# THE PROJECTION OF SEA LEVEL RISE IN SOUTHEAST ASIA'S COASTAL CITIES USING SATELLITE ALTIMETRY DATA (1992-2020)

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## ABSTRACT

The distribution of sea level rise (SLR) rates is not uniform, shows regional characteristics and changes over time. Most coastal areas in Southeast Asia countries have similar characteristics within the geographical proximity with a low-lying topography, high population, and diversified economic activities. However, the rates of SLR of these countries are varying, and at some places show a large deviation from the global average. Using earth observation data, SLR can be analyzed in various places, such as in coastal cities with a high population density and a high risk of flooding. This research was aimed at updating and analyzing the current trends and rough future projections of SLR in Southeast Asia coastal cities. The study was carried out using the SLR analysis between 1992–2020, resulting from altimetry satellite data. SLR analysis was performed on 20 (twenty) coastal cities in the Southeast Asia region. The study result identified the SLR rate varied between 1.12–7.37 mm/year, with the 8 (eight) cities having a higher rate than the global SLR rate. The risk of SLR impact is greater in densely populated and flood-prone cities such as Jakarta, Manila, Pattaya, Vung Tau, and Ho Chi Minh cities. The satellite altimetry projection predicts that the SLR in Southeast Asia will range 0.05–0.33 m in 2050 and 0.11–0.70 m in 2100. With regards to these insights, decision-makers can establish better planning to face the potential threats caused by SLR that can lead to actual disaster events such as floods.

**Keywords**: *sea level rise, coastal area, Southeast Asia, altimetry satellite*

## INTRODUCTION

Directly impacted by global warming as a result of greenhouse gases (GHG) effects, sea level rise (SLR) plays an important role as an indicator of climate change. SLR could cause serious implications to the coastal area, such as beach erosion, land inundation, increasing coastal aquifers salination, floods, and coastal ecosystem losses (Bellard et al., 2014; Brown et al., 2016; Fenoglio-Marc et al., 2012; Gilman et al., 2007; Hinkel et al., 2014). Because of these negative impacts, the understanding of past and future changes in sea level become necessary and important to be monitored. However, we should aware that SLR rate distributions are not uniform, shows regional characteristics, and change over time (Cheng et al., 2014; Kopp et al., 2015; Stammer et al., 2013).

The rising trend of global mean sea level (GMSL) has been accelerated significantly over the century, from 1.4 mm/year over the period 1901–1990, to 2.1 mm/year over the period 1970–2015, to 3.2 mm/year over the period 1993–2015, and 3.6 mm/year over the period 2006–2015 (IPCC, 2019). Within the Southeast Asia region, the observed average SLR rate in Indonesia was reaching up to 6 mm/year between 1992–2017 (Sutrisno et al., 2018; Takagi et al., 2016). The lowest sea level rate of Indonesia was detected in the southern Java Island with the rate of 2 mm/year, while the highest was detected in the northern Papua Island that reached up to 7.8–10 mm/year (Nababan et al., 2015; Sofian et al., 2011; Sofian & Nahib, 2010).

Most of Indonesia's neighboring countries' coastal areas have similar characteristics to it, with a low-lying topography, high population, and diversified economic activities (Paw and Thia-Eng 1991). However, apart from the geographical proximity and the similarity of the coastal characteristics, the rates of sea level rise of these countries are varying and might show a large deviation from the global average. Several SLR rates in this region have been compiled from previous studies, which reach up to 7.8 mm/year in Eastern Bangladesh (Sarwar and Khan 2007), 5.0 mm/year in the Gulf of Thailand (Sojisuporn et al. 2013), 4.6 mm/year in the Peninsular Malaysia (Luu et al. 2015), and 3.1 mm/year in Vietnam (Hanh and Furukawa 2007). The comparisons explained show that sea level rise is site-specific and needs to be more focused on investigated in the coastal cities.

We believe that the earth observation data and remote sensing application will be very beneficial and helpful in future research activities carried out in the broad area. Altimetry satellite is one of the remote sensing techniques with a notable role in oceanographic monitoring on climate change (Chambers et al., 2016; Sterlini et al., 2017). Having the potential to observe the spatial and temporal dynamics of the ocean, altimetry satellite now starts to replace the traditional tide gauge to forecast the rate of sea level. Some altimetry satellite radar has been launched and shows remarkable ability on sea level topography measurement with high accuracy, i.e., GeoSat (1985–1989), ERS-1 (1991–1998), TOPEX/Poseidon (1992–2006), ERS-2 (1995-–2011), GFO (1998–2008), Jason-1 (2001–2013), EnviSat (2002- 2012), Jason-2 (2008–2016), and Jason 3 (2016-–present) (Fu & Cazenave, 2001; Mansawan et al., 2016). These satellites have been broadly utilized on sea level monitoring/research in Southeast Asia seas. This research was aimed at updating and analyze the SLR trends of Southeast Asia coastal areas and the rough estimation of the future SLR projections. The study was carried out using the SLR analysis between 1992-2020 resulted from altimetry satellite data.

## METHODS

*Study area*

The study area for this work were 20 SLR observation cities located in Southeast Asia coastal areas, included Indonesia (Bandar Lampung, Batam, Denpasar, Jakarta, Makassar, Manado, Padang, Semarang, Surabaya), Malaysia (Kuching, Penang), Singapore (Singapore), Thailand (Pattaya), Vietnam (Da Nang, Ho Chi Minh, Vung Tau), and Philippines (Davao, Manila, Zamboanga). The location map of observation cities is shown in Figure 1.

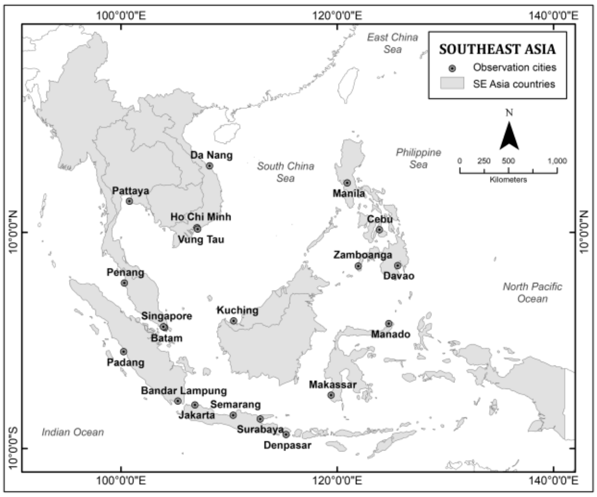


**Figure 1**. Southeast Asia region and SLR observation cities.

*Data sets dan methods*

The trends of SLR resulted through sea level height anomaly (SLHA) data sets analysis obtained from MEaSUREs Gridded Sea Surface Height Anomalies Version 1812 (Zlotnicki et al. 2019) on NASA PODAAC retrieved at https://doi.org/10.5067/SLREF-CDRV2. The fully corrected gridded data were derived from the SLHA data of TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3 satellites from October 1992 to January 2019. The original SLHA data from Jason-3 satellites (Lillibridge 2019), retrieved at https:// accession.nodc.noaa.gov/ 0122595, was used to fill the time series from February 2019 to October 2020 (downloadable data until the writing of this paper). The SLR rate obtained from the altimetry satellite analysis will be projected until 2100 and compared with the RCP2.6 and RCP8.5 scenarios from Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) by IPCC (2019).

## RESULT AND DISCUSSION

*Sea level trends and variability*

The trends of regional SLHA in Figure 2 were divided into 4 (four) groups based on the similarities of the chart shapes, which indicate the relationships between location proximity within the groups. In general, there are increasing trends of SLHA in all cities with varying rates. However, the SLHA trends of Vietnam and Thailand are showing a more distinct seasonal pattern which is lowest in the east monsoon season (June-July-August) and highest in the west monsoon season (December-January-February). There are some distinct SLHA decreases between 1997–1998 and 2015–2016 in the areas that are directly connected to the Indian and the Pacific oceans. Both periods are the time of the extreme climatic phenomena of El Niño–Southern Oscillation (ENSO). Due to the absence of supporting data regarding these two correlations, further studies are needed to obtain more scrupulous conclusions.

The SLR rates from 20 observation cities were generated and shown in Table 1. Generally, cities situated in lower latitudes are having lower rates than cities located in higher latitudes. The SLR rates of 8 (eight) cities were significantly higher than the rising trend of GMSL (3.6 mm/year). The highest rate is found in Ho Chi Minh, Vietnam (7.37 mm/year), while the lowest rate is found in Surabaya, Indonesia (1.12 mm/year). The map of the SLR trend based on altimetry satellite data (1992 – 2020) is shown in Figure 3. The interpolation method used in the mapping is using the spatial trend analysis.

**Table 1**. The rate of SLR (mm/year) at the observation cities.

| City | Country | SLR rate |
|---|---|---|
| Ho Chi Minh | Vietnam | 7.37 |
| Vung Tau | Vietnam | 7.19 |
| Pattaya | Thailand | 5.09 |
| Da Nang | Vietnam | 5.04 |
| Manila | Philippines | 5.03 |
| Manado | Indonesia | 4.51 |
| Singapore | Singapore | 4.35 |
| Batam | Indonesia | 3.88 |
| Davao | Philippines | 3.18 |
| Semarang | Indonesia | 3.08 |
| Cebu | Philippines | 2.61 |
| Kuching | Malaysia | 2.47 |
| Zamboanga | Philippines | 2.08 |
| Makassar | Indonesia | 2.00 |
| Penang | Malaysia | 1.98 |
| Padang | Indonesia | 1.82 |
| Bandar Lampung | Indonesia | 1.80 |
| Jakarta | Indonesia | 1.71 |
| Denpasar | Indonesia | 1.26 |
| Surabaya | Indonesia | 1.12 |

Although SLR rates in Indonesia's cities are significantly lower than those in Vietnam and Thailand, many other factors could exacerbate the coastal inundation impacts in densely populated coastal cities in Indonesia. The anthropogenic forces such as groundwater extraction and land development in populated cities will also increase coastal flooding risks

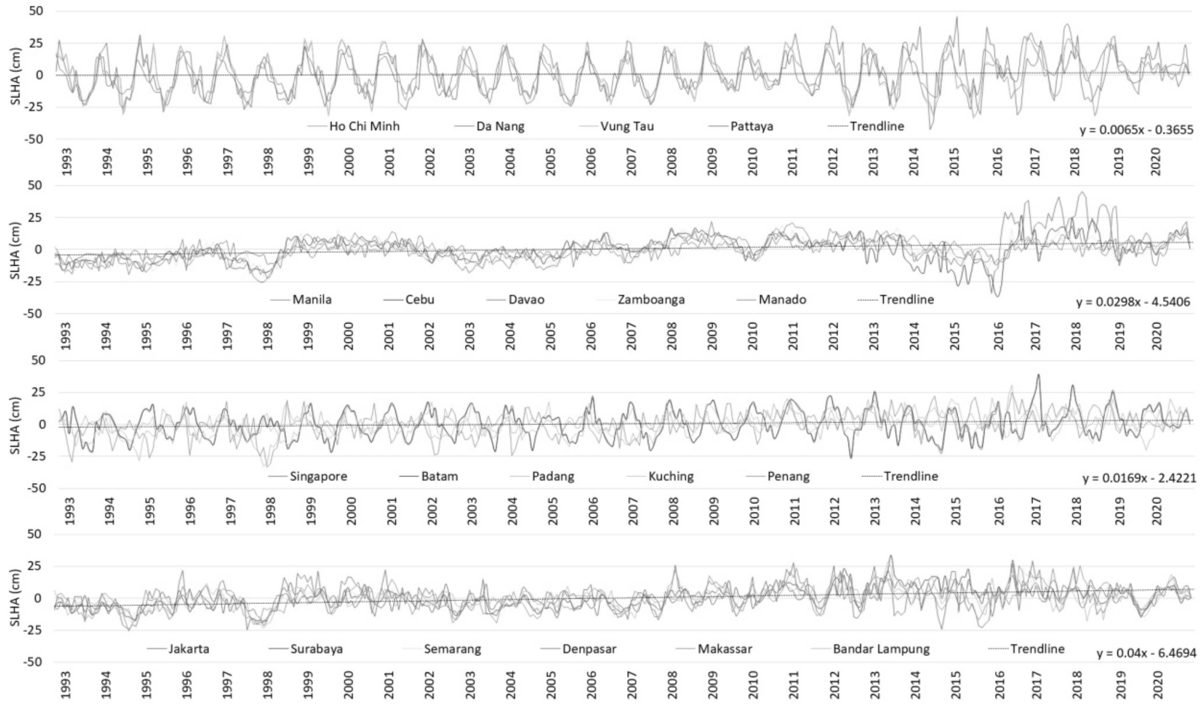


**Figure 2**. Sea level anomaly trends in Southeast Asia cities during the period of 1992 – 2020.

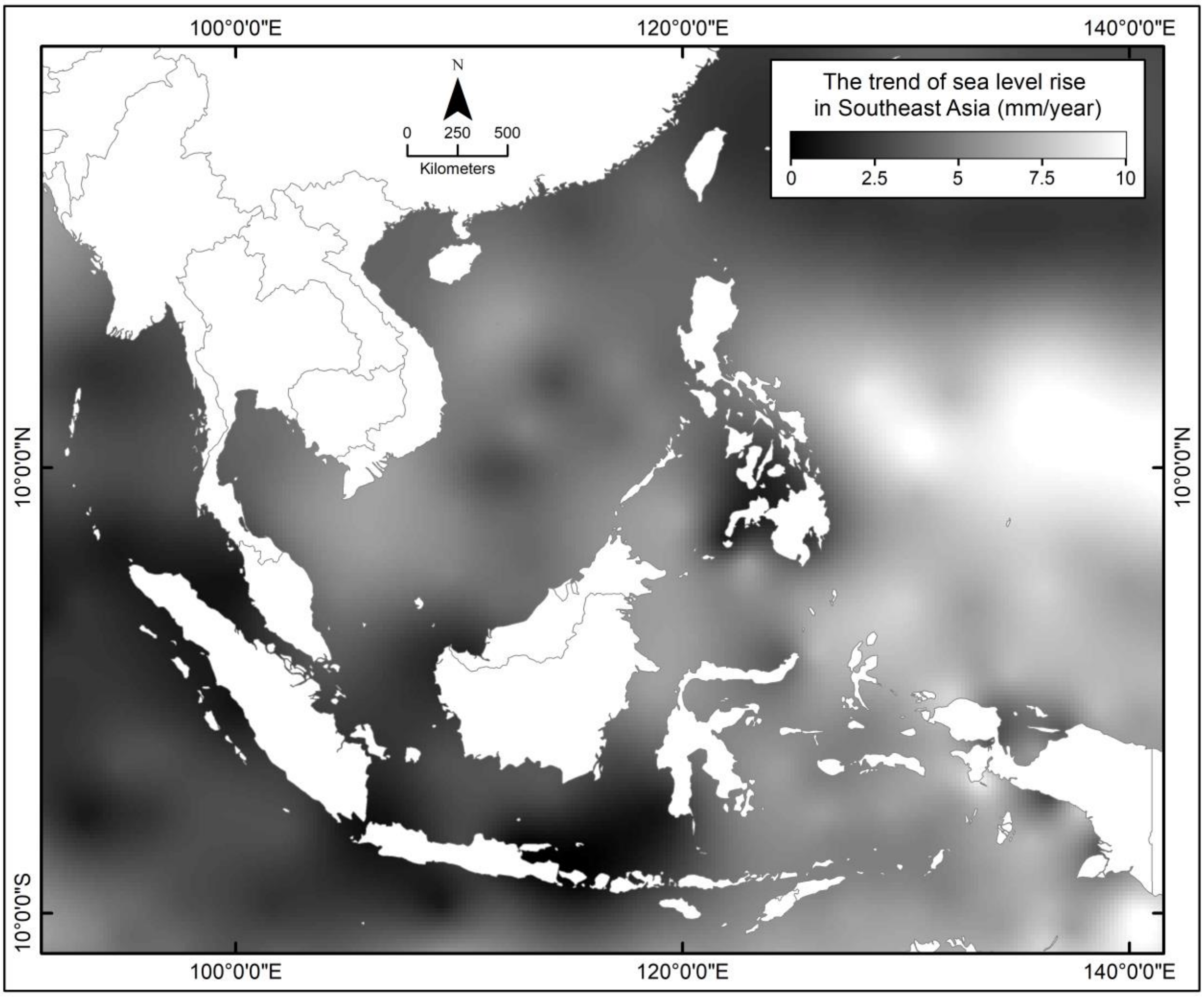


**Figure 3**. The map of SLR trend based on altimetry satellite data from 1992 – 2020.

and contribute to shoreline retreats (Triana & Wahyudi, 2020). By combining the SLR rate and the total city population, we identified 5 (five) cities with greater risk of SLR impact, i.e., Jakarta, Manila, Pattaya, Vung Tau, and Ho Chi Minh cities.

*SLR Projections*

In 2100, GMSL was projected to rise ranged from 0.29 – 0.59 m (RCP2.6) to 0.61 – 1.10 m (RCP8.5) relative to 1986–2005 (IPCC, 2019). We compare the global SLR trend (IPCC, 2019) and the SLR trend of Southeast Asia coastal areas using our regional rates generated from altimetry satellite data in the period of

1992 – 2020. Our analysis predicts that sea levels in Southeast Asia will rise to 0.05 – 0.33 m in 2050 and 0.11 – 0.70 m in 2100. The comparison is shown in Table 2. The lowest rates were lower than the RCP2.6 scenario while the highest rates were ranged in the RCP8.5 scenario. By analyzing narrower areas, the areas that more likely to have impacts due to SLR could be more precisely identified.

**Table 2**. SLR projection in Southeast Asia coastal areas since 2005

| Year | RCP2.6 | RCP8.5 | Satellite data |
|---|---|---|---|
| 2050 | 0.14 – 0.28 m | 0.29 – 0.52 m | 0.05 – 0.33 m |
| 2100 | 0.29 – 0.59 m | 0.61 – 1.10 m | 0.11 – 0.70 m |

## CONCLUSION

The application of satellite altimetry data as complements to the conventional tidal measurement methods is very beneficial in projecting the future SLR. It is time and cost-efficient, especially for broad or remote-spectrum areas. We analyzed the SLR rates of 20 Southeast Asia cities using satellite altimetry data from 1992 to 2020. The SLR rates are varying between 1.12–7.37 mm/year, meanwhile, eight cities were identified as having a higher rate than the rising trend of GMSL (3.6 mm/year). Besides the increase of sea level, many other factors could exacerbate the coastal inundation impacts, especially the anthropogenic forces that are influenced by dense population in coastal cities. The SLR impact will be worse on the densely populated and flood-prone cities such as Jakarta, Manila, Pattaya, Vung Tau, and Ho Chi Minh cities. The satellite altimetry projection predicts that the SLR in Southeast Asia's coastal area will range from 0.05–0.33 m in 2050 and 0.11–0.70 m in 2100. This regional projection is still ranged in the global projection produced by IPCC (2019). This preliminary study is expected to help the decision-makers to establish prevention planning to face the actual disaster events such as floods that aggravated by SLR.

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