

Impact Assessment of Current and Future Sea-Level Rises on Coastal and Underwater Archaeological Sites in Indonesia

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ABSTRACT

Despite the indirect impact of sea level rises on underwater archaeological sites, identifying future conditions is imperative to support conservation planning to minimise the possible effects that may occur. This study aims to identify the sea level trends in several important archaeological sites in Indonesia and estimate the future change due to sea level rises. Altimetry satellite data were employed to determine the sea level anomaly (SLA) of three chosen sites: Mandeh Bay, Banten Bay, and southern Tidore, where significant historical objects were recently discovered. Hydrodynamic-based modelling was also used to estimate the water properties alteration in 2100 as predicted by IPCC AR6, with a projection of about 0.68-0.70 meters (m) sea level increase. Under the sea level rise scenario, the current magnitude will increase significantly by about 33-35 per cent in 2100. It is followed by an increase in sediment transport of 18 – 37 per cent. As sedimentation is the primary issue in these three sites, sea level rises will induce sufficiently high sedimentation on archaeological remains, and artefact shifting position is also possible due to the more robust current regimes. Therefore, regular monitoring is an effort to protect the archaeological remains. If possible, excavations are also recommended to conserve the underwater cultural heritage (UCH) in Indonesia since it faces an upward sea level trend.

Keywords: UCH, shipwreck, artefacts, sea level trends, sea level projections

INTRODUCTION

Sea level rise has become a growing concern in recent years as it threatens coastal areas and poses a significant threat to the preservation of underwater archaeological sites (Wetsley et al. 2023, 251-253). Indonesia with its vast coastline and rich cultural history is no exception to this issue. The rising sea level in Indonesia is gradually eroding coastal areas and threatening to submerge many ancient underwater archaeological sites, which are essential for scientific research but also for the cultural heritage of the country (Adhityatama and Yarista 2019, 55-56). Understanding the relationship between sea level rise and underwater archaeological sites in Indonesia is crucial for preserving the country's cultural heritage and preventing the loss of valuable historical information. Several shipwrecks and underwater archaeological sites in Indonesia are threatened by sea level rise, including those in the waters of Java and Sumatra. These sites would be a significant loss for scientific research and destroy Indonesia's cultural heritage. Therefore, preserving these sites and preventing them from being lost to the sea is essential.

Historical shipwrecks are diving sites and the object of research in Indonesia (Dillenia et al. 2021, 2-3; Ridwan 2011, 5-6). To date, no studies assess the relationship of sea level trends with archaeological remains in the coastal and terrestrial zones. Some examples of well-known archaeological remains that may be threatened by sea level rise are: MV *Boelongan Nederland*, Gosong Nambi Shiwreck, and Ceramic findings in Sungai Nyalo, situated in the West Sumatra, USS *Houston* and HMAS *Perth* in

Banten Bay, and Tonguwai and Soasio archaeological sites in Tidore Island, North Moluccas Province. This study will compare the status of sea level trends in these sites and their possible influence on the UCH. Estimating the future state concerning sea level projection established by The Intergovernmental Panel on Climate Change (IPCC) can be approached using hydrodynamic modelling and statistical-based analysis. Therefore, this study describes the possible impact of sea level rises on underwater archaeological remains in Indonesia. This study is expected to become a basis for future decision-making regarding UCH preservation for local and central authorities.

CASE STUDIES

As mentioned earlier, this study will assess the possible impact of sea level rise on UCH in Indonesia. Therefore, in this section, we want to introduce several essential sites threatened by sea level rise.

There are many significant archaeological sites in the West Sumatra Province. However, in this stage, we will introduce the latest identified sites surrounding Mandeh Bay, namely MV *Boelongan Nederland* and Gosong Nambi Shipwreck underwater sites and Sungai Nyalo terrestrial site. In 2017, RICRV discovered plenty of artefacts in the terrestrial area of Mandeh Bay called Sunyai Nyalo Village, close to the MV *Boelongan Nederland* shipwreck. Of 654 fragments were conserved, consisting of ceramic pieces, green-glass bottles, and earthenware bottles with European, East Asian, and Southeast Asian motifs (Figure 1a and b). This finding is an example of the incredible impact of sea level rise since the upward trend of sea level induces significant erosion in the coastal area. Therefore, these artefacts could be discovered at a one-meter depth. Thus, analysing sea level anomalies in the West Sumatra region, particularly in the surrounding Mandeh Bay, is significant in understanding its impact on shipwreck future conditions and the faith of undiscovered terrestrial remains that may still exist in the West Sumatra Province.

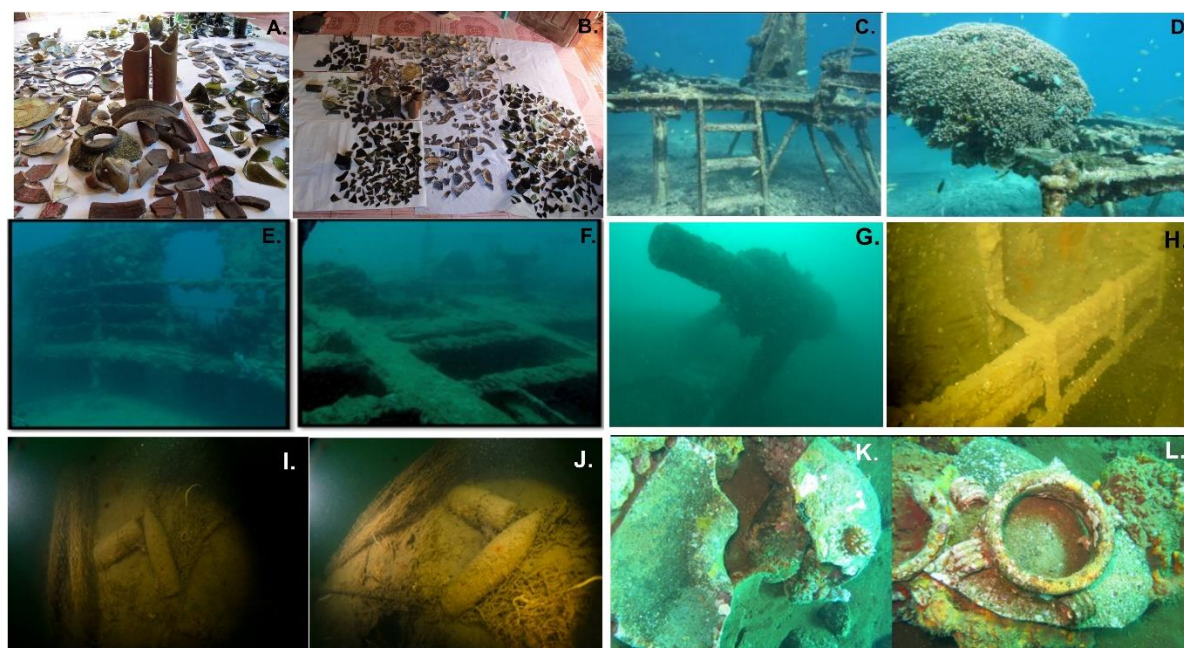


Figure 1. The documentation of archaeological remains in the Indonesia waters; Sungai Nyalo artifact (a and b); Gosong Nambi wreck (c and d); MV *Boelongan Nederland* (e and f); HMAS *Perth* (g and h); USS *Houston* (i and j); Artefact findings in Tidore (k and l)

A shipwreck discovered by local fishers in 2015 and initially established in 2020 is the Gosong Nambi wreck (Wisha et al. 2020, 63-65). Despite the lack of historical context for these remains, the shipwreck is the centre of biodiversity since it is trapped within an atoll formation (Figure 1c and d). Recently, locals reported that the position of this wreck is lowered due to the rubble avalanches induced by extreme weather and tides. Therefore, since the remains are vulnerable, the long-term sea

level rise could cause a more lowering position of this wreck and even be buried by rubble and sediment.

On the other hand, MV *Boelongan Nederland* was a cargo ship built in the 1920s by the Dutch shipping company Koninklijke Paketvaart-Maatschappij (KPM). The ship was used for transporting goods and passengers in and around Indonesia and Southeast Asia. During WWII, the ship was taken over by the Dutch and used to aid the war effort. However, in 1942, the Dutch scuttled the ship to prevent it from falling into the hands of the advancing Japanese forces (Ridwan et al. 2015, 84-87).

The remains of MV *Boelongan Nederland* now lie in the waters off Mandeh Bay, West Sumatra, Indonesia, and have become a popular recreation dive site. The shipwreck is also of historical significance as it provides insights into the maritime history of Indonesia and the role played by shipping companies like KPM in the region. This site is threatened by massive sedimentation, which frequently hampers the diving activity due to the high sediment supply from the Mandeh Estuary right in front of the shipwreck position (Figures 1e and f). The shipwreck lies at a depth of about 20 m, and under the scenario of sea level rises, it is hypothesised that the sediment issue will get worse with increasing sea levels.

The other case studies considered in this study are USS *Houston* and HMAS *Perth* shipwreck sites. The USS *Houston* and HMAS *Perth* were two naval warships that were heavily damaged during the battle and eventually sank during WWII in the Battle of Sunda Strait, which took place on 28 February 1942. Today, the USS *Houston* and HMAS *Perth* wrecks are popular dive sites in Indonesia and are located near the island of Java. The wrecks are historically and culturally significant and essential for scientific research and a reminder of the sacrifices made by those who fought in WWII. Efforts have been made to preserve and protect the wrecks, including establishing a protected zone around the sites and conducting ongoing monitoring and research to document changes in the condition of the wrecks over time (Figure 1g–j) (Shaw 2017, 2-7).

Based on the recent documentation and field identification conducted by RICRV in 2018, HMAS *Perth* is positioned at 19-34 m depth, while the USS *Houston* is at a depth of 16-30 m, both located in the northern Panjang Island. The main problem in these sites is high sedimentation, with almost zero visibility (Ridwan 2019, 1626-1627). Moreover, the shipwrecks are surrounded by mining and industrial activities; they are located in the fishing zone; and are degraded by marine debris pollution (Wisha et al. 2022a, 106009). Therefore, the increase in sea level could worsen the shipwreck conditions in terms of greater sedimentation and degradation.

In east Indonesia Tidore Island, was the location to witness the first circumnavigation of the Earth by Ferdinand Magellan and Juan Sebastian Elcano. There are many remains on Tidore Island as evidence of Portuguese and Spanish colonialism over spice resources in this area. The most reachable sites are Tongwai and Soasio, where many artefact fragments, such as cannon, ceramics, earthenware, and metals, are scattered on the surrounding coral reef ecosystem, increasing the attractiveness of these sites to recreation (Figure 1k and l) (Rahmawan et al. 2021, 173-174). Since it is directly connected to the Pacific Ocean, the sea level rise may deteriorate the site conditions.

RESOURCES

To review the sea level trend in the study sites, we used the ~27-year sea level data (1992-2019) from altimetry satellites, The Sea Level Explorer established by the University of Colorado Boulder, the University of Hawaii Sea Level Center, and NASA Jet Propulsion Lab, (see <https://ccar.colorado.edu/altimetry/>). The altimetry data were sourced from the Propulsion Lab's Physical Oceanography Distributed Active Archive Center (PODAAC). The sampled altimetry coordinates (Table 1) are in Mandeh Bay, Banten Bay, and southern Tidore Island.

On the other hand, to estimate the possible future alteration due to sea level rises, we employed a sea level projection data provided by the NASA Sea Level Projection Tool allowing users to visualize and

download the sea level projection data from the IPCC 6th Assessment Report (AR6) (see <https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool>). It is estimated that in 2100 CE the sea level will increase by 0.68 m for Mandeh and Banten Bay and 0.70 m for Tidore Island.

The archaeological and environmental data were obtained from RICRV reports of field surveys in Mandeh and Banten Bay in 2018 and in Tidore in 2019. The field survey consisted of diving activity to the shipwreck sites, mini excavation, oceanographic parameters measurements, sediment sampling, local social-economy, interviews, acoustic-based measurements, and many others.

Table 1. Coordinates of the sampled sea level data

Location	Longitude	Latitude
Mandeh Bay	100.2500°E	1.2500°S
Banten Bay	106.0833°E	5.9167°S
Southern Tidore Island	127.4167°E	0.5833°N

FRAMEWORK

The sea level anomaly (SLA) data was gained from yielded deviation between sea level at a specific time and the mean sea level. Then, a future linear trend was used to calculate the sea level trend, the annual amplitude, and the semi-annual amplitudes of each archaeological site.

As for estimating the future changes based on sea level projection, we employed a coupled model of MIKE21 with flexible mesh to simulate the mutual interaction between waves and currents using a dynamic coupling between the hydrodynamic and spectral wave models (Wisha et al. 2022b, 78). We sampled the result from the coupled model developed according to site locations.

The sediment transport model is based on the hydrodynamic models previously simulated (Wisha et al. 2022b, 78). The following equation defines the correlation between the wave energy flux component and the sediment transport:

$$W_{ef} = \frac{\rho g}{8} H_b^2 C_b \sin \alpha_b \cos \alpha_b \quad (1)$$

Where:

W_{ef} = Wave energy flux component along the coast at the time of wave breaking kilogram-meter per second ($kg.m.s^{-1}$)

ρ = Specific gravity (seawater) kilogram per cubic meter ($kg.m^{-3}$)

g = Gravity acceleration (9.81 meter per second squared ($m.s^{-2}$))

H_b = Wave Height at the time of breaking (m)

C_b = Breaking wave celerity meters per second ($m.s^{-1}$)

α_b = Breaking wave angle

A formula established by Triatmodjo (2012) was used to estimate the annum sediment transport. The formula is defined as follows:

$$Q_s = \frac{K}{(\rho_s - \rho)g(1-n)} W_{ef} \quad (2)$$

Where:

Q_s = Sediment transport along the coast cubic meter per second ($m^3.s^{-1}$)

K = 0.39

ρ_s = Specific gravity (sand) ($kg.m^{-3}$)

n = Porosity ($n \approx 0.4$)

RESULT

Sea Level Trend Over the Archaeological Sites in Indonesia

The altimetry data show upward trends of sea level over the sampled sites, at 0.39 centimetres per year (cm/year), 0.40 cm/year, and 0.52 cm/year for Mandeh Bay, Banten Bay, and southern Tidore (Figure 2 and Table 2). Over 27 years of observed data (1992-2019), different patterns were observed in the three parts of the Indonesian region. In Mandeh Bay, the sea level has increased since 2004 and peaked in 2017 with an SLA magnitude of about 38 cm. Similar to Mandeh Bay, the SLA in Banten Bay rose significantly in 2007, where the lowest sea level was observed in the next year, reaching -30 cm. The maximum sea level over 27 years was identified in 2018, reaching 26 cm.

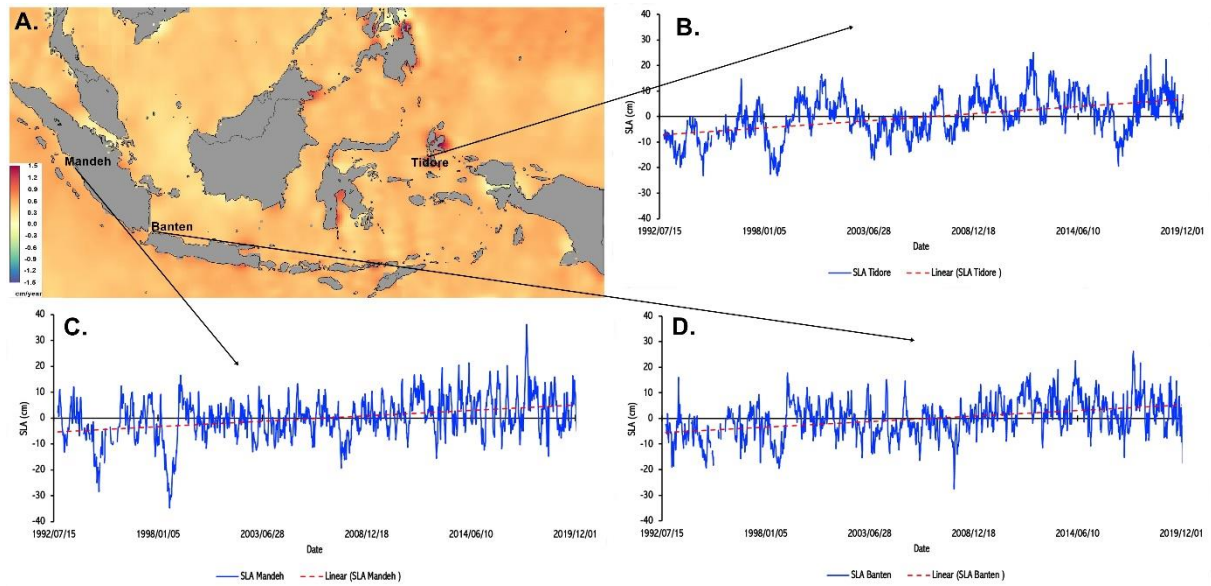


Figure 2. Sea level trend over Indonesia region (a) derived from Altimetry data; (b) SLA in southern Tidore island; (c) SLA in Mandeh Bay; (d) SLA in Banten Bay

In Tidore Island, the recorded sea level is arbitrarily erratic (Figure 2b). The sufficiently high sea level trend in this area is due to the influence and circulation of the Pacific Ocean, where El-Nino Southern Oscillation (ENSO) plays a significant role in shaping sea level (Moon et al. 2015, 8229). The lowest sea level ever recorded was observed in 1998, reaching -28 cm, while the peak levels were observed several times, such as in 2012 and 2018, reaching 25 cm. Overall, all those sampled archaeological sites face an upward trend in sea level (Table 2), so future estimation of coastal dynamics due to sea level rises is imperative.

Table 2. Sea level trend over 27 years of observation

Parameter	Mandeh Bay	Banten Bay	Southern Tidore Island
Trend (cm/year)	0.39	0.40	0.52
Annual Amplitude (cm)	1.66	3.03	3.63
Semi-Annual Amplitude (cm)	4.56	3.21	0.53

The Possible Impact of Sea-Level Rises on Archaeological Remains

Sea level rises significantly impact shipwreck sites, particularly those located in coastal regions or underwater. As sea levels rise it can lead to increased erosion, flooding, and sedimentation causing damage to shipwrecks and their associated artefacts. Additionally, changes in ocean currents and weather patterns can contribute to shipwreck deterioration.

One of the primary concerns with rising sea levels is the potential for loss of archaeological information. As shipwrecks are exposed to increased water pressure and changing environmental conditions, they can be subject to accelerated decay and destruction. This can result in losing valuable historical and cultural information these sites contain. Moreover, sea level rise can make it difficult for archaeologists and researchers to access shipwreck sites. As water levels increase, locating and exploring these sites, particularly submerged ones, can become more challenging. This can limit the ability of researchers to conduct surveys and excavations and potentially delay or prevent the recovery of artefacts and other historical evidence.

Overall, sea level rise significantly threatens shipwrecks and their associated cultural heritage. Archaeologists and policymakers must work together to mitigate the impact of rising sea levels and ensure the preservation of these valuable historical resources for future generations.

Future Projection of SLR and its Influence on Coastal and Underwater Cultural Heritages

In 2100 CE the IPCC sea level projection, with a scenario of high gas emission (SSP3-7.0) is that it will increase by ~0.68 m for Mandeh and Banten Bay, while in Tidore, the sea level is projected to increase by ~0.70 m (Figure 3). From these values, we simulated a model predicting the changes in water properties in the three sampled archaeological sites that have been validated using field-measured data provided by RICRV. Overall, the increase in sea level contributes to higher sedimentation (Figure 4).

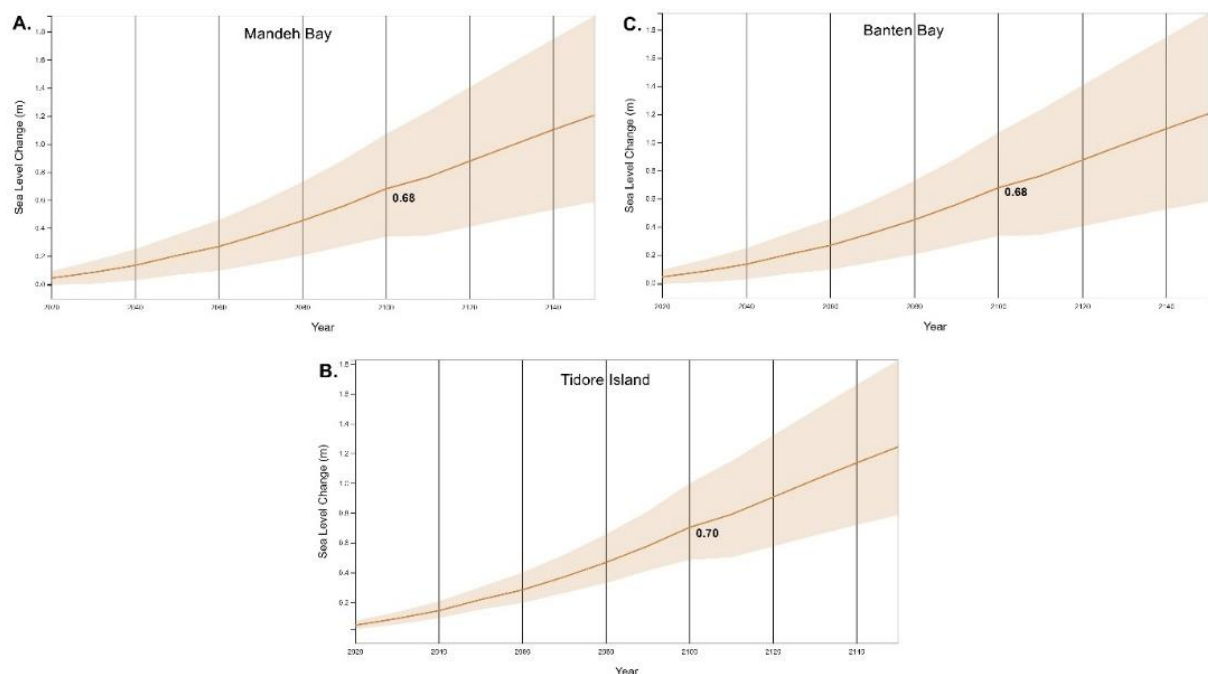


Figure 3. Sea level projection estimated by IPCC AR6 in 2100 CE in Indonesia: Mandeh Bay (a); Banten Bay (b); and Tidore Island (c)

In Banten Bay, the strongest current magnitude was approximately 0.66 m/s observed in August, and the lowest was in April with a magnitude of 0.54 m/s. Under the sea level rise scenario, the current

magnitude will increase by about 33.52 per cent ranging from 0.08 to 0.096 m/s (Figure 4a). A weaker current profile was identified in Mandeh Bay, ranging from 0.042 to 0.059 m/s. With the estimated sea level rise of 0.68 m in 2100, the current magnitude will increase by approximately 34.78 per cent, reaching 0.079 m/s (Figure 4b). In Tidore, the current profile ranged from 0.047 to 0.062 m/s, and the value will increase by about 35.73 per cent in 2100 CE, ranging from 0.079 to 0.09 m/s (Figure 4c).

Similar to the current features, sediment transport will also increase under sea level rise. Percentagewise, the increase in sediment transport in Banten Bay, Mandeh Bay and Tidore was approximately 34.86, 18.54, and 37.07 per cent, respectively. Generally, the highest sediment transport was observed during the southwest monsoon and vice versa for the northeast monsoon (Figure 4d-f).

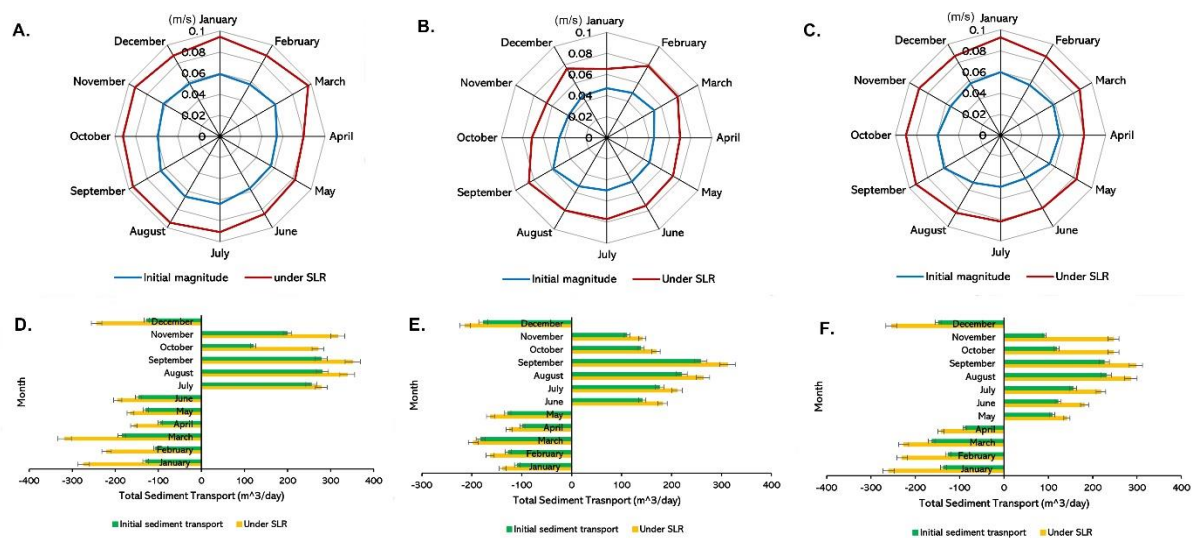


Figure 4. Monthly average of current magnitude in the surrounding site; Banten Bay (a); Mandeh Bay (b); Tidore Island (c); and the estimated sediment transport sediment in the Banten Bay (d); Mandeh Bay (e); and Tidore Island (f). The negative values denote the left-ward transport, and the positive values denote the right-ward transport.

Overall, the sea level rise potentially changes the water properties of the three sampled archaeological sites. The increase in current velocity relates to the potency of coastal erosion and sedimentation. Since sedimentation is the most crucial issue in these sites, the sea level rise will significantly impact the archaeological remains by inducing higher suspended sediment and sedimentation. In some cases, aside from making the remains more submerged, the shifting in the position of the shipwreck and artefacts due to the robust current profile is possible. Therefore, regular monitoring is required to protect the remains from the impact of sea level rise. However, archaeological excavation is also recommended if possible.

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