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Tidal Characteristics for Disaster Preparedness in the Port Area (Case Study: Port of Semarang, Central Java)

Nurkhalis Rahili[1], Buddin Al Hakim[1]*, Danang Ariyanto[1], Eny Cholishoh[1], Aprijanto[1], Destianingrum Ratna Prabawardani[1], Tjahjono Prijambodo[1], Gugum Gumbira[2]

[1]Research Center for Hydrodynamic Technology, National Research and Innovation Agency
Jl. Hidro Dinamika, Keputih, Kec. Sukolilo, Surabaya, Jawa Timur 60112 Indonesia
[2]Department Civil engineering and Industrial Design, University of Liverpool
The Quadrangle, Liverpool, L69 3GH, United Kingdom
Email: budd001@brin.go.id

Abstract

Tanjung Emas Port, Semarang, is vulnerable to hydrometeorological disasters and tidal flooding due to tides and rising sea levels. The tidal flood also impacts human activities and industrial operations around the coastal area. Several measures have been taken to make the community resilient to tidal flooding and adapt to this disaster. A tidal flood happened in Semarang from May to June 2022 with a flood height of up to 210 cm. This incident disturbed the primary port operations, with more than 75% of the port area full of water. The total loss was estimated up to IDR 615 billion. Many factors influenced this incident, such as the rising sea levels due to global warming, tides, and other atmospheric conditions, causing weather anomalies. This study aims to compare and validate Geospatial Information Agency (BIG) tide data with Meteorological, Climatological, and Geophysical Agency (BMKG) tide data using three kinds of statistical test, that are mean relative error (MRE), root mean square error (RMSE), and mean absolute error (MAE). Also, to conduct tidal analysis using 11 years of tide data measurement to know the tide's characteristics in Semarang's coastal area. The result will be used to provide input for strategic steps and preparation for disaster preparedness that will occur in the near future. Tide data analysis using MIKE21, the IOS method. The result shows data comparison error < 5% and a Formzahl value of 1.797 with the type of tide mixture prevailing diurnal and the change of water level up to 10 cm.y^{-1}.

Keywords: *Tidal, Disaster, Preparedness, Port Area, Coastal City, Semarang*

Introduction

Semarang City is one of the cities affected by natural disasters and hydrometeorological disasters (Hakim *et al.*, 2015; Sunaryo *et al.,* 2018). The Provincial Agency for disaster management (BPBD) stated that at least five tidal floods occurred in January - June 2022. This condition is higher than tidal events throughout 2021; local agencies categorized only two tidal floods as disasters. The worst tidal event in Semarang occurred on May 23, 2022. The coast of Semarang City experienced tidal flooding with a height of 210 cm with a daily average water level of 163 cm (BMKG, 2022). According to The Harbormaster's Office and Port Authority (KSOP), the total of the port area disturbed by this incident is estimated at 75%. The location points inundated by the flood were Yos Sudarso Street in front of KSOP Tanjung Emas, Nusantara Pier, Coaster Street, Deli Street, and the Lamicitra area. Losses in the port area due to this incident were conveyed by the Indonesian Customs and Excise of IDR 615 billion due to disruption of loading and unloading activities and goods delivery. The previous year, on May 29, 2021, there was also a tidal flood of the same height as the 2022 tidal flood. It was a result of the high intensity of rain that occurred in Semarang City, BPBD Semarang City recorded as many as 11,128 people, and 3,590 housing units were affected by flooding due to this incident (BPBD Kota Semarang, 2022). It can occur because the city of Semarang consists of lowlands in the lower region (north) and hills in the upper part (south). Northern Semarang has a low topography with a 0–2% slope. In the northern area, land subsidence reaches 6-15 cm.y^{-1} (Abidin *et al.*, 2013). Many locations have the same height as the sea level, and some places are below sea level.

Coastal Semarang, directly adjacent to the Java Sea, will be influenced by the sea conditions, tides, and tidal waves. Semarang water tidal type is a mixture of prevailing diurnal. It means that if the tide is at its peak, rob incidents can occur once a day. It will worsen the condition of the affected coastal communities. Semarang City experienced 16 tidal flood events during 2012-2020, generally occurring in December - February and May - July, with the full moon May - July (first and eastern transition season). Tidal flooding, strong winds, and full tide or heavy rain mainly contribute to tidal flooding from December to February (west monsoon) (Egaputra *et al.*, 2022).

*) Corresponding author

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Tidal flood impact is widespread and affects many aspects of life, from physical and environmental ecosystems to the social and economic conditions of the community. The sea wall collapse at Tanjung Emas Port on May 23, 2022, can be used as one of the initial hypotheses for the effect of tidal waves with a combination of tidal waves as a derivative impact related to infrastructure damage due to tidal flooding. Many buildings around the port area cannot be repaired, and the abandoned infrastructure is clear evidence of the impact of tidal flooding (Hakim *et al.*, 2022).

Several important factors that must be considered in formulating technical recommend-dations related to tidal flooding in Semarang include tidal factors, extreme weather, sea level rise due to global warming, land subsidence, and groundwater extraction. The main factors that cause tidal flooding in coastal areas are land subsidence and sea level rise during high tides (Wibowo *et al.*, 2015; Syafitri and Rochani, 2022). This research aims to validate the Meteorological, Climatological, and Geophysical Agency (BMKG) measurement tide data with Geospatial Information Agency (BIG) data. Knows the characteristics of tidal data and predicts the mean sea level in the next few years.

Material and Methods

The research was carried out at Tanjung Emas Port, Semarang. This location was chosen because it is Central Java's economy centre. The research uses the descriptive analysis method. Data analysis using several in situ tidal observations, including tide gauge data from 2011–2022 by the Geospatial Information Agency (BIG). Tidal observation data from the Meteorology, Climatology and Geophysics Agency (BMKG) maritime stations (Sta Mar II) from 2019-2022 that need validation.

Tidal characteristics analysis calculates the tidal data using Mike21 IOS methods. This method analyses and predicts hourly tidal elevation via least squares with at least 69 constituents (Foreman, 1977). BMKG data validation used statistical tests. Statistical data analysis to determine the quality and suitability of the data from BMKG with BIG's data. It was carried out using statistical analysis of mean relative error (MRE), root mean square error (RMSE), and mean absolute error (MAE). The three equations are defined as:

$$MRE = \frac{1}{n}\sum_{i=1}^{n}\frac{y_p - y_o}{y_o} \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_p - y_o)^2} \quad (2)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_p - y_o| \quad (3)$$

Note: n = the total of data observation, y_p = BMKG tide data observation, and y_o = BIG tide data observation.

In the end, using linear regression, tide-level data is used to predict sea-level changes in the next few years. Linear regression is a simple analytical model that uses interval or ratio data types. This analysis allows us to make predictions based on the data obtained. The regression analysis determines the relationship between two or more variables. At least one variable is the dependent variable (response) Y, and the other is the independent variable (predictor) X. The relationship between these variables is modelled as a function to obtain the regression model's parameter estimates (coefficient).

Result and Discussion

Characteristics of tides and data validation

The data obtained from BIG and BMKG are tidal observation data at the Tanjung Emas port. BMKG data is measured using a pressure sensor, while BIG data is measured using a radar and pressure sensor. BIG tidal data was obtained in the form of data with an interval of 2 minutes. This data is then filtered to get tidal data with 1-hour intervals.

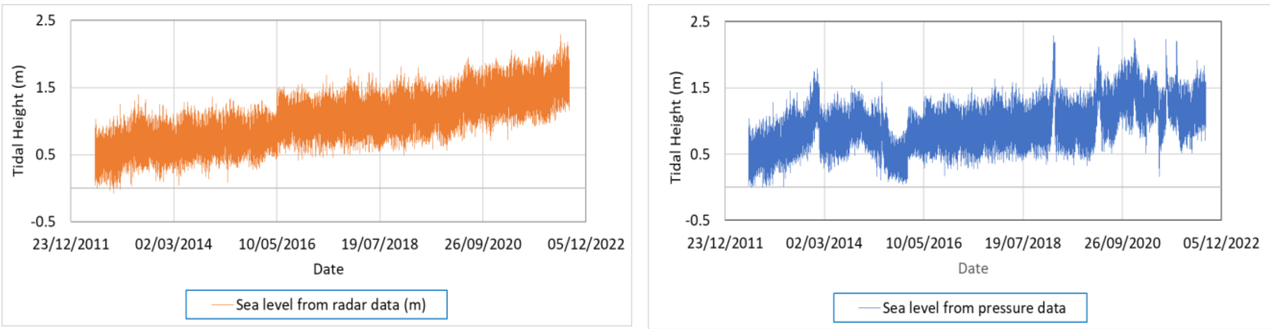
Figure 1 shows BIG tidal data from radar sensors (a) and pressure (b), where both sensors are mounted on the same platform. Data from the pressure sensor contains anomalies and some spikes, but neither for the data measured by the radar sensor. The data normalization process is carried out to obtain tidal harmonic data free from interference. The two data have similarities: rising sea levels every year.

The BMKG Station Marine, another supporting tidal observation station, has a different reference, so the tidal value issued by the BMKG needs to be validated with BIG's data. The results in Table 1 show that the test error value is <5%. The results of the MRE, RMSE and MAE tests gave a value of 4.58%, 0.30%, and 4.12%, respectively. It means that the similarity of the data is more than 95%, so the measurement results are good and can be used. To make the tidal data in the same reference, we need to offset the BMKG tidal data to BIG's data, shown in Figure 2.

The results of BIG tidal measurements at Semarang station were compared with global predicted data obtained from Mike 21 analysis. As a result, Figure 3 shows the difference between BIG tide values (blue) and global tide predictions (black) over 11 years. The measurement results show that water levels have increased yearly, but there is no increase in the prediction rate of the data, as shown in Table 3. The reason is the prediction of tides using constant tides component without being influenced by other factors, such as sea level rise and land subsidence. While the measurement results experience changes in these two factors, the graph changes yearly. It means there is a change in tidal characteristics on the coast of Semarang.

The results of the analysis of the tidal harmonic components at the BIG observation station showed there are no significant changes in the tidal components, which include the values of M_2, S_2, N_2, K_2, O_1, K_1, P_1, and Q_1 from 2011–2022 (Figure 4.). From this tidal generator component, there should be no increase in the mean sea level (MSL) from 2012-2022 as in the 'tides prediction' linear graph. The increase in the MSL value in tidal data from BIG is shown by the linear 'tide BIG' value in Figure 3. The increase in MSL in the 2012-2022 BIG tidal data indicates that the increase in MSL is due to the effect of vertical changes at the BIG station.

The analysis of tidal observation data using IOS methods for 11 years obtained eight tidal constituents, namely M_2, S_2, N_2, K_2, O_1, K_1, P_1, and Q_1, as shown in Table 2. From the analysis of tidal data for 11 years and annual analysis obtained tidal constituents as shown in Figure 4. Seen in Figure 4 (a), there is a phase anomaly in 2016. The K_1 component is a constituent with a dominant amplitude compared to the others, with a value between 0.211 m to 0.235 m. It was followed by constituents M_2, S_2, O_1, P_1, N_2, K_2, and Q_1 with a value range of 0.104 m to 0.011 m. The analysis results also found that the "form ratio" F-number value is 1.797, which means that Semarang, especially at Tanjung Emas Port, has the tide mixed prevailing diurnal, same as stated by (Permana *et al.*, 2012; Hakim *et al.*, 2013).



(a) (b)

Figure 1. Tides data of Geospatial Information Agency (BIG) 2012-2022 Radar Data; (b) Pressure Data

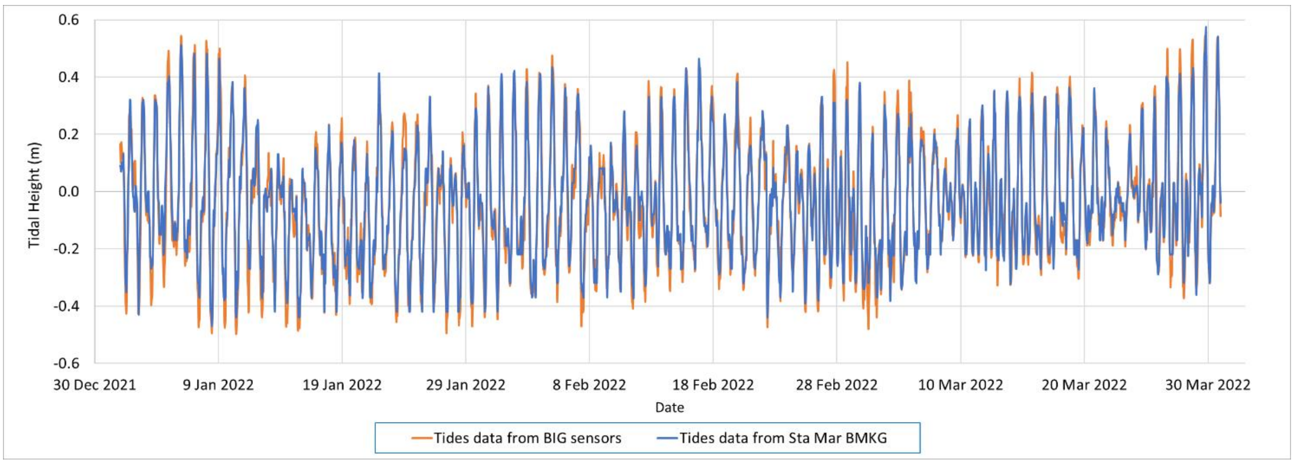


Figure 2. Tides data comparison from BIG dan BMKG

Table 2. The value of statistical calculating comparing BIG data and BMKG Sta Mar

No	Statistic Variable	BIG vs Sta Mar BMKG (%)
1	MRE	4.58
2	RMSE	0.30
3	MAE	4.12

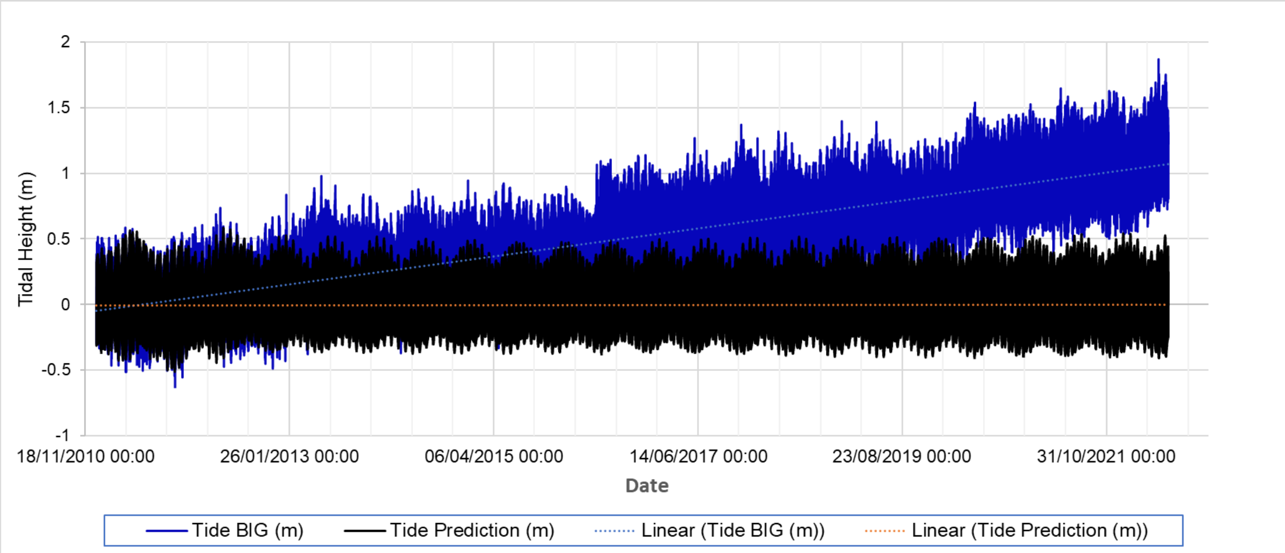
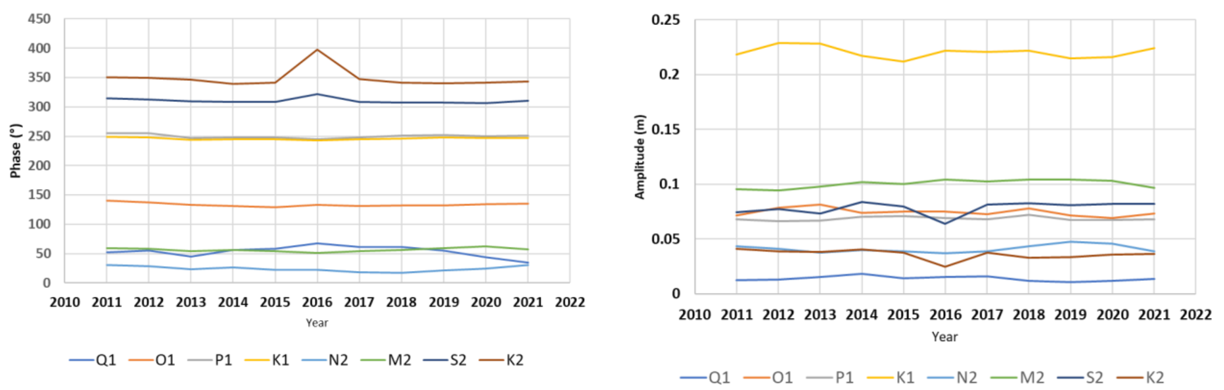


Figure 3. BIG Data Tide and Tide Prediction 2011-2022

Table 1. Tidal constituents from 11 years of analysis

Constituent Name	Amplitude	Phase	Description
M_2	0.099	56.240	Principal lunar semidiurnal constituent
S_2	0.078	310.290	Principal solar semidiurnal constituent
N_2	0.040	24.240	Larger lunar elliptic semidiurnal constituent
K_2	0.041	348.870	Luni solar semidiurnal constituent
O_1	0.083	135.670	Principal lunar diurnal constituent
K_1	0.235	244.800	Principal luni solar diurnal constituent
P_1	0.068	249.700	Principal Solar diurnal constituent
Q_1	0.015	57.850	Larger lunar elliptic diurnal constituent



(a) (b)

Figure 4. Yearly tidal constituents

Table 2. Variation of tide comparison in 2011 and 2021

Variation of Tide		Value in 2011 (m)	Value in 2021 (m)
Highest Astronomical Tide (HAT)	Xo+(M2+S2+N2+K2+K1+O1+P1+Q1)	0.625	1.637
Highest High-Water Level (HHWL)	Xo+(M2+S2+K2+K1+O1+P1)	0.569	1.584
Mean High Water Level (MHWL)	Xo+(M2+K1+O1)	0.386	1.398
Mean Sea Level (MSL)	Xo	0.000	1.004
Mean Low Water Level (MLWL)	Xo-(M2+K1+O1)	-0.386	0.610
Chart Datum Level (CD)	Xo-(M2+S2+K1+O1)	-0.460	0.529
Lowest Low Water Level (LLWL)	Xo-(M2+S2+K2+K1+O1+P1)	-0.569	0.424
Lowest Astronomical Tide (LAT)	Xo-(M2+S2+N2+K2+K1+O1+P1+Q1)	-0.625	0.372

Table 3. Yearly Tide Analysis

No	Data Series	MSL (rad) (m)	Reference to MSL 2011 (m)	Yearly increase (m)
1	2011	6.272	0.000	-
2	2012	6.355	0.083	0.083
3	2013	6.512	0.240	0.157
4	2014	6.556	0.284	0.044
5	2015	6.622	0.350	0.066
6	2016	6.796	0.524	0.174
7	2017	6.892	0.620	0.095
8	2018	6.931	0.658	0.039
9	2019	6.985	0.713	0.054
10	2020	7.150	0.878	0.166
11	2021	7.276	1.004	0.126

In Table 3 and Table 4, the MSL value in 2011 is used as a reference for calculating changes in MSL and the tide variation value. Changes in the value of the tide variations for components can be seen due to sea level rise at the observation location. The highest sea level rise occurred in 2016, followed by 2020 and 2013, with a water level rise of 17.4 cm, 16.6 cm, and 15.7 cm. The lowest value increase occurred in 2018, 2014, and 2019 with values of 3.9 cm, 5.4 cm, and 4.4 cm, respectively. The change in MSL value from January 2011 to December 2021 reached 1,004 m. The average sea level rise in Semarang is 10 cm per year. The results of the MSL analysis are used as a reference for conducting linear regression analysis with the values of land subsidence and sea level rise remaining constant. The linear regression equation is defined as

$$y = 0.0967x - 194.4806, \quad R^2 = 0.9882 \tag{4}$$

Note: y = MSL value; x = Year of projection; R^2: R square

The prediction results of sea level changes are shown in Table 5 and Figure 5. In 2030 the water elevation is predicted to be 1.838 m, with an increase of 9.3 cm yearly. It supposes severe handling and careful planning in Semarang coastal to minimise the water expansion and disrupt activities in coastal areas during ROB accidents.

From the analysis of tidal data for 11 years, it turns out that the increase in seawater in Semarang has a very high average value of 10 cm.y^{-1}. Sea level rise is impacted by climate change as a result of abnormal rises in the Earth's overall temperature (Akbar *et al.*, 2019; Putri *et al.*, 2021). Sea level rise varies yearly with a range of 0.039 - 0.174 m. y^{-1}. Several dominant factors that can affect sea level rise from the analysis of tidal data are global sea level rise, local sea level rise, land subsidence at the measurement station, and factors of accuracy and ability of tidal observers. From radar altimetry analysis, the sea level rise in Semarang reaches 2.1 mm.y^{-1} (Bott *et al.*, 2021). Global sea level is projected to rise further in the 21st century than between 1961 and 2003, increasing by about 4 mm. y^{-1} (Nebojsˇa *et al.*, 2014). The trend of sea level rise is still happening today; from 1993-2022 data, the global sea level rise reached 102.5 mm; this means that the average sea level rise reached ±3.53 mm.y^{-1} (NASA, 2022), the SLR trend in the tide gauge record from 1997 to 2015, with a rate of approximately 4.4 mm.y^{-1}. Calculation of sea level rise in Semarang has also been calculated from the tidal data of BMKG Semarang in 2003-2010, resulting in a sea level rise of 3.93 mm.y^{-1} (Hakim *et al.*, 2013). In Indonesia alone, sea level rise can be higher due to geographical influences, such as the ENSO atmospheric phenomenon (Handoko *et al.*, 2018). Using these data, the sea level rise in Semarang is ± 4.4 mm.y^{-1}. Data altimetry study from 1993 to 2016 shows SLR in the coastal region of Semarang is 5.1 mm.y^{-1} (Karondia *et al.*, 2019). The increment of SLR along Indonesia's coastline reflects a faster increase rate than the global rate (Takagi *et al.*, 2016).

In several previous studies, the northern area of Semarang experienced the fastest land subsidence rate compared to other sites. The high human activity in the area was positively correlated with the land subsidence rate. The tidal measurement station was analysed in the port area and the northern part of Semarang. The magnitude of the decline that occurred in the study location varied; GPS data collection from 2008 to 2011 shows that land subsidence in Semarang has spatial and temporal variations, with average spatial rates of about 6 to 7 cm.y^{-1} and maximum rates that can go up to 14–19 cm.y^{-1} at specific locations. Some references to the magnitude of the subsidence value are as follows: 8.1-8.3 cm.y^{-1} (Abidin *et al.*, 2013). 6.67-8 cm.y^{-1} (Yastika *et al.*, 2019), 10 cm.y^{-1} (Andreas *et al.*, 2018). 6.65-9.81 cm.y^{-1} (Fakhri *et al.*, 2017) 8.1-12 cm.y^{-1} (Ismanto *et al.*, 2012). Using historical land subsidence data around the port area shows that the value of land subsidence at the research point is 9.03 cm. y^{-1}; this value is based on historical values and the latest data closest to the research location. The value of land subsidence in the city of Semarang fluctuates. Some areas experience land subsidence at a slow rate and increase over time. In this study, the amount of land subsidence at the site is considered consistent at 9.03 cm. y^{-1} per the previously presented considerations. Judging from the sea level rise and land subsidence analysis in the coastal Semarang area, the water level rise more influenced by subsidence (Irawan *et al.*, 2021)

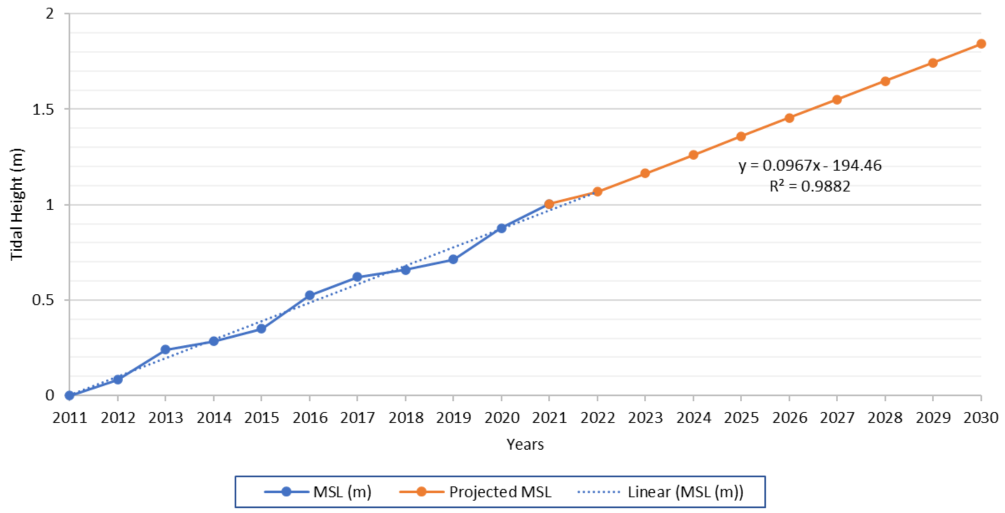


Figure 5. MSL 2011 to 2021 and projected MSL using linear regression

Table 4. MSL prediction with linear regression

No	Years	MSL Projected (m)
1	2022	1.066
2	2023	1.163
3	2024	1.259
4	2025	1.356
5	2026	1.452
6	2027	1.549
7	2028	1.645
8	2029	1.742
	2030	1.838

To get the tidal characteristics at the tidal station of 'BIG SMRG 2 Sta', it is necessary to correct the sea level rise and land subsidence values, which are 0.044 mm. y^{-1} and 9.03 cm. y^{-1}, so that the correction value The result obtained is 0.947 cm. y^{-1}. In contrast, the correction to the recording data that has been done can be corrected using the tidal model calculation data.

The correction value submitted can be used to make corrections to the value of tidal observations at the measurement point of the SMRG 2 BIG sta and other points around the station because they are similar to the value of land subsidence. The government and related parties can use this predicted value as a reference. In addition, the value of the results of this study can also be used as a scenario for preparing preparedness efforts in handling disasters in the coastal areas of Semarang, especially in the Tanjung Emas Port area, Semarang, because, in general, this analysis describes the conditions at the port. Henceforth, it can be used to determine elevation for port operations and infrastructure development.

With the increase in sea level and land subsidence, efforts must be made to deal with possible hazards in the coming year. The rise in water that exceeds the design of the building at the port can disrupt port operations and shorten the life of the building in the coastal area, so it is necessary to carry out periodic monitoring to minimize disaster events.

Conclusion

Tidal analysis can be used to correct the results of tidal measurements carried out by BMKG Sta Mar, which do not have a reference point with a data error of less than 5%. The Semarang coast has the tidal type of mixture prevailing diurnal with a Formzahl number value of 1.797, with the dominant constituent being K_1. There is an increase in the mean sea level in the waters, with an annual average of 10 cm. The prediction of tidal data for the next few years using linear regression equations gives a sea level rise of 9.3 cm.y^{-1}. The resulting linear regression equation can be used as a reference in determining the elevation of development and planning for the coastal area of Semarang.

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