The Impact of Sea Level Rise on the Coastal Region of Selangor

Kesan Kenaikan Aras Laut di Kawasan Persisiran Pantai Selangor

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Abstract

Climate change interacts in a particular perspective with the varieties of human activities and other drivers of coastal change. The phenomena of Sea Level Rise (SLR) are major impacts of global warming. Sea level rise may impact critical infrastructures such as jetty, coastal road, and the local community. This article aims to investigate the impact of inundation due to the Sea Level Rise along the Selangor coastal using the geospatial technique. The main objectives of this study are to predict the rise in sea level in the years 2020 and 2060, thus to determine the impact on infrastructure and land use along the Selangor shoreline. The data that were used were three altimeter satellites located at the border of Malaysia-Thailand, the Penang–Perak border, and the Straits of Johor as well as the three JUPEM tide gauge data. Hydrodynamic modelling along the coastline was developed using a MIKE 21 Flow Model. This hydraulic stimulation numerical is an ideal method for coastal studies. The parameter that has been used consists of bathymetry, currents speed, current direction and tidal data. The impact of sea level rise on the whole study area had shown that water was rising from 0.051 to 0.289 in the years 2020 and 2060. The impact of inundation shown that 192-274 units of infrastructures were potential to affect in period 40 years. The cropland and settlement area have been shown to be the most impacted land use area, which is caused by inundation ranging from 14.31% to 18.42% and 3.90% to 5.19% respectively. Therefore, the finding of this study can be used as a significant tool by coastal managers for developing sustainable resource management practices for future development.

Keywords: Sea Level Rise, Climate Change, Coastal, Hydrodynamic Modelling

Abstrak

Perubahan iklim berinteraksi dengan jenis aktiviti manusia dan faktor-faktor perubahan pesisir yang lain. Fenomena kenaikan aras laut (SLR) adalah berpunca dari kesan utama pemanasan global. Kenaikan permukaan laut boleh mempengaruhi infrastruktur kritikal seperti jeti, jalan pesisir, dan masyarakat setempat. Artikel ini bertujuan untuk mengkaji kesan genangan akibat kenaikan permukaan laut di sepanjang pesisir pantai negeri Selangor menggunakan teknik geospatial. Objektif utama kajian ini adalah untuk meramalkan kenaikan permukaan laut pada tahun 2020 dan 2060, sehingga dapat menentukan kesan terhadap infrastruktur dan penggunaan tanah di sepanjang garis pantai Selangor. Data yang digunakan adalah berdasarkan tiga satelit altimeter yang terletak di sempadan Malaysia-Thailand, sempadan Pulau Pinang-Perak, dan Selat Johor serta tiga data tolok pasang JUPEM. Pemodelan hidrodinamik di sepanjang garis pantai dikembangkan menggunakan Model Aliran MIKE 21. Nombor rangsangan hidraulik ini adalah kaedah yang sesuai untuk kajian pesisir. Parameter yang telah digunakan terdiri daripada batimetri, kelajuan arus, arah arus dan data pasang surut. Kesan kenaikan permukaan laut di seluruh wilayah kajian menunjukkan bahawa air naik dari 0,051 menjadi 0,289 pada tahun 2020 dan 2060. Kesan genangan menunjukkan 192-274 unit infrastruktur berpotensi terjejas dalam jangka waktu 40 tahun. Kawasan pertanian dan kawasan penempatan telah terbukti menjadi kawasan penggunaan tanah yang paling berpengaruh yang disebabkan oleh genangan masing-masing antara 14.31% hingga 18.42% dan 3.90% hingga 5.19%. Oleh itu, penemuan kajian ini dapat digunakan sebagai alat penting oleh pengurus pesisir untuk mengembangkan amalan pengurusan sumber lestari bagi pembangunan masa hadapan.

Kata kunci: Kenaikan Aras Laut, Perubahan Iklim, Persisiran, Model Hidrodinamik

Introduction

Sea level rise (SLR) is the phenomenon that is caused by significant factors such as climate change, declining ozone layers and the weather condition. The increase in sea level around the world attracts global attention. The level of the sea can change locally and globally, due to changes in total water mass, changes in ocean basin shape and changes in water density. Sarkar, Begum, Pereira, Jaafar, and Saari (2014), have explained that sea level rise has severe consequences on coastal areas in many countries, causing the flooding of coastal areas and islands, coastal erosion and degradation of valuable ecosystems such as mangroves and wetlands. In the upcoming years, the rise in sea level will enforce a substantial burden on the people and societies, particularly for a nation such as Malaysia which is surrounded by shorelines. In the recent study by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2012), the rise in sea level has been named as one of the significant challenges of the 21st century for modern society. Thus, active adaptation and mitigation measures need to be put in place in order to avoid and offset the influence of these issues. According to Meyssignac and Cazenave (2012), the worldwide mean sea level had increased at levels of 1.7 mm/year and 3.2 mm/year respectively, as a result of both the increase of sea thermal expansion and the loss of land ice.

In the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC), it has been clearly stated that sea level trends are projected to increase between 18 cm to 59 cm from 1980-2000 to 2090-2100 (IPCC, 2007). Accordingly, coastal areas are affected in different ways due to climate change since the coast is sensitive to higher sea levels that will eventually inundate low-lying ground (wetland and dry), which is also suffering from storm surges and shoreline erosion. As the ocean rises in the world, lowland and coastal areas will permanently disappear. Even a small increase in the extent of the sea level can have devastating consequences for the coastal regions, particularly in high population densities and other living species such as flora and fauna. Strauss and Kulp (2014) have highlighted on climate change in their analysis that more than 216 million people currently live in vulnerable areas that will be affected by the rising sea levels, and could be regularly or permanently inundated within the next 100 years. Therefore, the objectives of this research are to predict the rise in sea level in the years 2020 and 2060, in order to identify the impact on the infrastructure and land use along the Selangor shoreline.

Study Area

The study area is located along the coastal region of Selangor Darul Ehsan, which is one of the most developed states that is located on the west coast of Peninsular Malaysia. The coastal stretch between Sabak Bernam and Sepang extends over a distance about 291 km, overlooking the Straits of Malacca. The area lies between 3°50' to 2°35'N and 100°49' to 101°42' E approximately. The five districts in Selangor with a shoreline are Sabak Bernam (60km), Kuala Selangor (60km), Klang (76km), Kuala Langat (80km) and Sepang (15km) (Rajendra, 2016). Figure 1 shows the location of the study area.

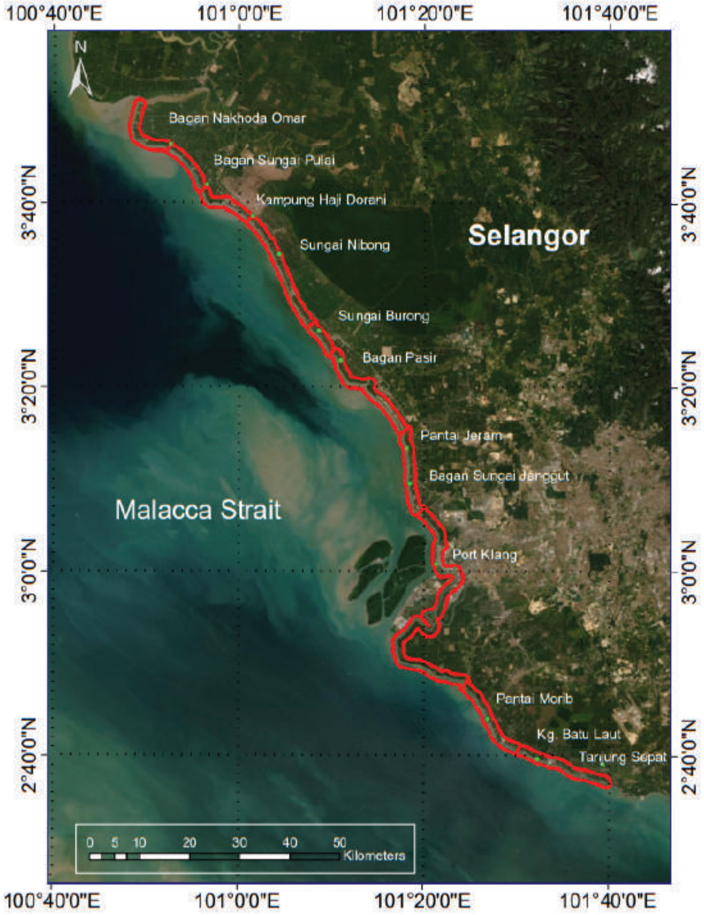

Figure 1: Study Area

Research Methodology

To achieve the objectives of the study the rise in the sea level along the coast of Bagan Nakhoda Omar to Tanjung Sepat, suitable methods have been designed and identify. Figure 2 shows the overall flow chart of this study. The whole study consists of two main sections, which are the rise in sea level and Hydrodynamic modelling. The flow chart comprises four key phases consisting of planning, data collection, data processing, and results and analysis. Planning is a phase that involves all the processes that are needed in the assessment of the rise in the sea level. The collection of data for this research included primary and secondary data; primary data include information from the altimeter satellite and the JUPEM tide gauge data while the secondary data involve the retrieval of information from technical reports of relevant Malaysian ministry agencies such as NAHRIM, JUPEM, UKM, and JPS. All of this data is required to process the SLR results and coastal hydrodynamics by using the ArcGIS 10.3 and MIKE21 FM software.

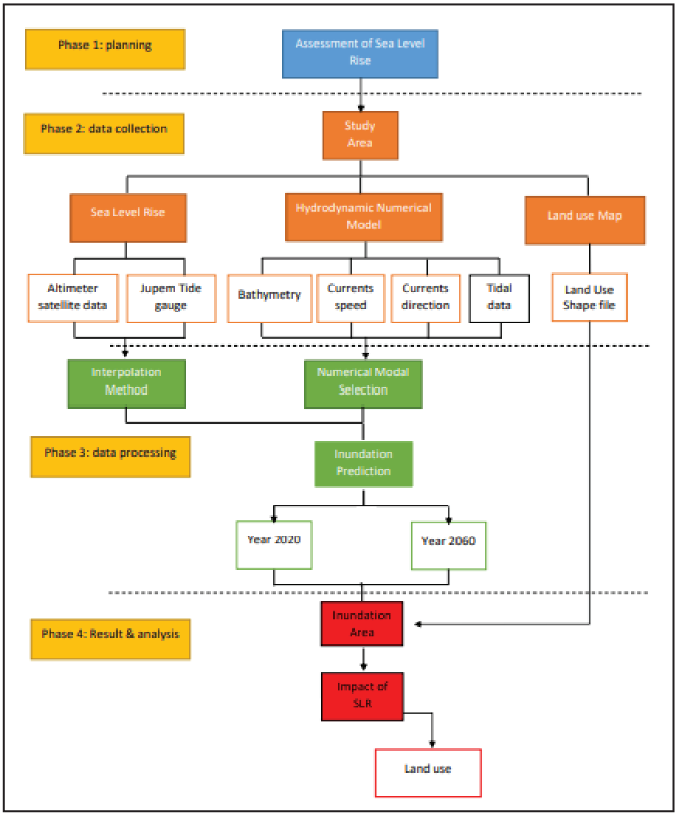

Figure 2: The Methodology Flowchart

Methods of Data Collection for Sea Level Rise Studies

Data acquisition for sea level rise involves the data from altimeter satellite. There are three station altimeter satellites, they are located at the border of Malaysia (Thailand to Perlis), the Penang to Perak border, and the Straits of Johor. The data collection was based on observations and measurements on 2017. The prediction of the rise in sea level was obtained from previous studies by government agencies such as JPS, NAHRIM, and JUPEM (Table 1). The data from the satellite altimeter were used to analyse the pattern of the year 1993 to 2010. NAHRIM can determine the projected sea level rise for the year 2020 and 2060 from an altimeter station across the Malaysian Ocean. Table 1 shows a summary of the data that are involved in the SLR in the watershed area of Bagan Nakhoda Omar to Tanjung Sepat.

Table 1: Summary of Data Used for SLR

No	Type data	Area	Period (year)	Remark	Source
1.	Rate of sea level	Border Malaysia-Thailand, border Penang-Perak, Straits Johor	2017	3 altimeter satellite (1) border Malaysia-Thailand, (2) border Penang-Perak, (3) Straits Johor	NAHRIM
2.	Prediction SLR	Malaysia include study area	1993 - 2010	satellite altimeter analysis pattern of the year 1993 to 2010	NAHRIM
3.	JUPEN tide gauge data	Peninsular Malaysia	2017	Data obtained on monthly	JUPEM

Methods of Data Collection for Coastal Hydrodynamic Model

The MIKE21 software was used to produce the coastal hydrodynamic model of the study area. This data was needed in the numerical hydrodynamic model as shown in Table 2; all the data for hydrodynamic modeling studies such as bathymetry, currents speeds, currents direction, tidal data were acquired from previous studies and government agencies.

Table 2: Summary of Primary and Secondary Data of the Study Area Used for Hydrodynamic Modelling

No	Type data	Area	Period (year)	Remark	Source
1.	Bathymetry Currents speed	Selangor Selangor	2017 23 May 2014 until 04 Jun 2014	Datum: MSL Use ADCP tools on 2 station	NAHRIM UKM
2.	Current direction	Selangor	23 May 2014 until 04 Jun 2014	Use ADCP tools on 2 station	UKM
3.	Tidal	Peninsular Malaysia	1984 until 2015	Data obtained for each month	JUPEM

Sea Level Rise

There are no official records of the seawater level in Bagan Nahkoda Omar to Tanjung Sepat. Another alternative to determine the sea level rise in the study area is by using the satellite altimeter which consists of three main stations that are located at the border of Malaysia, the Penang to Perak border, and the Straits of Johor. According to Ami Hassan and Kamaludin (2009), the altimeter radar is one of the most straightforward remote sensing techniques. The basics of geometry measurement involved divided into two, where the first one is the length between the satellite and the sea surface which is calculated by the travelling time of the microwave signal that is emitted by the satellite's radar and is reflected from the ocean. Second, independent tracking systems used to calculate the three-dimensional position of the satellite relative to a fixed system of earth coordinates. Data from the satellite altimeter and the position of tidal gauge station were used to assess the depth of seawater. The stations along Selangor coastal, such as Bagan Datuk, Pematang Sedepa and Port Klang were selected to measure the level of water using the interpolation method. The Sea level rise trend data for this study were obtained by measuring the relative sea level trend (mm/-year) using the nearest tidal gauge station and satellite altimeter along the coast of Selangor. The Inverse Distance Weightage (IDW) algorithm interpolation techniques have been used to predict the value of height that is not measured, using the known point values near the point being studied (DID, 2007). The IDW algorithm has been calculated using the sea level information from the altimeter satellite stations located at the border of Malaysia (S2), the Penang to Perak border (S4), the Straits of Johor (S5), and the tidal stations (Bagan Datuk, Permatang Sedepa and Port Klang) near the study area (Table 3).

Table 3: Coordinate Altimeter Satellite Station

No. Station	Location	X	Y
S2	Boundary Malaysia Thailand (100E,6N)	663305.531	663305.531
S4	Boundary Penang - Perak (99E,5N)	552664.296	552664.296
S5	Strait Johor (104E,1N)	110547.106	110547.106

Coastal Hydrodynamic Modelling

The hydrodynamic modelling of Bagan Nakhoda Omar to Tanjung Sepat coastline was developed using the MIKE 21 Flow Model software. The numerical application for hydraulic simulation is suitable for coastal studies. The data that are used for the hydraulic studies modelling in Bagan Nakhoda Omar to Tanjung Sepat area are different from other modules. Therefore, the first step is to identify the types of data that are needed for hydrodynamic simulation and to study the impact of the rise in the sea level. Referring to the previous study by NAHRIM and JUPEM in the year 2017, the data that have been used are the currents speed, currents direction, bathymetry and tidal data. All this data was recorded on spring tides and neap tides for two weeks. The scope of this data collection comprises:

a) Observation of current data using the Aquostic Wave and Current Profiler (AWAC) equipment for 2 locations over a two-week period.

b) Automatic tidal gauges were used to absorb tidal data for different locations for two weeks.

c) Hydrographic measurements were carried out at the estuaries and coastal areas of Selangor coastal on the year 2017.

Bathymetry Survey

Water depth Measurement for Selangor coast was carried out along the shoreline involving ten management units. The data that were needed as input for modelling study were longitude, latitude and depth (x, y, z). The Bathymetry data for the study area used the Universal Traverse Mercator projection coordinate system, UTM 48 (longitude and latitude). Before the measurement was carried out, all the information needed to be entered and compiled in the HYPACK software. The sounding area was developed using this software to track the zone travel. The coordinates and water depth of the study area were recorded at each interval that was defined in the system. During bathymetry work, the automatic tide gauges that are located at the jetty station that is near to the study area will record the tide measurement. All of the equipment was checked and calibrated before being used in order to avoid errors during measurement and technical problems during sounding work.

Currents Data

The measurement of velocity and direction of currents was conducted for 15 days, from 23 December 2014 to 7 January 2015 at two different locations. For this study, the Acoustic Doppler Current Profiler (ADCP) AWAC AST model (1MHz and 600 kHz) was used and located at two different locations near Carey Island (Table 4). The data were recorded with 2 different water depths (10 meters and 12 meters). All of these devices have their own memory, storage and battery that can measure, record and store data continuously. The ADCP tool mounted on the AWAC frame was then lowered to the bottom of the sea using ropes and plumbob bound with a frame that served as a weight. After 14 days, the ADCP is taken and cleaned before the data is downloaded to the computer and processed.

Table 4: Locations of AWAC 1 and AWAC 2

No.	Station	Latitude	Longitude	Depth (m)
1.	AWAC 1	02° 48’ 40”N	101° 20’ 11.18”E	10.324
2.	AWAC 2	02° 49’ 26”N	101° 18’ 58.14” E	12.557

Tidal Data

The tidal data for this study were obtained simultaneously with the current and wave measurements as shown in Table 5. The reference point (Datum) for this tidal measurement was based on the Mean Sea Level (MSL).

Table 5: Location of the Tide Gauge Station at Selangor coast

No.	Location of the Tide Gauge Station	X (m)	Y(m)
1	Bagan Datuk	442334.4154	694290.1124
2	Pematang Sedepa	335561.1981	761205.5595
3	Port Klang	318892.9069	722315.2937

In this study, the time that is taken to record the water level readings is in every 10 minutes. This tidal data measurement is adjusted and corrected to the MSL datum using the RTKNet service that is operated by the Department of Survey and Mapping Malaysia (JUPEM). These tidal data were downloaded and analysed using statistical applications to produce observational data sets.

Results And Discussion

The finding of this study will be discussed and analysed through the methods and formulas that are presented in this section. Diagrams and related tables accompany the analysis in this section. This result described the prediction of the inundation area and the impact of the rise in sea level through tables, graphs, and maps.

Sea Level Rise

The rate of sea level rise is obtained through Inverse Distance Weight (IDW) by the interpolation method. The formula has explained on Equations 3.1 to 3.2. IDW algorithm that is calculated using the coordinate point from three stations altimeter satellite and three tidal stations, as shown in Table 6 and Table 7.

Table 6: Rate of Sea Level Rise

Station	Station Name	Rate of Sea Level Rise (mm/year)
2	Border of Malaysia (Perlis-Thailand)	6.08
4	Border of Penang – Perak	6.45
5	Straits of Johor	3.87

Table 7: Projected Sea Level Rise Based on Tidal Stations

Station Name	Projection of Sea Level Rise	
	2020	2060
Bagan Datuk	0.051	0.289
Port Klang	0.049	0.279
Permatang Sedepa	0.048	0.277

Projection of Sea Level Rise in the Year 2020 and 2060

To determine the impact of the rise in the sea level of the study area as has been described, the hydrodynamic model for 2017 has been used as a basic model. The inundation area along the Selangor shoreline from Bagan Nakhoda Omar to Tanjung Sepat is shown in Table 8.

Table 8: Inundation Area from Bagan Nakhoda Omar – Tanjung Sepat on Year 2017

No.	(MU)	Location	Inundation Area (ha)
1	MU 1	Bagan Nakhoda Omar	4007.451
2	MU 2	Bagan Sungai Pulai	3360.051
3	MU 3	Kampung Haji Dorani	1528.757
4	MU 4	Sungai Nibong	3858.369
5	MU 5	Sungai Burong	775.209
6	MU 6	Bagan Pasir	3304.379
7	MU 7	Pantai Jeram & Bagan Sungai Janggut	1804.816
8	MU 8	Port Klang	2672.809
9	MU 9	Pantai Morib	1730.022
10	MU 10	Kg. Batu Laut & Tanjung Sepat	749.799

The results have found that all MU along the shoreline of Bagan Nakhoda Omar to Tanjung Sepat has been faced with inundation. Two areas, namely Bagan Nakhoda Omar (MU1) and Sungai Nibong (MU4) were the most impacted with an inundation area of 4007.451 ha and 3858.369 ha respectively. Most areas were located near the river basin. The Annual report of Flood 2016/2017 had also explained floods monsoon as a cause of the tide phenomenon that occurred in 2017 in some areas like Sabak Bernam and Sekinchan (DID, 2017). The results are shown in Figure 4.

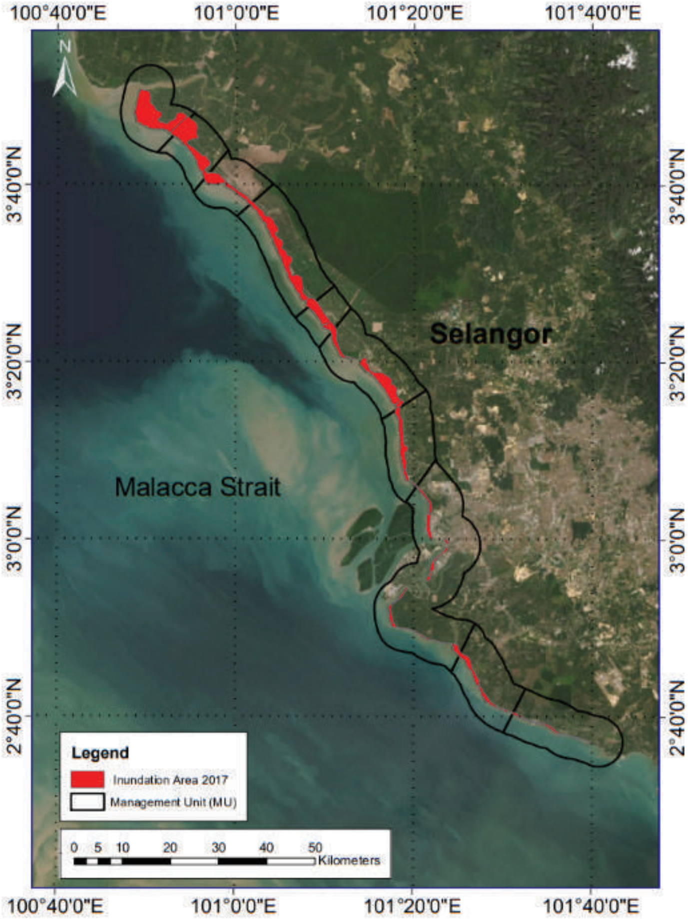

Figure 4: Inundation Area in the Year 2017

The five management units (MU) which are Bagan Nakhoda Omar (MU1), Bagan Sungai Pulai (MU2), Sungai Nibong (MU4), Bagan Pasir (MU6), and Port Klang (MU8) are faced with the high possibility of being affected by inundation, with a range between 2672.809 ha–4007.451 ha. The simulation results of the coastal hydrodynamic modelling have also found that some areas such as Bagan Nakhoda Omar and Sekinchan are faced with the rise in water, as has been stated in the annual report of Flood in 2016/2017 which reveals that the factors that cause the condition of the areas are located in the river basin and tidal phenomenon. The average projected sea level rise of the study area was tested and analysed in 2020 and 2060 and the average projected value of SLR from the three Altimeter satellite locations near the study area is shown in Table 9.

Table 9: Average of Sea Level Rise Using the Altimeter Satellite along Selangor Coastal

Location	Sea Level Rise	
	2020 (m)	2060 (m)
Bagan Datuk	0.057	0.237
Pelabuhan Klang	0.057	0.24
Permatang Sedepa	0.028	0.118

Analysis of the hydrodynamic modelling model shows consistent improvement for the entire MU area from Bagan Nakhoda Omar to Tanjung Sepat from 2020 to 2060, as shown in Table 10. In the year 2020, the range of the inundation area that is affected by SLR is between 829.943 ha–5485.066 ha. Sungai Nibong (MU4) shows the most drastic increased area as a result of the inundation phenomena for the past 40 years with 6522.360 ha.

Table 10: Predicted Value of Sea Level Rise Occurring along Selangor Coastal from 2020 and 2060

(MU)	Location	Inundation Area (ha)	
		2020	2060
MU 1	Bagan Nakhoda Omar	5485.066	6171.303
MU 2	Bagan Sungai Pulai	3399.223	3507.177
MU 3	Kampung Haji Dorani	1582.958	1494.925
MU 4	Sungai Nibong	4311.440	6522.360
MU 5	Sungai Burong	1287.275	1615.585
MU 6	Bagan Pasir	3461.370	3917.742
MU 7	Pantai Jeram & Bagan Sungai Janggut	1805.251	2011.416
MU 8	Port Klang	2693.841	2937.486
MU 9	Pantai Morib	1824.597	2056.622
MU 10	Kg. Batu Laut & Tanjung Sepat	829.943	954.752
	Total Area	**26680.964**	**31189.368**

Land Use Affected Along Selangor Coastal

The findings of the study on the rise in sea level in order to determine the potential impact on land use and land cover, along the coast of Bagan Nakhoda Omar to Tanjung Sepat, was obtained by overlaying two types of data that consisted of the numerical hydrodynamic modelling and land use shapefile. Five kilometres offsets from the coastline were defined to determine the impact on inundation every 40 years. Based on the classification of the land use five types of land use have been identified, they are cropland, grassland, forest, mangrove, settlement and wetland. Table 11 shows the types of land that are used along the coastal areas from Bagan Nakhoda Omar beaches to Tanjung Sepat in 2014. The total area to identify the impact of land use that is affected by inundation at 110,532 ha along coastal region of Selangor. Cropland is a dominant area compared to other classes; it covers almost all the areas in each MU, which is about 68 percent of the study area. Besides, there are settlements and developing areas that are clearly shown on the map that are located at Port Klang with an area of 20,482 ha.

Table 11: An Impacted Area of the Land Use Types along the Coastal Areas from Bagan Nakhoda Omar Beaches to Tanjung Sepat

No	Land Use Type	Area Coverage (ha)
1	Cropland	76162.218
2	forest	422.966
3	Grassland	143.977
4	Mangrove	8415.594
5	Settlement	20481.990
6	Wetland	4586.178
7	Other	318.940
	Total	**110531.862**

The table displays an increasing land use coverage that is affected for every land use class from the year 2020 to 2060 (Table 12). The study area along the Selangor coastal within 291 km from Bagan Nakhoda Omar to Tanjung Sepat and 5 km from the shoreline, involves an area as large as 110,531 ha. From the area, the percentage of land use that is affected by inundation can be concluded. The results show that the cropland area is the most affected, with flooding along the study area, which ranges from 14.31% to 18.42%.

In other words, at 15818.446 ha to 20355.248 ha will be inundated from 2020 until 2060. This is followed by the settlement and the mangrove area which range from 3.90%-5.19% and 3.12%-3.55%, respectively. From the total settlement area of 20481.990 ha, the potential urban area that will be affected by 2020, 2040 and 2060 is 4311.295 ha, 5091.247 ha, and 5731.099 ha, respectively. Thus, grassland and other types of land use will occur the less impact than another class.

Table 12: Percentage of Land Use Affected that is caused by SLR Phenomenon along Selangor Coastal

Year	Percentage of Land Use Affected at Study Area (%)					
	Cropland	Grassland	Mangrove	Settlement	Wetland	Other
2020	14.31	0.06	3.12	3.90	0.55	0.05
2060	18.42	0.06	3.55	5.19	0.63	0.05

Conclusion

All the objectives of this study have been successfully achieved. The prediction value was determined in the study area, and the inundation area has been mapped. Moreover, the impact of the sea level rise on infrastructure and land use has been recorded and mapped along Bagan Nakhoda Omar to the Tanjung Sepat coast. Based on the overall SLR study, Selangor coastal shows that the rate of inundation is at a high level. Therefore, coastal management should be given high vigilance in order to face natural disasters such as the cause of coastal erosion and estuaries, ecosystem disruption, pollution and declining water quality as well as a rising in sea levels in the long period. Based on the results, this study has found that the cropland area is the most impacted range, from 14.131% to 18.416%; in other words, from 2020 and 2060 about 15818,446 ha to 20355,248 ha would be inundated. Follow by the cropland and settlement area, there are show the most impacted of SLR with 14.31%-18.42% and 3.90%-5.19%, respectively.

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