Submerging paddy cultivation area due to coastal flooding in Kuala Kedah, Malaysia

Samera Samsuddin Sah\textsuperscript{1,2}, Khairul Nizam Abdul Maulud\textsuperscript{1,3*}, Nurul A'idah Abd Rahim\textsuperscript{3,4}, Othman A. Karim\textsuperscript{1}, Suraya Sharil\textsuperscript{1}

\textsuperscript{1}Department of Civil Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia
\textsuperscript{2}Faculty of Chemical Engineering Technology, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia.
\textsuperscript{3}Earth Observation Centre, Institute of Climate Change, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia
\textsuperscript{4}Coastal Management and Oceanography Research Centre, National Water Research Institute of Malaysia, Lot 5377, Jalan Putra Permai, 43300 Seri Kembangan, Selangor, Malaysia

*Corresponding E-mail: knam@ukm.edu.my

Abstract. Kuala Kedah is a coastal area where the majority of the community are paddy farmers and fishermen. Almost the entire coastal area is used as a paddy cultivation area. However, this area faces the threat of seawater intrusion into land due to climate change driven sea-level rise. The rising seawater has affected the surrounding area, not only in terms of crop yields but also property and livelihood to the locals. Therefore, this study is designed to detect and analyze the progress of seawater on land at the Kuala Kedah coastal area using a hydrodynamic approach. Mike 21 software was used to simulate the hydrodynamic effects on 2 segments (NA and SA) in this study area by considering two conditions namely Condition 1 (K1) and Condition 2 (K2) which are respectively with and without coastal protection structure. However, this structure was only built along the 2.5 km shoreline in the NA segment and not in the SA segment. The findings show that the coastal protection structure in K2 is effective in reducing 50 % of the impact of sea level rise in year 2100 at NA segment, while only 10 % at SA segment. Therefore, the construction of these structures permanently should be given consideration by local authorities in planning future development to ensure lowland areas are protected from coastal floods.

Keywords: Climate Change, Inundation, Modelling, Saltwater Encroachment, Seawater Intrusion.

Track Name: Coastal Management and Marine Ecosystem
1. Introduction

Malaysia is a country located in Southeast Asia with a coastline of 8840 km [1]. Malaysia’s coastline is rich in coastal resources and has a wealth of natural biodiversity [2]. As a record, 70 percent of the Malaysia’s population lived in coastal zone. The majority of communities in Malaysia’s coastal zone consist of fishermen and farmers, most of whom are senior citizens aged between 40 and 65 years [3] who have been permanent residents for more than 15 years in the area. However, these groups were affected by the sea level rise due to climate change. According to previous researches [4–6], the surface temperature and sea level in Malaysia were increasing by time to time, as well as the frequency of extreme events such as flooding, high rainfall and heatwaves.

As reported by Abdul Hamid [7], Malaysia will be expected to experience floods due to rising sea levels between 2070 and 2100 if the annual temperature increase is around 4°C due to continuously high gas emissions. Therefore, low-lying areas along the northeast and west coasts of the Peninsula Malaysia including the northwest coast were forecasted to face the problem of coastal flooding [8]. One of the affected areas on the west coast is at the mouth of the Kedah River where it is an agricultural area that covers 40% of land use in the coastal zone.

The coastal hydrodynamic study approach is used in monitoring and predicting coastal conditions based on the numerical model approach as part of the physical model test [9]. Hydrodynamic models are important tools for estuarine and coastal management and have been used in water quality studies, sediment transport, and predicting the effects of different climate scenarios on estuaries and coastal waters. Each of these models plays an important role in flood prediction, pollutant modeling and changes in estuarine and coastal morphology [10, 11].

In Kedah coastal zone, the main agricultural activity is paddy cultivation which is also facing the threat of flooding due to a rising sea level of about 0.5 m in the year 2100 [8, 12]. Subsequently, [12] also reported that the farmers, especially in the Kuala Kedah coastal area, had to bear losses of more than 75 percent due to the encroachment of seawater into paddy fields since 2016. The presence of seawater in this paddy field causes the crop to become stunted and eventually die due to salt stress [13–15]. After the seawater intrusion incident in year 2016, as recorded JPS Malaysia began to design and build a revetment along 2.5 km of coastline, only in the NA segment with a height of 3.2 m from the Mean Sea Level (MSL) to protect this low-lying area.

Therefore, the hydrodynamic simulation technique using MIKE 21 is a suitable approach to predict and forecast the seawater advancement in terms of distance and total inundated area in land [16]. This numerical modeling technique will consider the impact of sea level rise to 2100 in this study. Hence, this study was designed and focused on evaluating and assessing the impact of sea level rise on the advancement of seawater to land as well as the potential affected using Mike 21 for two different conditions with and without coastal protection structures, namely K1 and K2, and finally, produced the inundation risk maps that can be used to assist the local authorities in future coastal area development.

2. Materials and Methods

Generally, this study involved the Mike 21 software which is using a numerical model approach. This software is well-known hydrodynamic modeling using flexible mesh. Hydrodynamic module namely Mike 21 HD Flow Model was used to predict the coastal flooding along 55 km Kuala Kedah coastline, approximately and presented in the form of inundation map for the year 2020, 2050 and 2100. Figure 1 shows the flow of the hydrodynamic modelling process using Mike 21 FM HD.
The hydrodynamic parameters used in this study are bathymetry, waves, current speed, current direction and water level. The first step in this modeling, the identification of the domain and boundary was made by considering the location of the study area. The ocean area was divided into four polygons with different grid resolution as listed in Table 1. Each polygon is designed based on the distance from the nearest area to the farthest from the shoreline as shown in Figure 2. Afterward, this mesh was uploaded into the Mike 21 FM HD and ready to process. There are three outputs produced after completing this model which are water level, current speed and current direction.

![Figure 1. Flow process of Mike 21 FM HD.](image1)

![Figure 2. Flexible mesh using mesh generator.](image2)

| No | Area Segment | Distance from shoreline (m) | Grid Resolution (m) |
|----|--------------|-----------------------------|---------------------|
| 1  | Nearest area | 5,000                       | 100                 |
| 2  | Near area    | 13,000                      | 200                 |
| 3  | Far area     | 26,000                      | 600                 |
| 4  | Farthest area| 40,000                      | 1800                |
Next step, the water level, current speed and current direction results were calibrated and verified by comparing the modelled result with in-situ measurement data. The modelled result should meet the tolerance requirement as stipulated by the Department of Irrigation and Drainage (DID), Malaysia as stated in Table 2. The evaluation of this modelled result was done using Root-Mean-Square Error (RMSE) approach as shown in the formula below,

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{n} (y - \hat{y})^2}$$

where \( n \) is the number of samples, \( \bar{y} \) is the measured value, and \( \hat{y} \) is the modelled value.

Table 2. Tolerance value for hydrodynamic study [17].

| Parameter            | Tolerance value |
|----------------------|-----------------|
| Water Level          | Less than 10 %  |
| Current Speed        | Less than 20 %  |
| Current Direction    | Less than 20°   |

The final step, the coastal flooding due to sea level rise (SLR) for the year 2020, 2050 and 2100 were done using inundation analysis and mapped using ArcGIS software. Pulau Langkawi station was used as a reference point to analyse the SLR at the study area. In addition, only RCP 8.5 was chosen because it gives the most critical SLR value in the flooding analysis in this hydrodynamic model. This flooding analysis is divided into two conditions namely Condition 1 for analysis without coastal protection structure for northern part (NA) and southern part (SA) segment, and Condition 2 for analysis with coastal protection structure.

3. Results and Discussions

Hydrodynamic modeling in this study involves an area along 80 km of coastline from Kuala Perlis, Perlis to Yan, Kedah. The calibration and verification process were performed to ensure that the hydrodynamic modeling carried out were accurate and precise based on the actual conditions in the field. Subsequently, validate the findings from this modeling.

Figure 3. shows the calibration and verification graphs for the observed water level data and the modeling results. The blue line indicates the data observed by NAHRIM. Meanwhile, the black line is the result of this modeling. Therefore, the water level calibration value was determined based on the RMSE is 6.74 % which complies with the requirements of the guidelines issued by DID.

Figure 3. Calibration graph for water level parameters.
Next, figure 4 and figure 5 show the calibration graphs for the current speed and current direction. The RMSE value for current speed is 11.43 % while for current direction is 18.7º. These two parameters also meet the requirements as stated in the DID guidelines which are not more than 20% and 20º, respectively for speed and current direction.

![Figure 4. Calibration graph for current speed parameters.](image)

![Figure 5. Calibration graph for current direction parameters.](image)

Then, figure 6(a) shows the forecast condition of the areas affected by sea level rise in 2012, 2020, 2050 and 2100 for K1, while, Figure 6 (b) illustrates the affected area in 2020, 2050 and 2100 for K2. Visually, the SA segment is more affected than the NA segment from year to year for both K1 and K2. These simulation results show that more severe floods are expected to occur in the Kedah river estuary and low-lying zones. This is aligned with the findings by previous researchers [18,19].
Figure 6. Coastal flooding for (a) K1 and (b) K2.

Furthermore, in 2100, 469.0 hectares and 498.9 hectares are forecast to be inundated in the absence of coastal protection structures, respectively for the NA and SA segments as illustrates in figure 7. But, if coastal protection structures are included in this flood analysis, the affected area is expected to be reduced by up to 50%, even though this structure are only built in the NA segment.

Figure 7. Total affected area for K1 and K2.

While, Table 3 shows the total areas affected by SLR for those years. In the year 2012, for K1, the land area will be affected up to a distance of 643.7 m and 788.5 m from the shoreline and continues to increase up to 926.5 m and 1212.6 m in the year 2100, respectively for the NA and SA segments. However, these values are seen to decrease for K2 for both segments.
Overall, the total area affected for the NA segment for K2 is reduced by more than 50 % compared to K1. However, the SA segment for K2 is only reduced by 10 % because of the absence of coastal protection structure at this segment. According to non-parametric statistical analysis namely Friedman Test, Chi-square for is equal to 4.0 which is greater than 3.84146 and the p-value is 0.046 less than 0.05 which can conclude that there is significant different between K1 and K2. This result was aligned with findings by [20–22] which found that the coastal protection structure able to absorb high wave energy and reduce its impact as well as preventing wave overtopping and flooding during heavy storm events.

4. Conclusion

Usually, coastal areas are areas filled with activities involving the sea and land such as fishing, farming, tourism and so on. The coastal area of Kuala Kedah, Kedah which is located on the west coast of Peninsular Malaysia is an agricultural area of paddy fields. However, this low-lying zone has the potential to face coastal flooding due to rising sea levels. This study was conducted to evaluate the impact of SLRs on potential coastal flooding using a hydrodynamic model namely Mike 21 FM HD. According to the results, coastal flooding would be the worst if there were no coastal protection structures to protect lowland areas. With the structure of coastal protection in NA segment, the rate of advance of seawater into the mainland and the affected area can be reduced by up to 50 %. These results can be input and reference to assist local authorities in planning the development of this area in the future.

References

[1] Selamat S N et al 2019 Multi method analysis for identifying the shoreline erosion during northeast monsoon season. J Sustain Sci Manag
[2] Mokhtar A et al 2020 Planning the Malaysian Coastline – Integrated Shoreline Management Plan. Apac 2019 1169–76
[3] Mohamed Shafiril HA et al 2015 The coastal community awareness towards the climate change in Malaysia Int J Clim Chang Stratag Manag 7 516–33
[4] Daniel Tang K H 2019 Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations Sci Total Environ 650 1858–71
[5] NAHRIM 2017 Impact of Climate Change Sea Level Rise Projections
[6] Suparia W, Moh Yatim AN 2019 Characterization of Heat Waves: A Case Study for Peninsular Malaysia Geogr Tech 14 1460–155
[7] Abdul Hamid Z 2018 Climate change and human health 2018
[8] Ghazali N H M and Awang N A 2018 Impact of Sea Level Rise and Tsunami on Coastal Areas of North - West Peninsular Malaysia Irrig Drain
[9] Belibassakis K A and Karathanasi F E 2017 Modelling nearshore hydrodynamics and circulation under the impact of high waves at the coast of Varkiza in Saronic-Athens Gulf Oceanologica 59 350–64
[10] Mardani N et al 2020 Improving the accuracy of hydrodynamic model predictions using lagrangian calibration. Water (Switzerland) 12
[11] Vieira B F V et al 2020 Hydrodynamics and morphodynamics performance assessment of three coastal protection structures J Mar Sci Eng 8
[12] Samsuddin Sah S et al 2020 Impact of Saltwater Intrusion on Paddy Growth in Kuala Kedah, Malaysia. J Sustain Sci Manag
[13] Tran T et al 2016 Improvement of Salinity Stress Tolerance in Rice: Challenges and Opportunities Agronomy 6 54
[14] Kotagiri D & Kolluru VC 2017 Effect of salinity stress on the morphology & physiology of five different coleus species Biomed Pharmacol J 10 1639–49

Table 3. Seawater advancement distance for highest progress.

|         | K1 (meter) | K2 (meter) |
|---------|------------|------------|
|         | NA | SA | NA | SA |
| 2012    | 643.7 | 788.5 | - | - |
| 2020    | 752.7 | 810.6 | 586.4 | 717.5 |
| 2050    | 869.2 | 1123.8 | 690.1 | 879.8 |
| 2100    | 926.5 | 1212.6 | 759.9 | 960 |

4. Conclusion

Usually, coastal areas are areas filled with activities involving the sea and land such as fishing, farming, tourism and so on. The coastal area of Kuala Kedah, Kedah which is located on the west coast of Peninsular Malaysia is an agricultural area of paddy fields. However, this low-lying zone has the potential to face coastal flooding due to rising sea levels. This study was conducted to evaluate the impact of SLRs on potential coastal flooding using a hydrodynamic model namely Mike 21 FM HD. According to the results, coastal flooding would be the worst if there were no coastal protection structures to protect lowland areas. With the structure of coastal protection in NA segment, the rate of advance of seawater into the mainland and the affected area can be reduced by up to 50 %. These results can be input and reference to assist local authorities in planning the development of this area in the future.

References

[1] Selamat S N et al 2019 Multi method analysis for identifying the shoreline erosion during northeast monsoon season. J Sustain Sci Manag
[2] Mokhtar A et al 2020 Planning the Malaysian Coastline – Integrated Shoreline Management Plan. Apac 2019 1169–76
[3] Mohamed Shafiril HA et al 2015 The coastal community awareness towards the climate change in Malaysia Int J Clim Chang Stratag Manag 7 516–33
[4] Daniel Tang K H 2019 Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations Sci Total Environ 650 1858–71
[5] NAHRIM 2017 Impact of Climate Change Sea Level Rise Projections
[6] Suparia W, Moh Yatim AN 2019 Characterization of Heat Waves: A Case Study for Peninsular Malaysia Geogr Tech 14 1460–155
[7] Abdul Hamid Z 2018 Climate change and human health 2018
[8] Ghazali N H M and Awang N A 2018 Impact of Sea Level Rise and Tsunami on Coastal Areas of North - West Peninsular Malaysia Irrig Drain
[9] Belibassakis K A and Karathanasi F E 2017 Modelling nearshore hydrodynamics and circulation under the impact of high waves at the coast of Varkiza in Saronic-Athens Gulf Oceanologica 59 350–64
[10] Mardani N et al 2020 Improving the accuracy of hydrodynamic model predictions using lagrangian calibration. Water (Switzerland) 12
[11] Vieira B F V et al 2020 Hydrodynamics and morphodynamics performance assessment of three coastal protection structures J Mar Sci Eng 8
[12] Samsuddin Sah S et al 2020 Impact of Saltwater Intrusion on Paddy Growth in Kuala Kedah, Malaysia. J Sustain Sci Manag
[13] Tran T et al 2016 Improvement of Salinity Stress Tolerance in Rice: Challenges and Opportunities Agronomy 6 54
[14] Kotagiri D & Kolluru VC 2017 Effect of salinity stress on the morphology & physiology of five different coleus species Biomed Pharmacol J 10 1639–49

Table 3. Seawater advancement distance for highest progress.

|         | K1 (meter) | K2 (meter) |
|---------|------------|------------|
|         | NA | SA | NA | SA |
| 2012    | 643.7 | 788.5 | - | - |
| 2020    | 752.7 | 810.6 | 586.4 | 717.5 |
| 2050    | 869.2 | 1123.8 | 690.1 | 879.8 |
| 2100    | 926.5 | 1212.6 | 759.9 | 960 |
[15] Reddy I N B L et al 2017 Salt Tolerance in Rice: Focus on Mechanisms and Approaches. *Rice Sci* **24** 123–44
[16] Jia P et al 2018. Simulation of the effect of an oil refining project on the water environment using the MIKE 21 model *Phys Chem Earth* **103** 91–100
[17] Jabatan Pengairan dan Saliran Malaysia. Guidelines for Preparation of Coastal Engineering Hydraulic Study and Impact Evaluation 2013
[18] Mohd F A et al 2013 Assessment of coastal inundation of low lying areas due to sea level rise Assessment of coastal inundation of low lying areas due to sea level rise *IOP Conf Ser Earth Environ Sci* **169**
[19] Faour et al 2013 GIS-Based Approach to the Assessment of Coastal Vulnerability to Sea Level Rise: Case Study on the Eastern Mediterranean *J Surv Mapp Eng* **1** 41–8
[20] Zufayri Zulfakar M S et al 2020 The effect of coastal protections on the shoreline evolution at Kuala Nerus, Terengganu (Malaysia). *J Sustain Sci Manag* **15** 71–85
[21] Grases A et al 2020 Coastal flooding and erosion under a changing climate: Implications at a low-lying coast (ebro delta) *Water (Switzerland)* **12**
[22] Jahangirzadeh A et al 2012 Effects of construction of coastal structure on ecosystem *World Acad Sci Eng Technol* **65** 663–74

**Acknowledgments**
The authors would like to thank the National Hydraulic Research Institute of Malaysia (NAHRIM) for the relevant data and would like to thank UKM for funding this study through research grant DIP-2020-030.