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Evaluation of Mangroves Effectiveness in Strengthening Coastal Bund Using Geophysical Method (Non-Destructive Testing) at Tanjong Laboh, Batu Pahat, Johor

Mohd Adib Mohammad Razi[1*], Siti Nazahiyah Rahmat[1], Mohamad Hidayat Jamal[2], Mohamad Faizal Tajul Baharuddin[3], Mo Wang[4] , Tariq Mubarak Husin[5]

[1]Eco Hytech Research Centre, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

[2]School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA

[3]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Education Hub, 84600 Pagoh, Muar, Johor, MALAYSIA

[4]College of Architecture and Urban Planning, Guangzhou University, Guangzhou 510006, CHINA

[5]Forest Research Institute Malaysia, 52109 Kepong, Selangor, MALAYSIA

*Corresponding Author

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Abstract: In recent years, mangrove forests have rapidly become an endangered ecosystem in the world. On the coastal shorelines, the saltwater intrusion (SI) phenomenon is a main concern that can affect the quality of water. The saltwater intrusion might occur due to sea level rise, and extreme natural disasters along with changes in mangrove ecosystem distribution. The purpose of this research is to evaluate the effectiveness of mangroves for strengthening coastal bunds in Tanjong Laboh, Batu Pahat, Johor. By using the non-destructive geophysical method, the presence of saltwater intrusion and subsurface profile of the survey line in the coastal area with and without mangroves was determined. The coastal bund conditions with and without mangroves were also compared in order to evaluate how the mangrove forest acts as coastal protection. The result shows that the resistivity values of 0.1 to 1.0 ohm are more dominant in the mangrove bund area than in the engineered coastal bund and rock outcrop areas. The saltwater intrusion integrity map was produced from the 2D subsurface image profiles for both survey lines. The comparison of the coastal bund conditions for two different scenarios, which with and without mangroves, has shown that the coastal bund without the mangroves experienced cracking and erosion compared to the coastal bund with the presence of mangroves. This indicates the importance of mangroves in protecting the coastal regions.

Keywords: Mangroves, geo-physical method, coastal bund, Johor

Corresponding author: adib@uthm.edu.my

1. Introduction

One of the most heavily populated areas across the world is the coastal zone, which is also one of the major contributors to the nation's economy sector. However, in Malaysia, the coastline has faced prolonged exposure to ocean hazards of coastal erosion and sea level rise. The sea level rise phenomenon affected the intertidal communities [1]. According to the 2015 National Coastal Erosion Study, it has been reported that one third of an 8840 km shoreline that is constantly eroding falls into substantial categories that need structural protection. Coastal erosion can be defined as the loss of sediment during long periods that are brought about by variations in a hydrodynamic pattern that includes wind, waves and currents. The primary cause of erosion is mainly due to anthropogenic activities, but along with natural forces, the effects can be worsened by climate change. Climate change can also affect the rise in sea level, which then leads to coastal flooding, enhanced coastal erosion, land subsidence and saltwater intrusion [2].

The main concern in coastal areas is saltwater intrusion (SI), also known as seawater intrusion. Saltwater intrusion is the term when seawater carrying salt enters the coastal environment. SI usually occurs in coastal aquifers because of the difference in density of seawater and freshwater. Unconfined aquifers are the most affected by SI in coastal areas due to its direct connection to the sea. SI may affect the freshwater aquifer because of its groundwater contamination [3]. The contaminated groundwater cannot be used for drinking water purposes and has limited operations. The composition of salt will lead to corrosion of civil engineering structure. Furthermore, salinity greatly affects the soil surface, contributing to soil erosion and reducing the ability of soil to absorb rainfall, which causes surface runoff and flooding [4]. SI also alters the decomposition of nitrogen, which is essential for plant growth in wetlands and crop plantations. The existence of a mangrove ecosystem is vital to the shoreline as it can reduce the potential impact of saltwater intrusion.

Mangrove forest is known as a unique and endangered ecosystem that plays a significant role in tropical and sub-tropical regions. Due to its importance in preserving the sea level and maintaining the coastal areas, this ecosystem acts as a buffer zone, coastal protection, and nursery grounds for various types of marine organisms. Human and marine organisms that live near the mangrove area obtain various benefits in terms of ecological, environmental, biological, medical, and economic aspects [5]. Generally, the mangrove forest grows in intertidal zones such as sheltered coastlines, lagoons, or riverbanks, which encounter flooding at high tide and not flooding during low tide, as well as being able to tolerate saline conditions. The SI can be reduced with the ability of mangroves to eliminate the effect of salinity, pH and anaerobic conditions. The mangrove ecosystem also consists of a salt excreting gland and a salt-excluder gland [6]. This shows the importance of mangrove forest to protect the coastal environment.

The conventional method of saltwater intrusion mapping is always related to drilling methods, including the use of monitoring wells. However, this conventional method has several limitations such as expensive in terms of cost, time consuming and less coverage of data. Hence, the geophysical approach has been frequently used to identify the saltwater intrusion and to establish SI mapping. This method provides information related to distribution of resistivity within the subsurface structures [7]. The geophysical methods of electrical resistivity survey have been utilized extensively in hydrological study such as contaminated groundwater and saltwater intrusion due to this application of time-lapse electrical resistivity able to deliver better outcome regarding the SI studies. Therefore, this paper focuses on the geophysical method (non-destructive testing) that was used to determine the presence of saltwater intrusion and subsurface profile in different coastal areas with and without mangroves. The condition of coastal bund during high tide was also compared to two conditions - with and without mangrove areas. This will represent the ability of mangrove forest to strengthen the coastal bund.

2. Materials and Methods

The approach and methodology used in this study can be referred to Fig. 1.

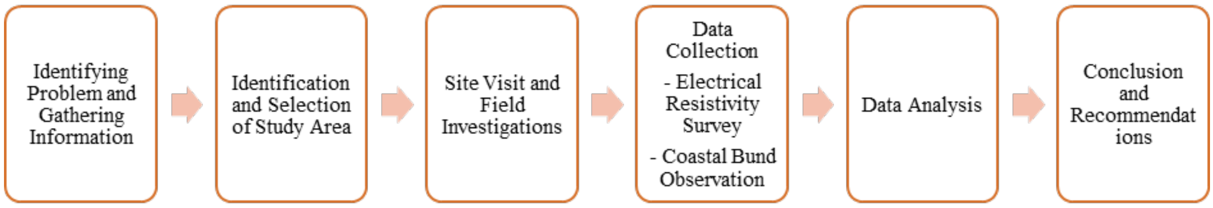


Fig. 1 - Methodology for this study

2.1 Description of Study Area

The study area is located on the South-West coast of Peninsular Malaysia and was known as Pantai Tanjong Laboh, Batu Pahat, Johor with longitudes of E 102.994540° to E 102.988420° and latitudes of N 1.739310° to N 1.741251°. The area of Pantai Tanjong Laboh was 60,000 m2 and the site topography is relatively flat. Pantai Tanjong Laboh was a muddy beach along the Malacca Strait where the shoreline was the land and sea border. The mangrove forest ecosystem along Tanjong Laboh shoreline is one of the primary study areas for restoration of mangroves where the soil structure and risk of erosion are the factors considered for forest rehabilitation [8]. This study focused on the importance of mangrove in strengthening the coastal bund. Fig. 2 shows the location of Pantai Tanjong Laboh through Google Maps and the area with and without mangroves through Google Earth.

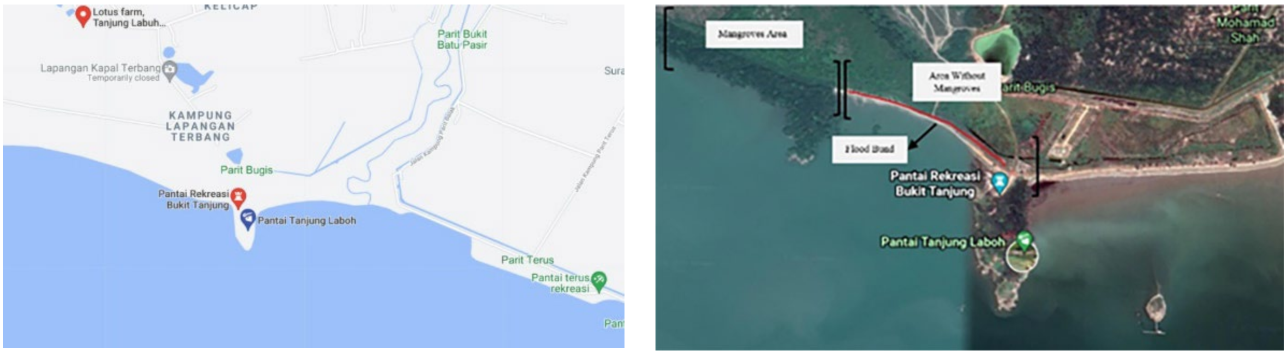


Fig. 2 - Location of Pantai Tanjong Laboh

2.2 Electrical Resistivity Surveys

Resistivity traverse was performed during January 2022 using electrical resistivity equipment set that consists of ABEM SAS 1000, multiconductor cables, stainless steel electrodes, electrodes connector and current sources. Two resistivity lines were carried out at study area and 41 electrodes were pegged 2.5 m apart on the ground along 0.5 km of the line survey. The Wenner-Schlumberger design configuration was utilized due to it has greatest signal strength and gives a dense near-surface cover of resistivity data. The equipment set up at study area as shown in Fig. 3. This method also has the ability to detect vertical resolution of horizontal structures and provides clear image of groundwater and saltwater intrusion [9].

Fig. 3 - The equipment set-up of ABEM SAS 1000

Fig. 4 shows the location of the electrical resistivity line from L1 to L1' where this line was located on an engineered bund and rock outcrop exposed without mangrove ecosystem. Meanwhile, the resistivity line from L2 to L2' was in the area with mangrove forest. There are four short cables of C1, C2, P1 and P2, that were used to connect the equipment terminal to the ground surface. The coordinates and reduced levels of resistivity line were tabulated in Table 1. In order to determine the subsurface resistivity, a certain amount of electric current (10 - 100 mA) was inserted into the ground through a pair of stainless-steel electrodes. The grounding of electrodes was properly installed to prevent penetration issues such as faulty datum point or inaccurate current transmission. Several electrodes also need to be wet by water during the data acquisition process to ensure proper penetration and propagation of current underground due to hot and dry weather.

The electrical resistivity raw data measured was processed using RES2DINV software to represent the subsurface profile of the seawater intrusion in two (2) different conditions with and without mangroves. The RES2DINV inversion algorithm was utilized to obtain electrical resistivity tomography (ERT) [10]. This program divides the two-dimensional model used in the subsurface into several rectangular blocks and in order to minimize the difference between the measured and the calculated apparent resistivity values, the resistivity of the blocks was adjusted iteratively. The latter was calculated by the finite-difference method. Other than that, this software is very flexible and can handle all conventional electrode configurations and custom 2D configurations, as well as underwater and cross-borehole surveys.

Fig. 4 - The location of resistivity line of L1 to L1' and L2 to L2'

Table 1 - Coordinates and reduced levels of survey line

Survey Line	ID No.	Distance (m)	North	Easting	Reduced Level (m.msl)
1	L1	0	1.739310°	102.994540°	~0.000
	CP1	200	1.739700°	102.992782°	~0.000
	L1'	400	1.740566°	102.991325°	~0.000
2	L2	0	1.740928°	102.989722°	~0.000
	CP2	75	1.741017°	102.989035°	~0.000
	L2'	150	1.741251°	102.988420°	~0.000

2.3 Coastal Bund Observations

A high tides phenomenon generally occurs due to the rotation of the earth and the gravitational pull of the moon which creates the tidal force. This is because the earth and water distend on the side closest to the moon. During this phenomenon, the most common consequence that can occur is flash flooding around the area near the coastal regions due to sea level rise. Furthermore, the sea level rise can contribute to the risk of erosion for the engineered coastal bund. The engineered coastal bund plays a vital role in safeguarding the coastal area from flooding and erosion as well as providing protection to the communities that live near coastal regions. Hence, the occurrence of overflow of water across the flood bund during high tides can evaluate the integrity of the flood bund in the study area.

3. Results and Discussions

3.1 Interpretation of Resistivity Value

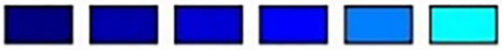
Two (2) profiles of 2-D electrical resistivity distribution were obtained from the surveys. The length of the survey line for L1-L1' is 400 m and depth of penetration is 20 m meanwhile the length for survey line L2-L2' is 150 m and the depth of penetration is 20 m. Two color codes of red and green-blue color codes are used to denote the different geologic materials as representative in an electrical resistivity model. The summary of electrical resistivity distribution as indicated in color codes versus material that are used in this study is shown in Table 2. In general, the 2-D profile obtained from the electrical resistivity survey revealed three categories of geologic materials which are as follows:

- Alluvium Quaternary deposits (silt, clay, sand and gravel materials) and bund system intruded by seawater showed the resistivity value ranges from 0.1 to 1.0 ohm.m.
- Alluvium Quaternary deposits (silt, clay, sand and gravel materials) and bund system not intruded by seawater showed the resistivity value ranges from 1.0 to 1000 ohm.m.
- Hard granite rock showed the resistivity value over 1000 ohm.m.

3.2 Data Analysis of Electrical Resistivity Image (ERI) Survey

The result from the ERI survey obtained for survey line L1 to L1' shows the resistivity values between 1 and 1000 ohm.m which indicates the presence of quaternary alluvial deposits and bund systems that are not intruded by seawater intrusion along with the presence of granite hard-rock. A high resistivity value represents that seawater was not dominantly found in the subsurface profile as shown in Fig. 5. The saline water was more dominant in the subsurface with low resistivity and well-made construction of engineered bund can prevent SI in surface soil. In addition, the yellow to red colour represents the presence of hard layers such as the rock. Meanwhile, the turquoise to green colour indicates the presence of freshwater and the seawater can be seen a dark blue colour.

Table 2 - Summary of resistivity value interpretation

No.	Resistivity Value (ohm.m)	Resistivity Legend	Interpretation
1	0.1~1.0	 0.100 0.300 0.800	Alluvium Quaternary deposits (silt, clay, sand and gravel materials) and bund system intruded by seawater.
2	1~1000	 0.800 5.00 50.0 200 1000	Alluvium Quaternary deposits (silt, clay, sand and gravel materials) and bund system that is not intruded by seawater.
3	Above 1000	 1000 10000	Hard granite rock.

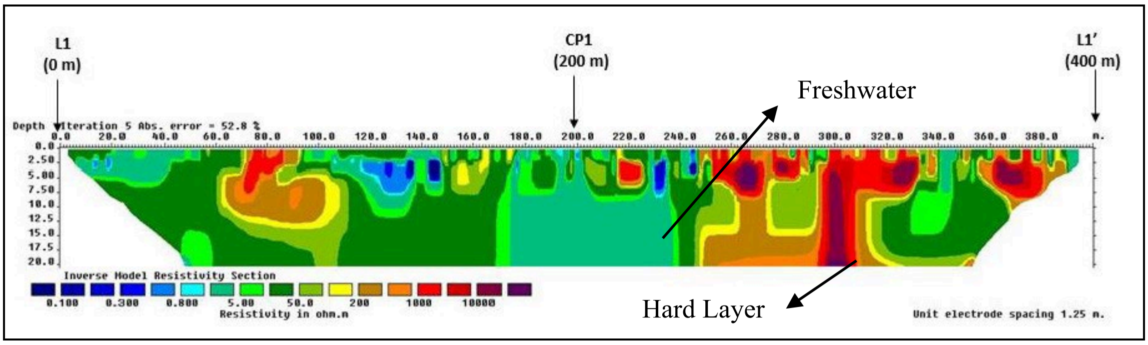


Fig. 5 - Subsurface profile image for survey line L1 to L1'

For survey line L2 to L2', the ERI survey resulting in resistivity values of 0.1 to 1.0 ohm.m that indicates the presence of quaternary alluvial deposits with the bund system intruded by saltwater. Low resistivity value shows the mangrove bund area was more dominant to seawater intrusion. This is indicated that a resistivity value less than 5 ohm.m shows the presence of saline water and frequent seawater waves during high tides also can influence the visibility of SI in mangrove area. During high tides, the pushing effect of waves and increase of seawater levels can lead to the movement of seawater towards inland area. The subsurface profile line L2 to L2' as illustrated in Figure 6 shows two colours of blue and green with no presence of hard granite rock due to there is no yellow or red colour present in the profile. The turquoise-green colour indicates the presence of freshwater and the seawater can be seen a dark blue colour.

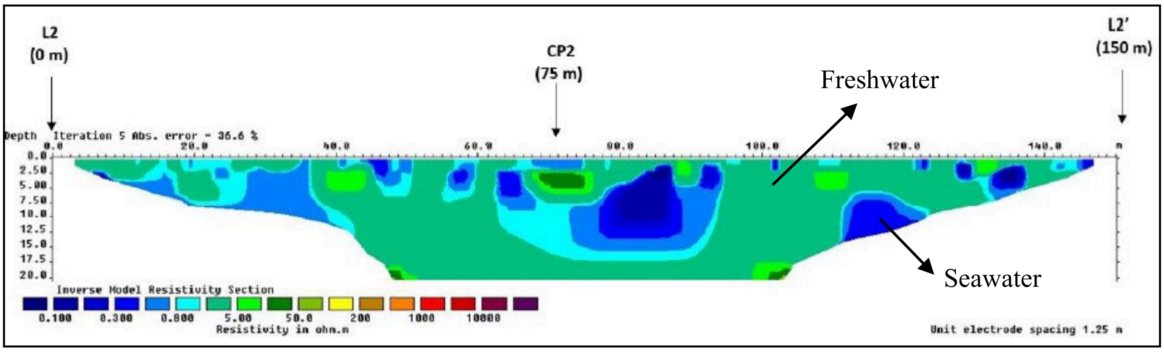


Fig. 6 - Subsurface profile image for survey line L2 to L2'

From the obtained results, the saltwater intrusion was more prominent in survey line L2 to L2' where there is mangrove bund meanwhile, there is no SI presence on survey line L1 to L1', which is located on engineered bund and rock outcrop areas. Mangrove forest has the ability to reduce SI, however, the studies also concluded that the SI might occur due to the reduced quantity of freshwater supply resulting in seawater completely entering the coastal area. This indicates that other than the presence of mangroves or not, there are other factors were considered as source of SI in the study area.

In Selangor, the saltwater intrusion in the mangrove area was not significant because the mangrove acts as a buffer to seawater encroachment and as a natural filtration system [7]. This shows that even on the face of the mangrove bund of the study area shows the presence of salt water, the SI concentration can be reduced as mangrove is able to eliminate the effect of salinity as well as pH value. Hence, mangrove forest is vital in protecting the coastal area as it can preserve other places in the study area from SI.

3.3 Engineered Coastal Bund Observations

Engineered coastal bund plays an important role in protecting the shoreline area from coastal threats such as coastal erosion and sea level rise. Natural factors such as waves, tides, currents and wind, anthropogenic activities or a combination of both can cause coastal erosion. Human activity along the coastline also has the potential to change the ecosystem [11]. It can be seen that the phenomenon of high tides can enhance coastal erosion. This is because this phenomenon pushes large amounts of water onto the beach or coastal line along with tide forces that can cause coastal erosion and may endanger the populations' lives behind the coastal bund. Mangrove forest as coastal protection was proven during the 2004 Indian Ocean Tsunami where it helped to dissipate the wave energy and reduce the impacts [12]. Hence, the coastal bund with and without mangrove ecosystem in the study area were observed during high tides phenomenon to determine the effectiveness of mangroves in strengthening the coastal bund.

Fig. 7 - Coastal bund without mangrove ecosystem before and after high tides phenomenon

Fig. 8 - Coastal bund with mangrove ecosystem before and after high tides phenomenon

The coastal bund condition for area with revetment and without mangroves was observed and the picture taken on 1 November 2021 shows no sign of erosion. However, on 6 December 2021, there was a high tides phenomenon and the same coastal bund area experienced erosion and cracking due to tides force and overflowing of water across the bund. The difference in coastal bund condition without mangrove ecosystems before and after high tides are shown in Fig. 7.

Moreover, for comparison purposes, the coastal bund condition for areas with mangrove forest was also observed. The picture taken on 1 November 2021 of the coastal bund covered with mangroves indicates no erosion occurred. However, the coastal bund condition remains the same even after the high tides' phenomenon on 6 December 2021 with no sign of erosion and there is no overflowing of water across the bund. The difference between the coastal bund condition with mangrove ecosystems before and after high tides are shown in Fig. 8. This shows the effectiveness of mangroves in strengthening the coastal bund where the dense roots of mangroves that bind together the soil can minimize the impacts against destructive natural forces of wind and wave action [13].

4. Conclusions

The ERT survey was used to determine an overview of the whole subsurface profile with particular reference to soil profiling and characterization in the study area. The ERT survey was believed to be a good alternative method for shallow subsurface profiling due to its effectiveness in terms of cost, time and quality. This method used a surface method during data acquisition which enables the preservation of site destruction, thus contributing to our sustainable environment in the construction industry. The subsurface profile of each survey line was successfully investigated using 2D electrical resistivity tomography. The presence of saltwater intrusion (SI) was also indicated by the resistivity values obtained. From the study, mangrove forest is vital in strengthening the coastal bund by reducing SI, minimizing the effect of high tides, preventing coastal erosion and protecting the coastal areas. More mangrove rehabilitation must be conducted as the degradation of mangrove lessens the mangrove function as coastal protection. It is also recommended to perform future analysis by combining geophysical methods with geochemical data to determine more about the boundaries of saline water as well as the effects of SI.

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