamic processes. These two components, SMB and DYN, are then combined to obtain the total contribution of the ice sheet to sea level rise. This approach helps to understand how climate change affects the ice sheets in Antarctica and Greenland and its impact on global sea level rise. The contribution of changes in groundwater storage to sea level rise, SLR(t)groundwater is calculated using a global hydrological model that estimates changes in groundwater storage due to human water use and recharge rates. The decrease in groundwater extracted for needs such as irrigation, industry, and domestic use can cause a redistribution of water mass from land to sea, thereby contributing to sea level rise.

This hydrological model integrates data on water use and recharge rates to calculate the total impact on sea level rise. Meanwhile, SLR(t)GIA (Glacial Isostatic Adjustment) refers to changes in the Earth's surface that occur in response to mass redistribution due to melting of ice from the previous glacial period. GIA takes into account the rebound of the Earth's crust due to the release of ice load and the redistribution of ocean mass. The GIA model uses historical data and simulations to estimate these impacts on sea level changes.

The contribution of GIA is very important in understanding regional patterns of sea level rise and its impacts on a global scale. The sea level rise projections, which are carried out by parameterization using the MIROC6 climate model in CMIP6 following the approach used in the IPCC AR5 report, include simulations of contributions from changes in temperature, ice melting, and other factors that affect sea level rise (IPCC, 2013). The data contains sea level rise projections based on the RCP4.5 scenario. RCP4.5 provides projections of emissions that affect factors causing sea level rise, such as ocean temperature (ocean thermal expansion), ice melting, and changes in groundwater mass, all of which are accounted for in the sea level rise estimates. The formula for total sea level rise (total SLR) can be written as:

$$\text{Total SLR} = \sum (\text{SLR Component}) \times 1000 \quad (4)$$

The SLR component includes each factor that contributes to sea level change, and multiplication by 1000 is used to convert the results from meters to millimeters, providing a more detailed measure that is sensitive to small changes in the projection. The sea level rise projection is based on the components that cause it in the RCP4.5 scenario. The main components that contribute to sea level rise include ocean thermal expansion SLR(t)ocean , glacier melting SLR(t)glaciers, and melting of Greenland and Antarctic ice sheets SLR(t)ice sheets. Components such as Groundwater and GIA are also taken into account, with GIA having a negative effect on the projected rise. Overall, the total contribution from all these factors provides an idea of the expected sea level rise in the future. The data used to conduct the study.

Tabel 1. Technical and Data Collection

Data	Sumber Data
Sea Surface Height	ESGF (Earth System Grid Federation)
Sea level rise projections based on RCP 4.5 scenario	International Climate Data Center, University of Hamburg
FABDEM	Copernicus
Map of Pandeglang District and Village Area	Geospatial Information Agency Geoportal
Value of sea level rise in 2020	IPCC

Sea level rise can be predicted using 30 m fabdem data with the following formula:

$$\text{var rise} = \text{meters} \times (\text{year} - \text{baseYear}) / 1000 \quad (5)$$

Description:

Meters : Average value (rate) per year of sea level rise in millimeters (mm).
(Year – base year) : Difference between the analyzed year and the base year.

/ 1000 : Conversion of sea level rise from millimeters (mm) to meters (m).

The projection is carried out in 2020, 2040, 2060, 2080, 2100 with a base year in 2015. Determining the average value of sea level rise for a specified year can use linear regression with the following formula:

$$y = a + bx \quad (6)$$

Description:

y : Dependent variable
a : Constant
b : Regression Coefficient
x : Independent variable

In addition to determining the average sea level rise projection, it is necessary to carry out standard deviation and standard error as a comparison of the projected year value that has occurred in 2020 with the projection value that will be carried out with the following formula:

$$SD = \sqrt{Varians} \quad (7)$$

$$SE = \frac{SD}{\sqrt{n}} \quad (8)$$

Description:

SD : Standard Deviation
SE : Standard Error
n : Sample Error

The results obtained from the calculation of sea level rise are exported from Google Earth Engine (GEE) into shp format for further processing into QGIS for further visualization. The limitation of this study is that it does not conduct research on land subsidence.

3. RESULTS AND DISCUSSION

3.1. Location Overview

Panimbang District is one of the districts located in Pandeglang Regency, Banten Province, Indonesia. Demographically, the Panimbang District area has a fairly dense population and has an area of 536.34 km2 with 54,021 people in 2023 who depend on the fisheries, agriculture and tourism sectors (BPS, 2024). Panimbang District is located on the south coast of Java Island, so it has a long coastline. Its geographical condition which is located on the coast also makes it an area that is prone to natural disasters such as floods and tsunamis.

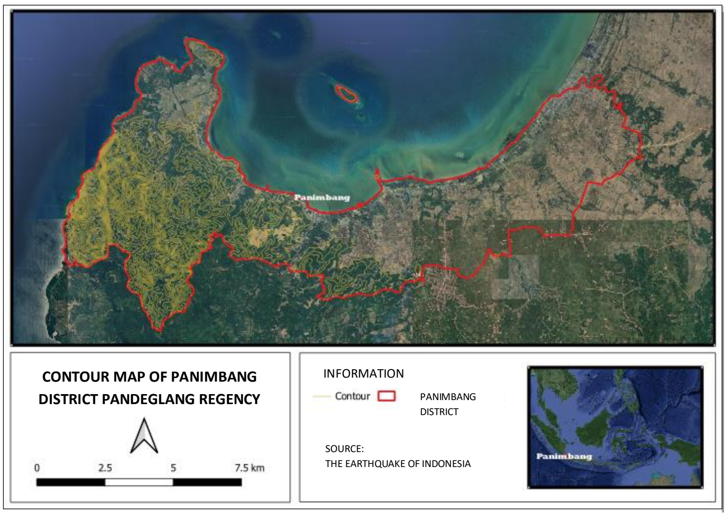


Figure 2. Contour Map of Panimbang District, Pandeglang Regency

Based on the contour map, it shows variations in height that have characteristics that tend to be flat around the coast with gradual heights. Panimbang District is directly adjacent to Cikedal District in the north, Labuan District in the east, and Sumur District in the west. Panimbang District is famous for its beautiful nature such as beaches that are used as tourist locations in Banten, such as Tanjung Lesung Beach which has beautiful white sand and clear sea water. Panimbang District also has forests and hills that are used as ecotourism.

3.2 Projection of Sea Level Rise

Projections on sea level rise will have a significant impact on the Panimbang District area which has coastal characteristics with a water depth of around 0.2 meters and a coastline length of 22 km. climate change, especially related to the phenomenon of sea level rise caused by global warming and melting ice. Based on data obtained from CMIP6 modeling using the Shared Socioeconomic Pathways (SSP) 585 scenario, water inundation projections and affected areas can be estimated for various projection years, starting from 2020 to 2100.

Table 2. Results of Sea Level Rise Projections Based on RCP4.5 Scenario Components

SLR(t) components	Number of values (mm)
SLR(t)*ocean*	0.80
SLR(t)glaciers	0.51
SLR(t)ice sheets Greenland Dynamic Ice)	0.18
SLR(t)ice sheets (Antarctical Dynamic Ice)	0.33
Total *ice sheets*	0.52
SLR(t)groundwater	0.12
SLR(t)GIA	-0.012

shows the sea level rise projection based on the causal components in the RCP4.5 scenario. The main components contributing to sea level rise include ocean thermal expansion (SLR(t)ocean), glacier melting (SLR(t)glaciers), and melting of Greenland and Antarctic ice sheets (SLR(t)ice sheets). Components such as (Groundwater) and (GIA) are also taken into account, with GIA having a negative effect on the projected rise. Overall, the total contribution of all these factors provides an idea of the expected sea level rise in the future. Linear regression can be used to predict, understand and compare the results of hypotheses statistically over time, and to evaluate the accuracy of the model. This method provides information on the influence and relationship between the variables analyzed through a statistical approach described by a linear line. This test aims to find a straight line that minimizes the error between the relationship between the dependent variable and independent variables such as slr_ocean and slr_total.

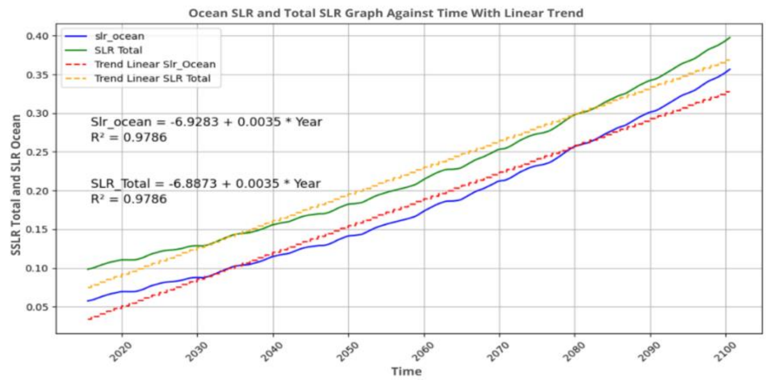


Figure 3. Time series and linear regression of slr_ocean and slr_total

Both variables (slr_ocean and slr_total) show an increase in the upward trend over time with a linear line that has a positive gradient. Based on the analysis, the average annual sea level rise is 3.5 mm. The equation of linear regression for total sea level rise is with a coefficient of determination (-6.8873) of 97%. This value shows that the regression has high accuracy, where variations in total sea level rise can be explained by the time variable.

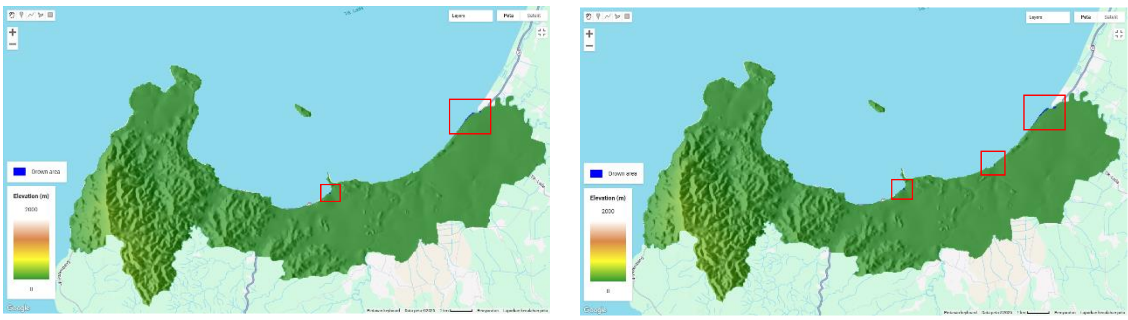
Figure 3 shows the relationship between time and the two variables (slr_ocean and slr_total) for the period 2015 to 2100. Based on the average increase in total sea level in the Panimbang District area, which is 0.0035 meters or equivalent to 3.5 mm per year. The following statement shows a significant change over time, so it is important to pay attention to the impacts and mitigation steps in the Panimbang District area. Data obtained in 2020 from international sources shows that the rise in global sea levels continues. Sea level rise since 1901 can be estimated at around 200 mm with a rate of increase of 3.3 mm per year in the period 1993-2020 which is a finding officially supported by the Intergovernmental Panel on Climate Change (IPCC) in the assessment reports (Assessment Reports) is considered scientifically valid because the data is supported by a standardized measurement methodology, verified through other independent research and compiled based on global scientific consensus [4].

Making a comparison in 2020 with the projection calculation, the standard deviation and standard error calculations can be carried out which obtain the results obtained in the standard deviation calculation of 0.1 mm then for the standard error getting a value of 0.070 mm. It can be said that the 2020 data between the value of 3.3 mm and the 2020-2100 projection data with a value of 3.5 mm has a small deviation value with an average uncertainty of around 0.070 mm, which means that the estimate on the projection is quite reliable. The high R^2 value also indicates that the linear trend is very suitable for the data, so that sea level rise shows an almost identical pattern and consistently increases until 2100. The results of slr_ocean and the SLR(t) component in Table 2 will be analyzed and get the results of the sea level rise inundation projection as in Table 3.

Table 3. Results of sea level rise predictions for 2020-2100 in Panimbang District

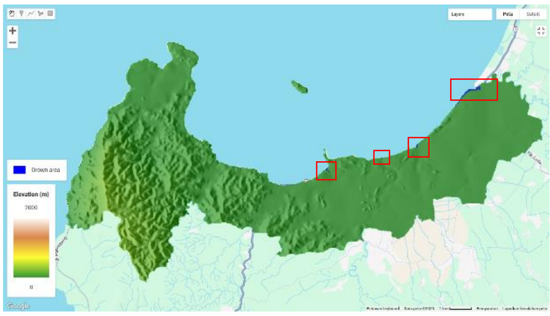
Projection Year	Inundation Projection (mm)	Total Area (km)	Standard Error (mm)	Standard Deviation (mm)
2020	110.540	0.047	0.07	0.01
2040	155.857	0.082	0.07	0.01
2060	214.533	0.142	0.07	0.01
2080	298.091	0.219	0.07	0.01
2100	394.051	0.357	0.07	0.01

Calculation of sea level rise predictions is done using Google Earth Engine with high resolution with 30 meters per pixel so that it can calculate the area in more detail. The sea level rise data projections presented show an increasing impact on land areas over time, which is measured based on the inundation that occurs due to sea level rise. Therefore, the spatial visualization of the results of sea level rise can be seen as follows.

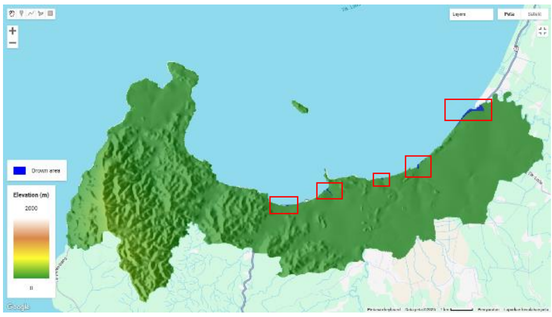


a). Year Projection 2020

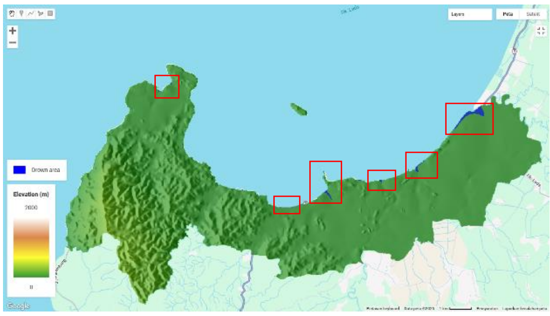
b). Year Projection 2040



c). Year Projection 2060



d). Year Projection 2080



e). Year Projection 2100

Figure 4. Projected sea level rise in 2020, 2040, 2060, 2080, and 2100.

The results of this analysis were conducted using Google Earth Engine (GEE), as shown in Appendix 2, which shows a visualization map generated from the submerged area marked in blue to illustrate the impact of sea level rise. Google Earth Engine (GEE) shows that this technology allows for a more detailed and accurate analysis of the impacts of climate change on coastal areas, with more detailed mapping at high resolution. The use of satellite-based mapping technology allows for more targeted mitigation actions to be planned and increases preparedness for the impacts of climate change [11]. Other functions also allow for exporting data in SHP format which is useful for further analysis.

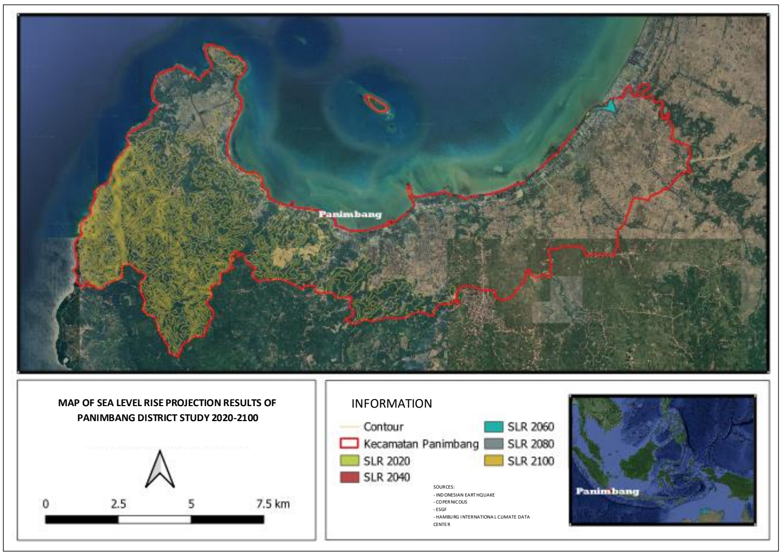


Figure 5. Map of the projected sea level rise results for Panimbang District 2020-2100.

It can be seen in 2020, the sea level rise projection carried out by the CMIP6 model reached 110,540 mm, causing around 0.047 km² of area to be submerged. Until its peak occurred in 2100, when the sea level rise reached 394,051 mm, causing around 0.357 km² of area to be submerged. This rate of increase can be seen from the increasing trend in each projection period, namely 2020, 2040, 2060, 2080, to 2100, which indicates a real threat to coastal areas. A comparison of accuracy can be seen in the research conducted by Mujadida et al. (2021), which uses the Recurrent Neural Network (RNN) model to analyze sea level dynamics in the Java Sea, predicts that sea level rise will reach 0.152 meters or equal to 152 mm in 2032, with an estimated upward trend that will continue until 2036. The predicted increase figures are different, both of which indicate a significant trend of sea level rise in the future [12]. The annual rate of global sea level rise has also increased to 0.17 inches/year (0.44 centimeters/year or equal to 4.4 mm/year) [13]. Compared with the global sea level rise rate, data from the IPCC (Intergovernmental Panel on Climate Change) shows that the global average SLR during the 21st century is around 3-4 mm per year [4]. This means that the global cumulative increase in 2100 is estimated to reach 30-40 cm in a high emission scenario.

3.3 Impact of Sea Level Rise

This sea level rise projection needs special attention because of its multidimensional impact, the influence of land subsidence can exacerbate sea level rise (Rais et al., 2022) resulting in land subsidence, tidal flooding and abrasion[14]. Plains that are often exposed to sea water will result in abrasion which will reduce the area of land so that it can easily bring sea water towards settlementsy. Overall, these impacts can increase the risk of environmental damage in coastal areas [9]. Land subsidence is also a result of sea level rise which will add new problems such as tidal flooding, this can show the continuity between land subsidence [9]. The existence of these impacts can be mitigated and adapted such as raising the floor of the house or building embankments [15]. Another mitigation strategy is to manage groundwater and also utilize mangrove conservation in Lembur mangrove patikang located in Citeureup Village, Panimbang District. Mangroves function as mitigation and global climate change [16]. The existence of mangroves on the Serang coast is a form of natural protection from abrasion [17]. Mangrove forests function as sedimentary sediments for sedimentation on tree root mud which can be used as a barrier to seawater seepage into the mainland. Mangrove forests also play a role in reducing abrasion and also binding the soil which can offset sea level rise [10]. Collaboration with the community to increase awareness of environmental protection policies also needs to be a priority to reduce the risks and impacts of sea level rise. Sea level rise in Panimbang Regency can result in losses that are much greater than the global average impact if not addressed immediately, given the vulnerability of the area to climate change.

4. CONCLUSION

Based on the MIROC6 global climate projection model and the SSP 585 scenario, the sea level rise projection in Panimbang District shows a significant trend from 2020 to 2100. In 2020, the increase is estimated to reach 110,540 mm, causing around 0.047 km² of area to be submerged, and in 2100, the sea level rise is estimated to reach 394,051 mm, causing 0.357 km² of area to be submerged. The average sea level rise is 3.5 mm per year, with an R^2 value of 97%, which shows a consistent linear pattern. Sea level rise has multidimensional impacts such as causing land subsidence, tidal flooding and abrasion. The existence of these impacts can be mitigated and adapted such as raising the floor of the house or building embankments, managing groundwater and also utilizing mangrove conservation in Lembur mangrove patikang located in Citeureup Village, Panimbang District. The existence of mangroves is a form of natural protection from abrasion, in addition, collaboration with the community to increase awareness of environmental protection policies is a priority to reduce the risk and impact of sea level rise. Sea level rise in Panimbang Regency can cause losses that are much greater than the global average impact if not addressed immediately, given the vulnerability of the region to climate change. The recommendations given from this study are to use a topography model that has a higher resolution, seen from this study only discussing the CMIP6 model from the SSP 585 scenario, so it is necessary to make a comparison using several models and scenarios to find out and be a comparison of the worst conditions.

REFERENCES

[1] Wahyuanto, E., Heriyanto, H., & Hastuti, S. (2024). Study of the Use of Augmented Reality Technology in Improving the Learning Experience in the Classroom. West Science Social and Humanities Studies, 2(05), 700–705.

[2] Dinas LHKab. Buleleng (2019). Pemanasan Global. Dinas Lingkungan Hidup Kab. Buleleng.

[3] Baroleh, S. E., Massie, C. D., & Lengkong, N. L. (2023). Implementasi Konvensi Internasional Paris Agreement Tentang Mitigasi Perubahan Iklim Di Indonesia. Lex Privatum, 11(5).

[4] IPCC. (2021). IPCC Sixth Assessment Report: The Physical Science Basis. Intergovernmental Panel on Climate Change.

[5] IPCC. (2018). IPCC Special Report on Global Warming of 1.5°C. Intergovernmental Panel on Climate Change.

[6] IPCC. (2019). Special Report on the Ocean and Cryosphere in a Changing Climate. Intergovernmental Panel on Climate Change.

[7] Sung, H. M., Kim, J., Shim, S., Ha, J. C., Byun, Y. H., & Kim, Y. H. (2021). Sea Level Rise Drivers and Projections from Coupled Model Intercomparison Project Phase 6 (CMIP6) under the Paris Climate Targets: Global and around the Korea Peninsula. Journal of Marine Science and Engineering, 9(10), 1094.

[8] Reshmidevi, T. V., Kumar, D. N., Mehrotra, R., & Sharma, A. (2018). Estimation of the climate change impact on a catchment water balance using an ensemble of GCMs. Journal of Hydrology, 556, 1192-1204.

[9] Iskandar, S. A., Helmi, M., Muslim, M., Widada, S., & Rochaddi, B. (2020). Analisis Geospasial Area Genangan Banjir Rob dan Dampaknya pada Penggunaan Lahan Tahun 2020-2025 di Kota Pekalongan Provinsi Jawa Tengah. Indonesian Journal of Oceanography, 2(3), 271-282.

[10] Puryono, S. (2018). Pelestarian hutan mangrove dan peran serta masyarakat pesisir.

[11] Mulyani, A. S. (2020). Antisipasi terjadinya pemanasan global dengan deteksi dini suhu permukaan air menggunakan data satelit. CENTECH, 2(1), 22-29.

[12] Mujadida, Z., Setiyono, H., Handoyo, G., Hariyadi, H., & Marwoto, J. (2021). Analisis dinamika permukaan laut di Laut Jawa dengan Recurrent Neural Network periode 1993 sampai 2019. *Indonesian Journal of Oceanography*, *3*(1), 100-110.

[13] Willis, J. K., Hamlington, B. D., & Fournier, A. (2023). Global mean sea level. NASA. Retrieved January 7, 2025, from https://sealevel.nasa.gov/understanding-sea-level/ key-indicators/global-mean-sea-level Beckley, B., et al. (2017). GMSL dataset. NASA.

[14] Rais, A., Lestari, D. A., & Arifin, W. A. (2022). Model Prediksi Kenaikan Permukaan Air Laut Menggunakan Data Satelit Altimery Jason-1 dengan pendekatan Algoritma Long-Short Term Memory (Studi Kasus: Teluk Jakarta). *Jurnal Georafflesia: Artikel Ilmiah Pendidikan Geografi*, *7*(2), 165-172.

[15] Kartika, F. D. S., & Helmi, M. (2019). Meta-analysis of community's adaptation pattern with tidal flood in Pekalongan City, Central Java, Indonesia. In E3S Web of conferences (Vol. 125, p. 09001). EDP Sciences.

[16] Ati, R. N. A., Rustam, A., Kepel, T. L., Sudirman, N., Astrid, M., Daulat, A., ... & Hutahaean, A. A. (2014). Stok karbon dan struktur komunitas mangrove sebagai blue carbon di Tanjung Lesung, Banten. Jurnal Segara, 10(2), 119-127.

[17] Vidyan, S. dan Aswin R. 2018. Kajian erosi dan sempadan pantai potensial di ekosistem pesisir Kota Serang dan Kabupaten Demak. Wetlands International Indonesia. Bogor.