Assessment of coastal inundation of low lying areas due to sea level rise

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Abstract. Sea level rise due to climate change have a profound impact on low lying coastal zones. The objective of this study is to identify the potential of coastal inundation area due to Sea Level Rise (SLR) along of Cherating to Pekan coast. The shoreline of Pahang has been undergoing severe erosion and inundated by sea water in some locations, hence affects the socio-economy and the livelihood of the coastal communities. Numerical modelling using the MIKE 21 FM software was done to predict coastal inundation for the years 2020 and 2080 along the Cherating to Pekan shoreline by using the condition for the year 2017 as the baseline. The results of the statistical analysis of this numerical model is congruous with the measured data, such as tide, current, and wave direction. The results show that about 17 to 22% of the Cherating to Pekan shoreline is at risk of being inundated due to the projected SLR for the years 2020 and 2080. The map for projected inundation shows that the infrastructure located in the 1km buffers zone from the shoreline will be affected by the sea level rise. This information could be of benefit to all parties involved in ensuring effective coastal management and making preparation and plan to and protect the coastal areas from the potential impacts of climate change and future disasters.

1. Introduction

Climate change has been recognized as an indicator of the great impact on some coastal areas and the communities living in the area (1). The Inter-governmental Panel on Climate Change (IPCC), in its Fourth Assessment Report (AR4), have stated that the warming of the climate system is undoubtedly occurring (2). Data has shown a clear trend in the global increase of average water and ocean temperatures, melting of snow and ice, and average sea level during the 20th century.

According to [3], the effects of global warming is very obvious, as can be seen in the increase in water levels due to thermal expansion of sea water and melting of ice. Geological and tidal data have provided the evidence that the rise in sea level in the 20th century is approximately 1 to 2 mm/year due

to melting of glaciers and thermal expansion of the ocean as a result of global warming. IPCC (2007) predicted that the global sea level will rise by almost 59 cm by the year 2100. In the future, the climate change caused by worsening greenhouse effect is very likely to accelerate the rate of sea-level rise. By the end of the century, the coastal ecosystems in the Asian continent is expected to suffer the profound adverse impact of SLR, particularly in low lying areas [4–9].

Sea level rise is the main characteristic of climate change by virtue of its impact on human society, natural environment, and ecosystem in the coastal zones [10,11]. This issue is being debated at the global level and, in general, the increase in sea level is contingent on various climate factors. The rate of sea level rise also varies from one place to another, depending on various local factors, including changes in temperature, atmospheric pressure, wind, and ocean circulation.

Coastal zones are experiencing accelerated sea level rise, and despite having a rich natural resource, these areas are densely populated and highly developed. These zones are characterized by low topography which makes them vulnerable to erosion. This will continue to result in severe environmental impacts such as saltwater intrusion into coastal groundwater aquifers and flooding of wetlands and estuaries; these impacts will also be a threat to historical and cultural sites as well as infrastructures in the affected areas [3].

In Malaysia, rising sea level is another consequence of climate change. Among the serious impacts of climate change on coastal communities are flooding or rising temperature, coastal erosion, and extreme waves [11]. Local researchers [12] have contended that the Pahang shoreline in the East-Coast of Peninsular Malaysia is undergoing serious coastal erosion. More than 288 of the 4809 km Malaysian coastline is classified as Category 1, namely the type erosion which poses immediate danger of collapse or damage to shore-based facilities and infrastructures [11].

A study by [13], which observed the rising sea levels in Peninsular Malaysia as a result of climate change, noted that the Tanjung Gelang station in the coast of Pahang recorded the highest sea level rise compared to other tide stations in Malaysia. Linear trend analysis and deterministic seasonality model have given the rate of monthly SLR increase. In this light, the study endeavors to predict future sea level rise along the Cherating to Pekan coast for the years 2020 and 2080. The inundation risk map is expected to provide early warning as well as guideline to help relevant agencies and Non-Governmental Organisations (NGOs) formulate their development plan in coastal areas.

2. Study Area

The study area is located along the coast of Pahang in the east of Peninsular Malaysia and faces the South China Sea. It is located between latitude 4° 07' 38.39" and 3° 32' 5.25" East, and longitude 103° 23' 44.68" and 103° 27' 41.08" North, as shown in Figure 1. The shoreline of Pahang begins in Sungai Endau in the south and extends to the north to the border with Terengganu; it includes Pulau Tioman which is about 271km [14]. The shoreline in this study stretches about 85 km from Cherating to Pekan. The entire shoreline is made up of sand material. The climate in Pahang is characterized by the Northeast monsoon that begins in early November until March. During this monsoon season, the winds in eastern Peninsular Malaysia may reach 30 knots or higher during periods of strong surges of cold air from the north (Malaysian Meteorological Department, 2009).The region is characterized by diurnal tides which vary between 1m and 2m with a mean wave height of less than 1.8m. The annual temperature ranges between 25.6 °C to 27.8 °C [15].

3. Methodology

The simulation of SLR prediction for 2020 and 2080 was done using the MIKE 21 software, which includes a Hydrodynamic FM module. By using numerical model application, MIKE 21 Flow Model FM models a system for 2D free surface flow based on a flexible mesh approach. The process flow for hydrodynamic modelling using MIKE21 is shown in Figure 2. The hydrodynamic data used in this study are bathymetry, tide, current direction, and current speed.

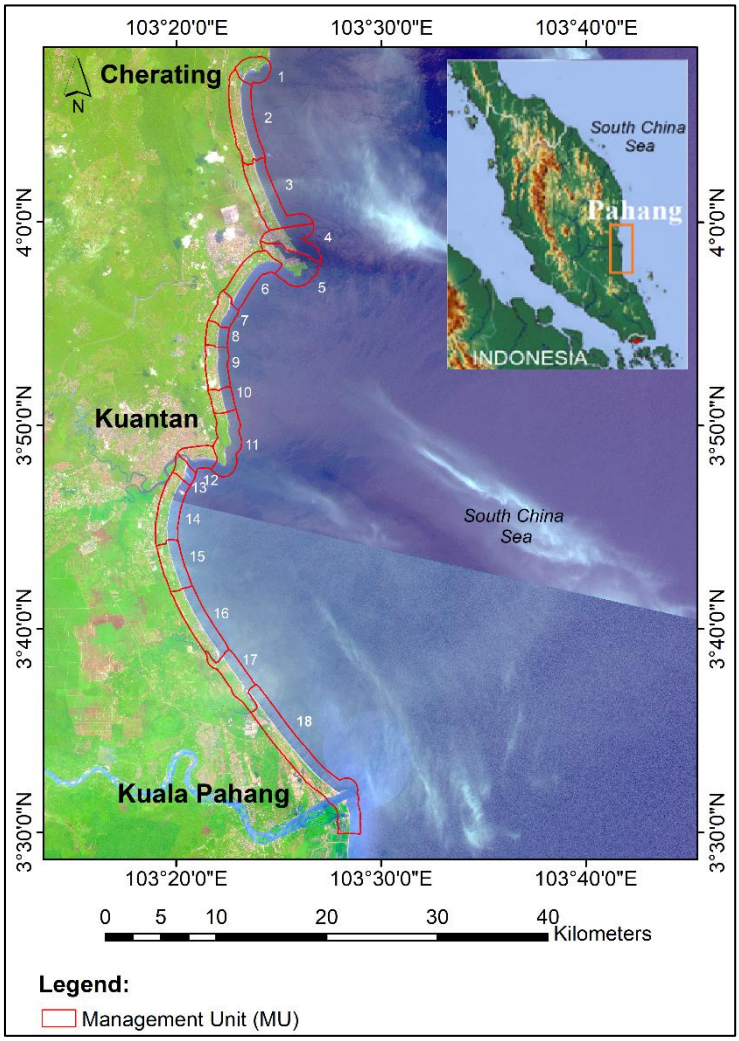


Figure 1. Study Area along the Pahang Shoreline

The bathymetry survey covers an area 5 km wide and 87km long from Cherating to Tanjung Agas in Pekan. The interval between sounding lines is 500 m. Measurements were made at Mean Sea Level (MSL) during spring tide. The in-situ measurement comprising water level, current speed and current direction at the Pahang coast was collected during spring and neap tides using AWAC instrument.

Calibration and verification of the model was done by comparing the hydrodynamic data from in-situ measurement with that of the model until the required tolerance is achieved. Statistical analysis of simulation and in-situ measurements, such as water level, current speed, and current direction, was done to assess the accuracy and confidence level of the simulated model. The result for the simulated model was determined using a statistical method based on the guideline for standard error allowed for hydraulic study stipulated by the Department of Irrigation and Drainage (DID) for 2013 [16], which is shown Table 1. Evaluation of the performance of the numerical modelling for the Cherating to Pekan shoreline was done using the RMSE technique.

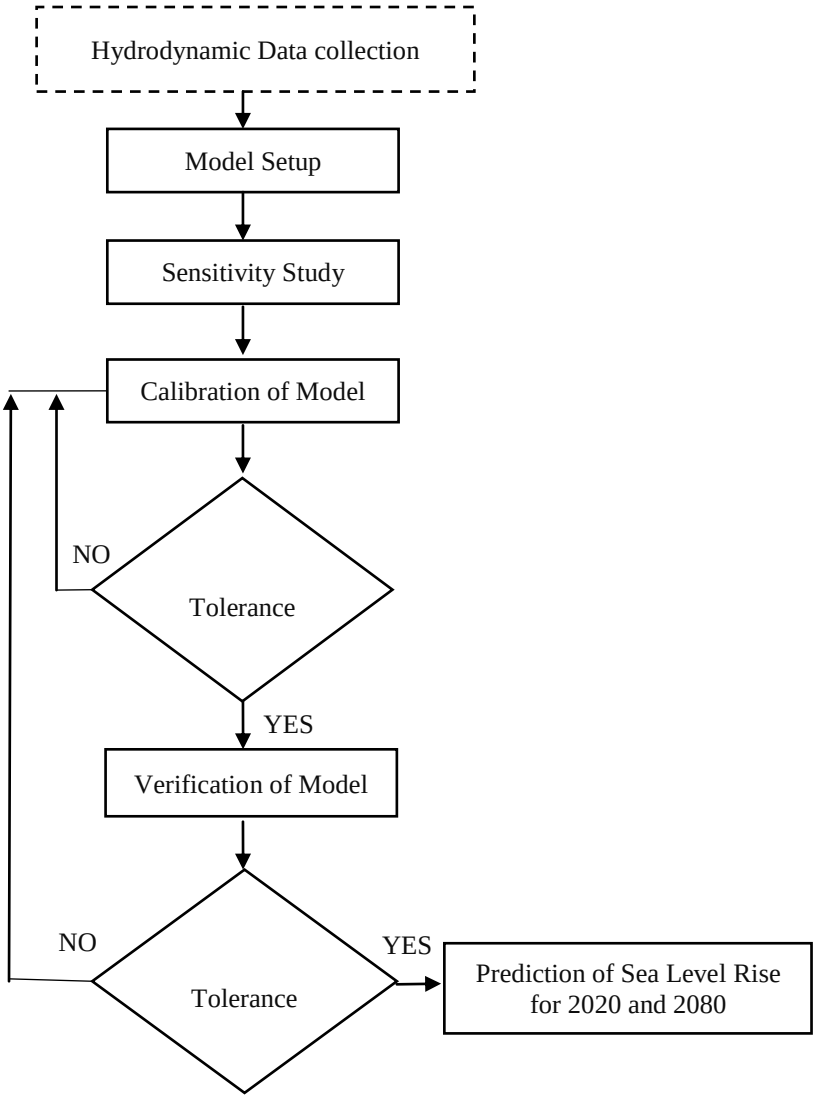


Figure 2. Hydrodynamic modelling

Table 1. JPS Guideline for Tolerance Value

No	Items	Tolerance Value (%)
1	Water Level	10%
2	Current Speed	20%
3	Current Direction	20^0

4. Results And Discussion

The following sections presents the results of the assessment of coastal inundation obtained using the MIKE21 software. The results from the simulation of hydrodynamic modelling was used to project sea level rise in 2020 and 2080.

4.1. Management Units

In this study, the Cherating to Pekan shoreline was divided into Management Units (MU) based on those adopted by the Department of Irrigation and Drainage (DID). The physical characteristics and

land use along the entire shoreline vary tremendously, making it rather difficult to design a meaningful study. To overcome this problem, the shoreline is sub-divided into smaller units called MU. Each MU is a stretch of shoreline with coherent characteristics with regard to both natural coastal processes and land use. Figure 3 shows that the MU of Cherating to Pekan shoreline comprises 18 management units. The MU is defined based on the Integrated Shoreline Management Plan (ISMP), Pahang for the year 2002. A study conducted by [14] categorized the Pahang shoreline into three major coastal sectors, namely the offset coast in the north, the delta coast in the central area, and the spit coast in the southern region.

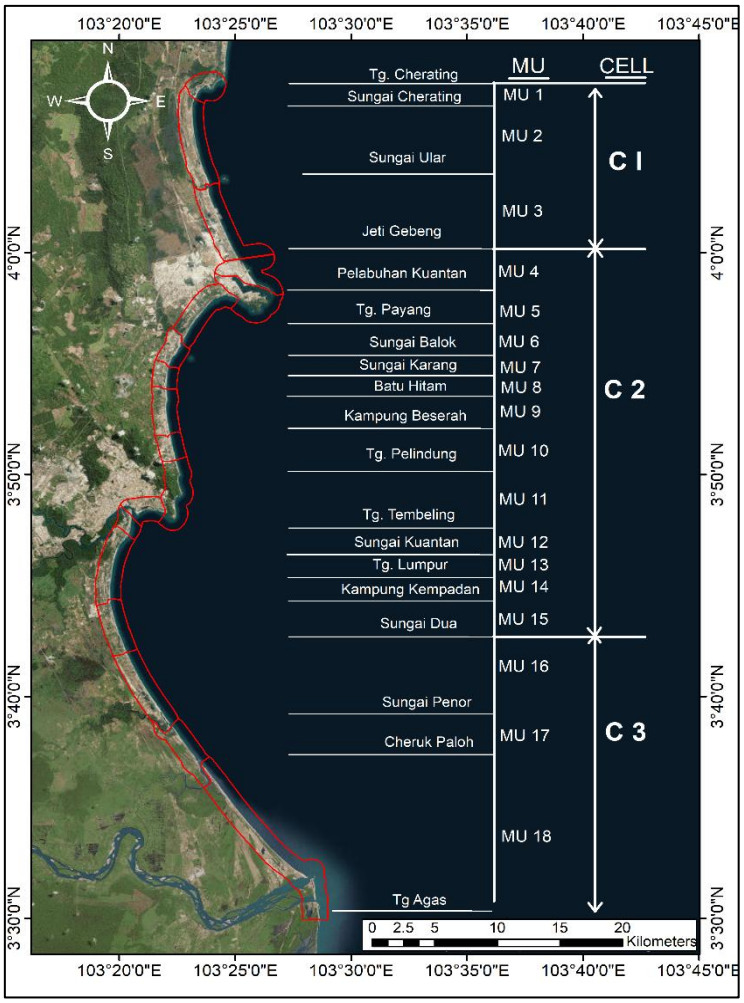


Figure 3. Management Units of the Cherating-Pekan shoreline

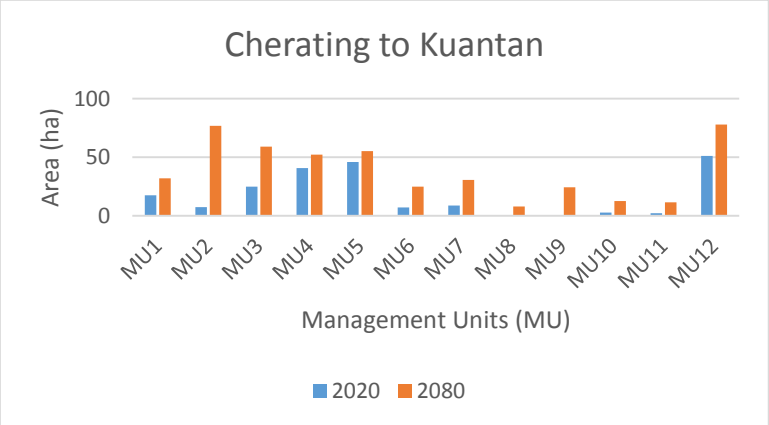
4.2. Prediction of Sea Level Rise for 2020 and 2080

In this section, the Cherating to Pekan shoreline is divided into 2 areas, namely the areas from Cherating to Kuantan and from Kuantan to Pekan. The simulation modelling show that, of the total 18 MUs, MU2, MU3, MU12 and MU18 will experience rising water level between the years 2020 and 2080. As can be seen in Table 2 and Figures 4 (a) and (b), MU4, MU5 and MU12, which are located in the Cherating to Kuantan area, form a large land area which will be impacted by sea level rise. These areas are the most important economic sectors to the state government. For instance, MU4 and MU5 encompass the Port Zone and MU12 is the urban area of Pahang's capital. Most of the infrastructures and buildings in these zones were built in the 1 km buffer zone from the shoreline.

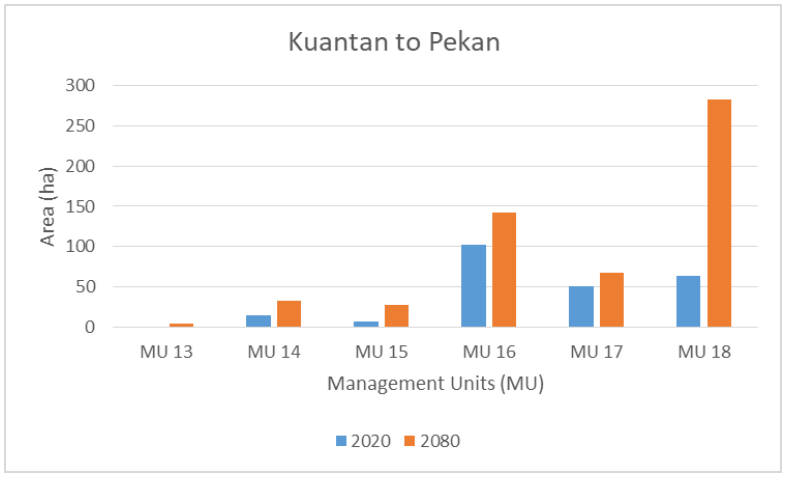
Table 2. Prediction of Sea Level Rise for 2020 and 2080

No	MU	Location	2020 (ha)	2080 (ha)
1	MU1	Tg Cherating - Sg Cherating	17.35	31.97
2	MU2	Sg Cherating - Sg Ular	7.21	76.69
3	MU3	Sg Ular - Jeti Gebeng	24.86	58.94
4	MU4	Jeti Gebeng - Pelabuhan Kuantan	40.80	52.29
5	MU5	Pelabuhan Kuantan -Tanjung Payang	45.85	55.25
6	MU6	Tanjung Payang - Sg. Balok	7.02	24.94
7	MU7	Sg. Balok - Sg. Karang	8.68	30.55
8	MU8	Sg. Karang - Batu Hitam	0.00	7.98
9	MU9	Batu Hitam - K. Beserah	0.55	24.27
10	MU10	K. Beserah - Tg. Pelindung	2.72	12.50
11	MU11	Tg. Pelindung - Tg. Tembeling	2.20	11.47
12	MU12	Tg. Tembeling - Sg. Kuantan	51.11	77.87
13	MU13	Sg. Kuantan - Tanjung Lumpur	0.00	4.24
14	MU14	Tanjung Lumpur - Kampung Kempadang	15.07	32.55
15	MU15	K. Kempadang - Sg Dua	6.83	27.63
16	MU16	Sungai Dua - Sungai Penur	102.42	142.36
17	MU17	Sungai Penur - Cheruk Paloh	51.11	67.54
18	MU18	Cheruk Paloh - Kuala Pahang	64.14	282.55

The total land area in MU2, MU3, MU6, MU7, MU9 and MU12 predicted to be affected by sea level rise in 2020 and 2080 increase dramatically, as can be seen in Figure 4 (a). The simulation modelling shows that sea level rise is predicted to occur in river mouths and low lying areas. MU 8 and MU9 is not expected to experience sea level rise in 2020 as a result of the existence of relatively abundant protective structures. As a result, the potential impact of sea level rise in this area is not significant. The values for in-situ measurement is congruous with that of previous studies conducted by [14,15], which classified this area as rocky muddy beach that is able to withstand the effects of erosion. Figure 5 shows that most MUs in the Cherating-Pekan area, are expected to experience sea level rise in 2080.



(a) The Cherating-Kuantan area



(b) The Kuantan-Pekan area

Figure 4. (a) and (b) Areas predicted to be affected by sea level rise in 2020 and 2080 based on management units (MU) in the Cherating-Pekan area

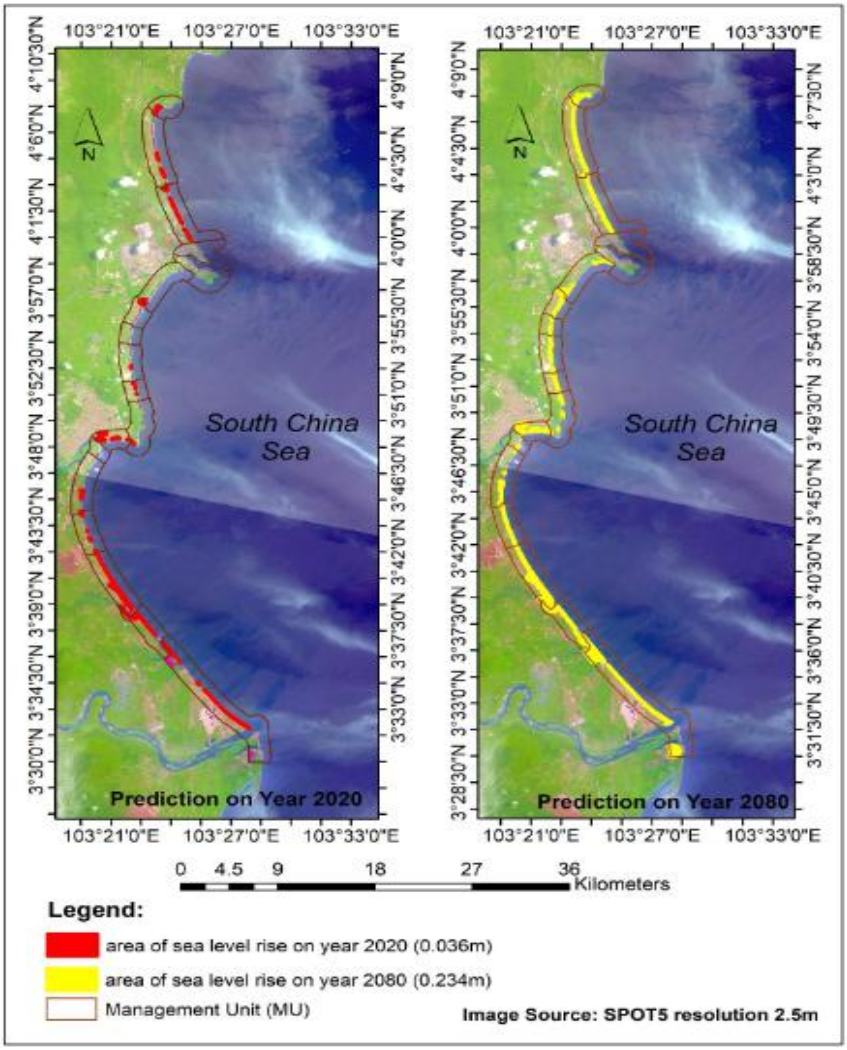


Figure 5. Prediction of Sea level Rise in the Cherating-Pekan area for 2020 and 2080

In the Kuantan to Pekan area, only MU13 is predicted to not experience sea level rise in 2020. In 2080, however, MU13 to MU18 will all experience sea level rise, as can be seen in Figure 4 (b). MU16 and MU18 are expected to experience the most significant rise in sea level. Two areas in particular are Sungai Penur and Sungai Kuala Pahang, which are low lying coastal beach-ridge plain with coarse and yellowish sand. This is supported by a study conducted by [14] which found that these coastal plain are vulnerable to storm surges. The extreme weather events in December 1999 resulted in sands and tidal water reaching up to about 100m inland. Furthermore, Figure 4 (b) shows that MU18 will experience a dramatic rise in sea level in 2020 involving a land area of approximately 218.41 ha. On site observation show that the erosion in this area began after the implementation of an aquaculture project. Figure 6 shows the distribution of infrastructures in MU9 which will be affected by the projected sea level rise in 2080.

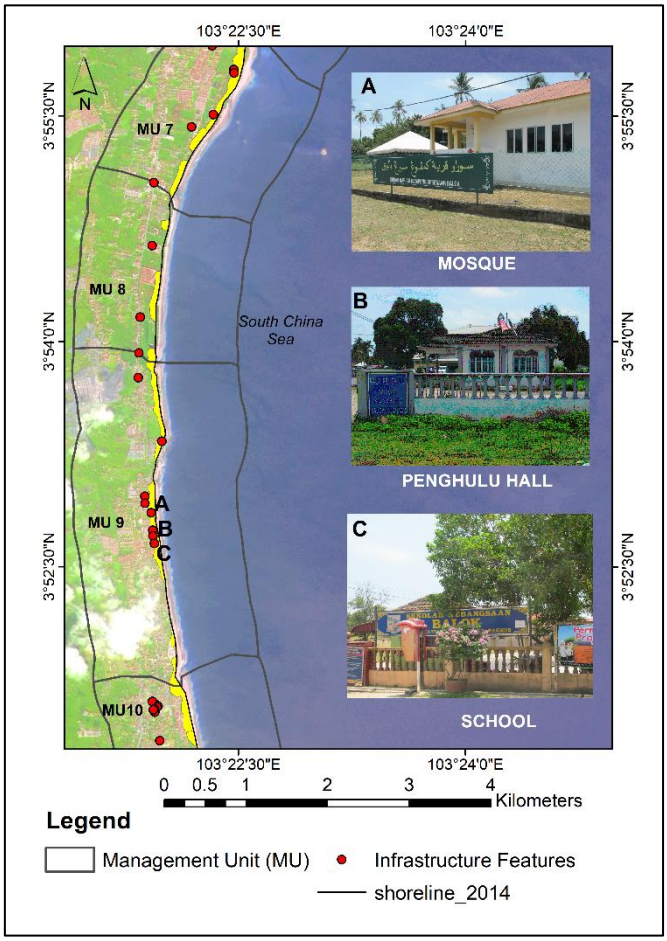


Figure 6. Location of infrastructures at MU 9 which will be affected by the predicted sea level rise prediction in 2080

5. Conclusion

This investigation has found that sea level rise is expected to have an impact on the infrastructures located in the 1 km buffer zone along the Cherating to Pekan shoreline. Most MU in this study area will be undergoing varying rates of sea level rise. MU2, MU9, MU12 and MU18 are predicted to be experience the highest sea level rise in 2020 and 2080. The MIKE 21 software was used to predict the areas at risk of being inundated in the years 2020 and 2080 due to SLR. The SLR simulation predicted that between 0 to 102.42 ha and 4.24 to 282.55 ha of the land area within the Cherating to Pekan shoreline will be affected by SLR in 2020 and 2080, respectively. These findings provide insights for

future research in the effort to identify the areas which might be inundated as a result of sea level rise along of this shoreline in the years 2040, 2060 and 2100. Therefore, the output from the hydrodynamic simulation for SLR prediction can be used for coastal management and to protect the areas which might be inundated in the future.

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