Graduate School of Bioresources

Mie University

Ph.D. Thesis

Impact of sea level rise and conservation strategies in coastal areas, Indonesia

(インドネシアの沿岸域における海面上昇の影響と保全戦略)

Jimy Kalther

March, 2022

INDEX

1. General Introduction

Coastal communities, infrastructure, and landscapes are already facing threats of flooding and coastal erosion (Committee on Climate Change 2018). Climate change has increased the risks to the natural environment due to changes in ecosystems and coastal erosion as a result of rising sea levels, seawater temperature, and the potential for higher intensity cyclones, which also raise the possibility for larger storm surges (Esteban et al. 2015). In the future, coastal communities and facilities are likely to become unviable in their present form (Gracia et al. 2018). In the face of this threat, an exceedingly improved coastal management strategy is urgently required. Integrated coastal zone management, taking into account the many interactions between resources and the coastal system, has been identified and highlighted by the IPCC as well as the United Nations Framework Convention on Climate Change as the most important vehicle for adapting to climate change whilst improving the present situation in coastal areas (Bijlsma 1997).

In order to implement adequate coastal management, it is important to establish strategic action plans involving institutional development and coastal governance processes and operational actions that incorporate activities specifically related to marine coastal territories, thereby ensuring socio-environmental preservation (Scherer et al. 2014). At the strategic level, Kay and Alder (1999, p. 327) described the present activities as “the drafting of relevant legislation, the formulation of policy for a wide range of issues, the establishment and resourcing of programs to identify and declare potential protected areas, and the development of other programs.” Additionally, at the operational level, they described practical actions that should be taken, including “communication and education, research, monitoring and site planning.”

It is important to understand the ongoing processes in the complex and sensitive system of nature–human interactions through coastal research (Directorate General Environment of European Union 2010). Coastal research is essential for carrying out the following: marine and coastal spatial planning, where the competitive usage of coastal space is decided; monitoring, which aims to assess the current status of the coastal environment, short-term trends, and their (deterministic) short-term forecasts; assessing hazards/risks/opportunities for further development; and presenting scenarios or useful outlooks through the assessment of the consequences of possible future developments and uncertainties (Von Storch et al. 2015). For example, in the first part of this study, the monitoring of coastal areas and the assessment of current and potential hazards, specifically related to the phenomenon of coastal erosion in Indonesia, were carried out. The information derived from this study should provide important insights into the formulation of coastal protection strategies. As stated by Williams et al. (2018), the choice of management strategy must be based on the knowledge of erosion processes, including their causes and magnitude. These data will facilitate the selection of one or more specific options for protecting coastal areas from coastal erosion, as "defense," "accommodate," "retreat," or a combination of these words (Oppenheimer et al. 2019).

After understanding the present situation concerning coastal hazards, it is also important to identify the priority areas where efforts and funding must be directed. Conservation practitioners frequently face the fact that the cost of maintaining global biodiversity far exceeds available financial and human resources (Mace and Possingham, 2006). In fact, the Government had to relocate some communities where the villages are heavily eroded such as Demak and Pekalongan, in Central Java Province (Asiyah et al., 2015), which was involved substantial funding (Jolliffe, 2016). Therefore, it is important to determine the appropriate sequence of intensive maintenance procedures for maximum benefit. This is an urgent task to protect the coast of Indonesia, which is surrounded by the sea. Spatial prioritization of conservation action has been particularly valuable for conservation planning (Wilson et al., 2009), it has been applied in a lot of studies on conservation (Moilanen et al., 2011; Lehtomäki & Moilanen, 2013; Mendoza-Ponce et al., 2020). Prioritization methods can be divided into two main categories: scoring-based and complementarity-based approaches (Ferrier & Wintle, 2009). In the approach based on scoring, for example, Singh et al. (2021) scored lakes based on four characteristics such as ecological lake characteristics, lake catchment characteristics, threat to the lake ecosystem, conservation and management policy. The complementarity approach (Leathwick et al., 2010; Kullberg et al., 2015; Monroy-Gamboa et al., 2019) chooses areas of complementary richness areas that in combination have the highest species richness.

Marxan Tools

Marxan as complementarity approach have been used for conservation plans (Ban et al., 2013; Pasnin et al., 2016), such as design and establishment of conservation areas (Henriques et al., 2017). Several marine spatial planning tools including visual gradient overlay, categorical classification, Marxan as the target-based site optimization algorithm, and zonation conservation priority ranking were compared, Marxan proven to show better result (Allnutt et al., 2012), some reports have also shown that Marxan as complementarity-based approach is more able than other methods in terms of accuracy (e.g. Allnutt et al. 2012). Marxan was applied to solve problems encountered in marine conservation network planning to protect diverse components of biodiversity (Ball et al., 2009). For instance, Mills et al. (2016) used Marxan to identify appropriate methods for adapting to sea level rise. Henriques et al. (2017) used Marxan to select the best areas for aquaculture management. The model uses systematic planning to select prioritized areas for coastal protection. Therefore, in our second part of the study, we used the Marxan to identify priority areas for coastal protection against sea level rise around Java, Indonesia.

Java Island

Indonesia is an archipelagic country with many small islands that are very vulnerable to sea level rise (Ministry of National Development and Planning 2014). Sea level in Indonesian waters is projected to rise by 80.0 ± 5.0 cm by 2100 (Indonesia Climate Change Sectoral Roadmap - ICCSR Scientific 2010). This rise is expected to influence coastal areas of Indonesia in at least two ways: (a) an increase in the inundation area of coastal zones as the coastlines move, and (b) an areal increase in the zone affected by saltwater intrusions via river mouths and ground water (Ministry of National Development and Planning 2014). Moreover, coastal areas in Indonesia have experienced severe erosion; 29,261 ha of the coastal zone has been eroded over 15 years which mostly located in Java Island (Siry 2018).

Mangroves, which have been widely acknowledge as the natural barrier in coastal areas (Danielsen et al. 2005; Gedan et al. 2011; Máñez et al. 2014; Spalding et al. 2014), in Java Island has steadily declined. Between 2010 and 2015, the annual cover loss was about 41,055 ha (Siry 2018). The main driver behind mangrove loss is conversion to fish or shrimp ponds (Novianty et al. 2012). The coastal area of Java is also economically important, especially for the agriculture and fishery sector. Sixty five percent of the population of Java lived in coastal areas in 2009 (Miladan 2009), generating 8-9% of the total GDP from fishery sector (Statistics of West Java

Province 2018). Coastal flooding has occurred frequently in many large coastal cities, particularly in the northern part of Java Island, such as Karawang (Azhar 2012), Semarang (Marfai 2011), and Demak (Sasmito and Suprayogi 2017), have already experienced severe coastal erosion. Semarang (Ramadhany et al. 2012) and Demak (Sasmito and Suprayogi 2017) also regularly experience coastal floods.

Due to its severe natural condition and significant social-economic importance, deeper understanding on the current magnitude of coastal disaster as well as appropriate coastal protection measures are urgently required. Our first and second part of the study were aimed to answer these needs.

Reference list

Allnutt TF, McClanahan TR, Andréfouët S, Baker M, Lagabrielle E, McClennen C, Rakotomanjaka AJM, Tianarisoa TF, Watson R, Kremen C (2012) Comparison of marine spatial planning methods in Madagascar demonstrates value of alternative approaches. PLoS One. doi: 10.1371/journal.pone.0028969

Azhar RM (2012) Physical vulnerability of the coastal zone on the north coastal of Karawang in West Java [In Indonesian with English summary]. Undergraduate Thesis, Universitas Padjadjaran

Ball IR, Possingham HP, Watts ME (2009) Marxan and relatives: software for spatial conservation prioritization. In: Moilanen A, Wilson KA, Possingham HP (eds) Spatial conservation prioritization. Quantitative methods & computational tools. Oxford University Press, United Kingdom, pp 185–195, https://rune.une.edu.au/web/handle/1959.11/20240. Accessed 15 Oct 2019

Ban NC, Bodtker KM, Nicolson D, Robb CK, Royle K, Short C (2013) Setting the stage for marine spatial planning: Ecological and social data collation and analyses in Canada's Pacific waters. Mar Policy 39:11–20. doi: 10.1016/j.marpol.2012.10.017

Bijlsma L (1997) Climate change and the management of coastal resources. Clim Res 9:47–56. doi: 10.3354/cr009047

Committee on Climate Change (2018) Managing the environment in a changing climate. London [Report] http:://www.theccc.org.uk/publications/

Directorate General Environment of European Union (2010) Participation and integration are key to coastal management. Sci. Environ. Policy Spec. Issue Coast. Manag. 1–8 [Ressearch Summary] http://ec.europa.eu/environment/integration/research/newsalert/

Danielsen F, Sørensen MK, Olwig MF, Selvam V, Parish F, Burgess ND, Hiraishi T, Karunagaran VM, Rasmussen MS, Hansen LB, Quarto A, Suryadiputra N (2005) The Asian Tsunami : a protective role for coastal vegetation. Sceince 310:643. doi: 10.1126/science.1118387

Esteban M, Takagi H, Shibayama T (2015) Handbook of Coastal Disaster Mitigation for Engineers and Planners, 1st edn. Elsevier Inc., Oxford, UK

Gedan KB, Kirwan ML, Wolanski E, Barbier EB, Silliman BR (2011) The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm. Clim Change 106:7–29. doi: 10.1007/s10584-010-0003-7

Gracia A, Oakley JA, Williams AT (2018) Use of ecosystems in coastal erosion management. Ocean Coast Manag 156:277–289. doi: 10.1016/J.OCECOAMAN.2017.07.009

Henriques NS, Monteiro P, Bentes L, Oliveira F, Afonso CML, Gonçalves JMS (2017) Marxan as a zoning tool for development and economic purposed areas - Aquaculture Management Areas (AMAs). Ocean Coast Manag 141:90–97. doi: 10.1016/j.ocecoaman.2017.03.016

Indonesia Climate Change Sectoral Roadmap - ICCSR Scientific (2010) Scientific Basis: analysis and projection of sea level rise and extreme weather event. Ministry of National Development and Planning, Jakarta, https://www.bappenas.go.id/files/2013/5229/9917/analysis-and-projection-of-sea-level-rise-and-extreme-weathe__20110217130224__1.pdf. Accessed 15 Oct 2019

Kay R, Alder J (1999) Coastal Planning and Management, Second Edition, 2nd edn. Taylor & Francis, London

Mace GM, Possingham HP (2006) Prioritizing choices in conservation. In: Macdonald D, Service K (eds) Key Topics in Conservation Biology, 1st edn. Willy-Blackwell, New Jersey, pp 17–34

Marfai MA (2011) The hazards of coastal erosion in Central Java, Indonesia: an overview. Malaysian J Soc Sp 7:1–9

Máñez KS, Krause G, Ring I, Glaser M (2014) The Gordian knot of mangrove conservation: Disentangling the role of scale, services and benefits. Glob Environ Chang 28:120–128. doi: 10.1016/j.gloenvcha.2014.06.008

Miladan N (2009) Study of climate change vulnerability of the Coastal Area of Semarang [In Indonesian]. Master Thesis, Dipenogoro University https://core.ac.uk/download/pdf/11723071.pdf. Accessed 15 Oct 2019

Mills M, Leon JX, Saunders MI, Bell J, Liu Y, O'Mara J, Lovelock CE, Mumby PJ, Phinn S, Possingham HP, Tulloch VJD, Mutafoglu K, Morrison T, Callaghan DP, Baldock T, Klein CJ, Hoegh-Guldberg O (2016) Reconciling development and conservation under coastal squeeze from rising sea level. Conserv Lett 9:361–368. doi: 10.1111/conl.12213

Ministry of National Development and Planning (2014) National Action Plan on Climate Change Adaptation [In Indonesian]. Ministry of National Development and Planning, Jakarta, pp. 204, http://sekretariat-ranapi.org/storage/app/media/RAN-API.pdf. Accessed 15 Oct 2019

Novianty R, Sastrawibawa S, Prihadi DJ (2012) Identification of damages and rehabilitation efforts mangrove ecosystem in North Coast in the Subang Dustrict [In Indonesian with English summary]. J Fish Mar Sci 3:41-47. doi: 10.4135/9781412950589.n774

Oppenheimer M, Glavovic BC, Hinkel J, Wal R van de, Magnan AK, Abd-Elgawad A, Cai R, Cifuentes-Jara M, DeConto RM, Ghosh T, Hay J, Isla F, Marzeion B, Meyssignac B, Sebesvari Z (2019) 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing

Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press., pp 321–446

Pasnin O, Attwood C, Klaus R (2016) Marine systematic conservation planning for Rodrigues Island, western Indian Ocean. Ocean Coast Manag 130:213–220. doi: 10.1016/j.ocecoaman.2016.06.014

Ramadhany AS, Agus DS A, Subardjo P (2012) Coastal flood prone area in Semarang [In Indonesian with English summary]. J Mar Res 1:174-180, doi: 10.14710/jmr.v1i2.2035

Sasmito B, Suprayogi A (2017) Coastal ecosystem vulnerability assessment in Demak district based on coastline change using remote sensing technology and geographic information system. Teknik 38:13-20 [In Indonesian with English summary]. doi: 10.14710/teknik.v38n1.12181

Scherer M, Andrade J, Felix A (2014) Prioritizing actions for coastal management : A methodological proposal. doi: 10.1016/j.ocecoaman.2014.01.012

Siry HY (2018) Policy and disaster mitigation in small islands [Presentation]. In: Diskusi Pojok Iklim, Tanggap Darurat Bencana Iklim. Ministry of Environment and Forestry, Jakarta [In Indonesian], http://simlit.puspijak.org/files/other/Bahan_Direktur_P4K_Ditjen_PRL_@_Pojok_Iklim.pdf. Accessed 15 Oct 2019

Spalding MD, McIvor A, Tonneijck FH, Tol S, van Eijk P (2014) Mangroves for coastal defence: guidelines for coastal managers and policy makers. Wageningen, The Netherlands, Wetlands International and The Nature Conservancy, http://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf. Accessed 15 Oct 2019

Statistics of West Java Province (2018) West Java in Figures 2018. Statistics of West Java Province, Bandung [In Indonesian and English], https://jabar.bps.go.id/publication/2018/08/16/d8b96de222796402938666e4/provinsi-jawa-barat-dalam-angka-2018.html. Accessed 15 Oct 2019

Von Storch H, Emeis K, Meinke I, Kannen A, Matthias V, Ratter BMW, Stanev E, Weisse R, Wirtz K (2015) Making coastal research useful - Cases from practice. Oceanologia 57:3–16. doi: 10.1016/j.oceano.2014.09.001

Williams AT, Rangel-Buitrago N, Pranzini E, Anfuso G (2018) The management of coastal erosion. Ocean Coast Manag 156:4–20. doi: 10.1016/j.ocecoaman.2017.03.022

2. Coastline changes and their effects on land use and cover in Subang, Indonesia

Abstract

Indonesia is at high risk of coastal erosion. Therefore, is important to understand the current status over a large area in order to devise protection strategies. This study measured the coastline changes and examined the land use and cover affected by coastal changes in Subang, Indonesia, using Landsat images from 1990 and 2018. The modified normalized difference water index (MNDWI) was used to separate the water and non-water features of the images, and land use and cover were classified using object-based image analysis based on the red, green, and blue bands and normalized difference vegetation index (NDVI). The results revealed considerable coastal erosion in Legonkulon. In the most extreme case, the coastline had moved 2,361.46 m inland, and the total area lost to erosion was 1,012.25 ha. This area was mostly covered by fishponds (983.34 ha) in 1990. Given that the fishery sector is the main livelihood of communities in the study area, the disappearance of fishponds might have affected their income and worsened their poverty. We found marked coastal accretion in Blanakan. In the most extreme case, the coastline had moved 1,695.61 m seaward from 1990 to 2018, adding a total area of 1,856.62 ha. The new areas were used as fishponds (1,738.95 ha) in 2018. Although the accretion exceeded the erosion, the distributions differed regionally. Therefore, a regional protection strategy is necessary.

***Keyword*:** Accretion, Erosion, Fishpond, MNDWI, Satellite image

Introduction

Coastal areas have always been preferred places for people to live and work (Jonah *et al*. 2016). According to the Food and Agriculture Organization (FAO; 2017), 2.4 billion people, roughly 40% of the world's population, live within 100 km of a coast, and around 600 million occupy low-elevation coastal zones (≤10 m.a.s.l.). Coastal erosion is a threat to coastal areas worldwide (Xue *et al*. 2009; Jonah *et al*. 2016), especially those with sandy substrates (Wong 2003). Wong (2003) reported that 70% of the world's sandy beaches experienced coastal erosion, and only 10–20% remained stable or experienced no change. Although not all coastal erosion is influenced by sea level rise, the predicted sea level rise due to climate change will undoubtedly initiate coastal erosion in currently stable coastal areas and exacerbate it in areas currently experiencing erosion (Bird 1996). Furthermore, coastal erosion will likely have negative effects on people living near the coast.

Indonesia is at high risk of coastal erosion, as two-thirds of Indonesia is covered by ocean, and people tend to live in coastal areas. Most populated cities, such as Jakarta, Surabaya, and Medan, are located in coastal areas, and 65% of the population of Java lived in coastal areas in 2009 (Miladan 2009). Subang is a regency of West Java, Indonesia, and about 300,000 of its 1.5 million inhabitants reside in coastal areas (Subang Statistics Agency 2018). The high population also indicates that many important economic activities are concentrated in these areas. Subang is heavily dependent on agriculture, i.e., both crop production and fisheries, which are considered part of the agricultural sector in Indonesia. About 37% of the GDP of Subang came from the agricultural sector in 2010 (Subang Statistics Agency 2010). Although this dropped to 28% in

2017, agriculture is still the greatest contributor to the GDP (Subang Statistics Agency 2017). Subang produced 24,330 tons of marine fishery products in 2017 (Subang Statistics Agency 2018).

Several studies have focused on coastal environments in Subang. Vina (2011) investigated the physical vulnerability of coastal Subang to waves, currents, tides, elevation, and soil type. In a spatiotemporal analysis from 1996 to 2010 using remote sensing technology, Taofiqurohman and Ismail (2012) showed that part of coastal Subang had undergone drastic changes through erosion and accretion, whereas Munibah *et al*. (2010) emphasized the accretion of land. Novianty *et al*. (2012) noted that the mangrove ecosystem in Subang was damaged and might no longer provide its optimum services as a natural barrier against disasters. Sakuntaladewi and Sylviani (2014) assessed the vulnerability and adaptation of the coastal community of Subang to various disasters, especially climate change. Although coastal erosion has had a great influence on coastal areas, these authors did not mention the effects on land use and cover by coastal erosion. To assess the extent of erosion damage related to local livelihoods, it is important to investigate this.

As the cost of coastal conservation might be very high (Zhu *et al*. 2015), it is necessary to determine which areas require more urgent protection (Mills *et al*. 2016). It is very important to understand the current conditions, including factors related to livelihood, over a large area in order to devise protection strategies. Therefore, this study measured coastline changes in Subang and examined the effects on land use and cover by the coastal changes using satellite images in 1990 and 2018.

Materials and Methods

Study area

The study area is located between 107°34'–107°56'E and 6°09'–6°19'S in the northern part of Subang Regency on the northern coast of West Java Province, Indonesia (Figure 1). It is bordered by Karawang Regency to the west, Purwakarta Regency to the east, and the Java Sea to the north. It covers about 707.18 km^2, with elevations ranging from 0 to 46 m.a.s.l. The areas with elevations below 10 m.a.s.l. that are hydrologically connected to the sea are categorized as low-elevation coastal zones (McGranahan *et al*. 2007; Lichter *et al*. 2011). The coastline in our study area has several river mouths and deltas (Handiani *et al*. 2017). Shallow beaches with sandy and muddy substrate dominate. The slopes range from 0.06% to 0.40% and are characterized by low wave heights of 0.3–1.7 m (Environmental Agency of West Java 2008). The wave height is around 1.7 m upon reaching the shore (Taofiqurohman 2014).

Subang Regency is located in the tropical zone, with an annual rainfall of around 3049 mm. The precipitation ranges from 60 mm in August to 468 mm in January (Climate-data.org 2019). In the coastal area, the precipitation ranges from 150 to 300 mm during the rainy season, which is influenced by the monsoon (Sipayung 2009). The annual variation in temperature is only 1.3°C, with an average temperature of 26.7°C. The warmest and coldest months are October (27.4°C) and January (26.1°C), respectively (Climate-data.org 2019).

Analysis procedure

Figure 2 shows the analysis procedure followed in this study. The coastline extraction method of Liu *et al*. (2017) was used. Landsat satellite images were used to produce the modified normalized difference water index (MNDWI) and were converted into binary images using Otsu segmentation (Otsu 1979) to extract the coastline. After the land use and cover were detected using the red, green, and blue bands and the normalized difference vegetation index (NDVI) was calculated from Landsat satellite images, the land use and cover types where the coastline changed were investigated.

Satellite images

Time-series satellite images with path/row 122/064 were downloaded from the United States Geological Survey (USGS) website (http://glovis.usgs.gov/) and used to detect the coastline and classify land use and cover. Landsat-5 TM images on 9 July 1990 and Landsat-8 OLI on 6 July 2018 were acquired. They had a 30-m ground spatial resolution. We analyzed five bands: red (Landsat-5 TM, 630–690 nm; Landsat-8 OLI, 630–680 nm), green (Landsat-5 TM, 530–600 nm; Landsat-8 OLI, 525–600 nm), blue (Landsat-5 TM, 450–520 nm; Landsat-8 OLI, 450–515 nm), near infrared (NIR; Landsat-5 TM, 760–900 nm; Landsat-8 OLI, 845–885 nm), and middle infrared (Landsat-5 TM, 1550–1750 nm; Landsat-8 OLI, 1550–1650 nm). Image pre-processing, which converted numbers into the top-of-atmosphere reflectance, was performed using ERDAS IMAGINE 2016 (Hexagon Geospatial).

Detecting the coastline

The NDWI, which is a non-linear conversion of the green and NIR bands of multispectral images, is one of the most widely used water indices for coastline extraction (McFeeters 1996). This study used the MNDWI, which employs the middle infrared instead of the NIR. This enhances open-water features while efficiently suppressing and even removing built-up land noise, as well as vegetation and soil noise (Xu 2006). The MNDWI was defined as

$$MNDWI = \frac{\rho\text{Green} - \rho\text{MIR}}{\rho\text{Green} + \rho\text{MIR}},$$

where ρGreen and ρMIR are the reflectance values of the green and middle infrared bands of multispectral images, respectively. The index can range from −1 to 1. Water surfaces tend to have positive values, and non-water surfaces have negative values.

Once the MNDWI image was produced, a threshold value was necessary to divide the image into two classes: land and water. However, the MNDWI threshold value is not constant, but depends on the land cover components (Ji *et al*. 2009). The Otsu (1979) method automatically selects an optimal threshold from a gray image, and the threshold maximizes the inter-class discrepancy. Li *et al*. (2013) and Du *et al*. (2014) demonstrated that the Otsu method can be used to map water bodies from Landsat imagery. Where t represents the threshold value, ranging from a to b ($-1 \le a \le b \le 1$), the optimal threshold value t^* can be obtained by the following algorithm:

$$\begin{cases} \sigma^2 = P_{nw} \cdot (M_{nw} - M)^2 + P_w \cdot (M_w - M)^2 \\ M = P_{nw} \cdot M_{nw} + P_w \cdot M_w \\ P_{nw} + P_w = 1 \\ t^* = \operatorname{Arg} \underset{a \le t \le b}{\operatorname{Max}} \{P_{nw} \cdot (M_{nw} - M)^2 + P_w \cdot (M_w - M)^2\} \end{cases},$$

where σ is the inter-class variance of non-water and water pixels, P_{nw} and P_w are the probabilities of a pixel's being non-water or water, respectively, M_{nw} and M_w are the respective mean values of all non-water an water pixels, and M is the mean value of the entire image. Pixels with values equal to or higher than the optimal threshold value were classified as water and scored 1. The remaining pixels were classified as non-water and scored 0. The boundary between water and non-water was the coastline.

To assess the changes in coastline between 1990 and 2018, Digital Shoreline Analysis Software (DSAS) was used. DSAS is an extension that enhances the normal functionality of ESRI ArcGIS software (Thieler 2005). The DSAS approach calculates shoreline rates of change based on the measured differences between the shoreline positions associated with specific time periods (Oyedotun 2014).

Classifying land use and cover

The NDVI was calculated using the red and NIR bands. The NDVI is a numerical indicator that uses these bands of the electromagnetic spectrum to analyze remote sensing measurements of vegetation to assess whether the target being observed contains live green vegetation (Rouse *et al*. 1973). It is often directly related to other ground parameters such as the percent of ground cover, photosynthetic activity of plants, surface water, leaf area index, and amount of biomass. NDVI was defined as

$$NDVI = \frac{\rho\mathrm{Red} - \rho\mathrm{NIR}}{\rho\mathrm{Red} + \rho\mathrm{NIR}},$$

where ρRed and ρNIR are the reflectance values of the red and NIR bands of multispectral images, respectively. The index ranges from −1 to 1. Vegetation surfaces tend to have positive values, and non-vegetation surfaces negative values.

Supervised object-based classification, which is a maximum-likelihood classifier, was applied for a combined image using ArcGIS 10.6 (ESRI). The land use and cover were grouped into five categories: fishponds, rice fields, built-up areas, vegetation, and water. In our dataset, 10 polygons for each category were used for classification training, and 50 points for each category were used to assess classification accuracy. The training and testing data were annotated manually by visually interpreting photographs obtained from Google Earth Pro and Google Street View. A confusion matrix was constructed by comparing the test data with predicted values to quantify the overall accuracy and the kappa coefficient (Story and Congalton 1986; Congalton 1991).

Results

Figure 3 shows the coastline changes. Both accretion and erosion occurred in the study area. The greatest accretion occurred in Blanakan Sub-district, where the coastline moved 1,695.61 m seaward. The total accretion area from 1990 to 2018 was 1,856.62 ha, with the largest area in Blanakan Sub-district. The mouth of the Blanakan River is located in this area and was likely the main source of the sedimentation causing accretion. The greatest and the least erosion occurred in Legonkulon Sub-district, where the coastline moved 2,361.46 m and 8.73 m inland, respectively. The total area eroded from 1990 to 2018 was 1,012.25 ha, and Legonkulon Sub-district had the largest erosion area. Based on the transect data, the average erosion rate in Subang is 21.4 m/year.

Figures 4 and 5 show the distribution of the land use and cover detected using Landsat images, and Tables 1 and 2 shows the accuracy matrices for the land use and cover classifications, respectively. The overall accuracy and kappa were 87.2% and 0.84 for the 1990 images and 80.8% and 0.78 for the 2018 images, respectively. For the 1990 images, most misclassification occurred between fishponds and rice fields. The images might have been made during the season when rice fields are filled with water for irrigation. Most misclassification in the 2018 images occurred between water and fishponds. The land use and cover in 1990 and 2018 were dominated by rice field and fishpond which covered almost 90% of the area, 59.7% (in 1990) and 59.2% (in 2018) for rice field and 30.7% (in 1990) and 30.6% (in 2018) for fishpond. There is no noticeable changes in the distribution of land use and cover between both years, except the increase in vegetation cover from 1.2% in 1990 to 3% in 2018. However, the increase mainly occurred in the inland area. Figure 6 shows the land use and cover in the accretion and erosion areas. The total eroded area was 1,012.25 ha, of which 97.14% (983.34 ha) was fishponds, 1.68% (17.06 ha) was rice fields, and 1.17% (11.85 ha) was water areas. The total accreted area was 1,856.62 ha, of which 93.66% (1,738.95 ha) was fishponds, 0.15% (2.87 ha) was rice fields, and 6.18% (114.80 ha) was vegetation areas.

Discussion

The coastline and land use and cover change between 1990 and 2018 in Subang were detected from Landsat images. Much coastal erosion occurred in Legonkulon, and eroded areas were mostly covered by fishponds in 1990. There was marked coastal accretion in Blanakan, and the accreted areas were used as fishponds in 2018.

Remote sensing can monitor large areas, making it possible to prioritize protection strategies for erosion. Remote sensing and GIS techniques were used to monitor coastal areas as early as the 1980s (Loubersac and Populus 1986). The extraction methods and data used have since evolved to improve accuracy. High-resolution images are ideal for assessing the coastline. Nevertheless, Liu *et al*. (2017) showed that low-resolution images had reasonable accuracy and that the coastline position and its changes over time could be detected using Landsat images. We also decided to use Landsat images (30 m resolution) due to its long time coverage that makes it ideal tool to find out the decadal evolution of the area (Lira and Taborda 2014) especially since other sources are not available for this area. In this study, we identified the land use and cover types that were affected by the coastline changes due to both erosion and accretion and assessed the magnitude of these changes. Taofiqurohman and Ismail (2012) and Handiani *et al*. (2017) have already presented evidence of coastline changes in Subang. However, they did not survey large areas or show the relationships with the land use and cover.

We found marked coastal accretion in Blanakan. In the most extreme case, the coastline moved 1,695.61 m seaward (60.55 m/year) from 1990 to 2018, adding a total area of 1,856.62 ha. Those areas were used as fishponds in 2018. Although accretion exceeded erosion overall, the distribution differed regionally. Therefore, regional protection strategies are necessary. Taofiqurohman and Ismail (2012) gave a detailed explanation of the potential cause of heavy sedimentation in this area, attributing it to sediment supplied by run-off from the mouth of the Ciasem River. Similarly, Munibah *et al*. (2010) reported that the Cipunagara River supplied more sediment to the coastal areas of Subang than the ocean did. The accretion areas had been occupied local communities and were predominantly covered by fishponds (Munibah *et al*. 2010). We found some vegetation recovery in the accretion areas. The appearance of mangrove in this area might be due to mangrove planting or to the application of silvofishery or *tambak tumpangsari*, as the local people call it (Kiswanto 2015). This is a unique aquaculture method that allows both aquatic animals and mangrove trees to be reared in the same pond (Takashima 2000).

We found marked coastal erosion in Legonkulon. In the most extreme case, the coastline moved 2,361.46 m inland (84.33 m/year); the total area lost to erosion was 1,012.25 ha. Other studies reported erosion in other coastal areas of Indonesia at highest rates of 8.44 m/year in West Pasaman Regency of Sumatra (Dhiauddin and Husrin 2016) and 6.3 m/year in Yogyakarta (Mutaqin 2017). Our rates were much higher. Our study area was mostly covered by fishponds in 1990. Because the fishery sector is a livelihood for residents of the study area (Subang Statistics Agency 2018), the disappearance of fishponds might have affected their income and worsened their poverty (Pawitro *et al*. 2015). The cause of erosion in Subang was a decline in the mangrove ecosystem, in terms of both coverage and density (Kusumaningtyas and Chofyan 2012; Taofiqurohman and Ismail 2012). A reduced mangrove ecosystem means less protection for the coastal area from waves, tides, currents, and winds. The mangrove ecosystem coverage in Subang has undergone a severe decline (reported in Mongabay, an environmental news website, by Iqbal

2018), mainly due to conversion into unsustainable fish and shrimp ponds; this process started in the 1970s and led to massive conversion in the 1990s (Sakuntaladewi and Sylviani 2014). Around 1,000 ha of mangrove forest in Subang have been heavily damaged by development. A local newspaper reported several mangrove planting activities by multiple actors, such as non-governmental organizations, universities, companies' corporate social responsibility initiatives, and other community efforts (Kotasubang.com 2014; Adji 2017). However, most were unsuccessful due to a lack of proper maintenance and monitoring (reported on Mongabay by Iqbal 2017). When the mangrove ecosystem is used to defend against coastal erosion, a long-term planting strategy is needed.

Conclusions

The coastline and land use and cover change between 1990 and 2018 in Subang were detected using Landsat images. Much coastal erosion was found in Legonkulon, and the eroded areas were mostly covered by fishponds in 1990. Since the fishery sector is an important local livelihood, the disappearance of fishponds might have affected people's income and worsened their poverty. We found marked coastal accretion in Blanakan, and the accreted areas were used as fishponds in 2018. Although the accretion exceeded the erosion overall, the distribution differed regionally. It was conceded that the cause of erosion in Subang was a decline in the mangrove ecosystem, in terms of both coverage and density mainly due to conversion into unsustainable fish and shrimp ponds. Although several mangrove planting activities have carried out, most were unsuccessful due to a lack of proper maintenance and monitoring. A long-term planting strategy is needed. The data on the current condition of coastal areas, including the magnitude of coastal erosion, and on land use and cover produced by this study should provide insights for the formulation of coastal protection strategies. In our next study, we will consider which areas require more urgent protection from disasters based on the results of this study.

Acknowledgment

We would like to express our great appreciation to Prof. Ishikawa, who provided helpful comments and suggestions. Finally, we would like to acknowledge the Ministry of Education, Culture, Sports, Science and Technology (MEXT) for a scholarship that made it possible to complete this study.

References

Adji Y (2017) 3.000 Mangroves were planted in the coast of Subang. . https://www.pikiran-rakyat.com/jawa-barat/2017/09/06/3000-mangrove-ditanam-di-pesisir-subang-408870. Accessed 28 Dec 2018

Bird ECP (1996) Coastal erosion and rising sea-level. Sea-Level Rise Coast Subsid 87–103. doi: 10.1007/978-94-015-8719-8_5

Climate-data.org (2019) Climate of Subang. In: Clim. Subang. https://en.climate-data.org/asia/indonesia/west-java/subang-764289/. Accessed 28 Dec 2018

Congalton RG (1991) A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens Environ 37:35–46

Dhiauddin R, Husrin S (2016) Shoreline changes analysis of West Pasaman Regency, West Sumatera. Jurnal Segara 12(2):91-98

Du Z, Li W, Zhou D, Tian L, Ling F, Wang H, Gui Y, Sun B (2014) Analysis of Landsat-8 OLI imagery for land surface water mapping. Remote Sens Lett 5:672–681. doi: 10.1080/2150704X.2014.960606

Environmental Agency of West Java (2008) Environmental status of West Java 2008. Bandung [In Indonesian with English summary]

FAO (2017) Facsheet: People and Oceans. New York https://www.un.org/sustainabledevelopment/wp.../05/Ocean-fact-sheet-package.pdf

Handiani DN, Darmawan S, Hernawati R, Suryahadi MF, Aditya YD (2017) Identification of coastline and coastal ecosystem change in Subang. Online J Natl Technol Inst 2017:61–71 [In Indonesian with English summary]

Iqbal D (2017) Beach belt on the north coast of West Java, only memories. How come? http://www.mongabay.co.id/2017/08/08/sabuk-pantai-di-pesisir-utara-jawa-barat-tinggal-kenangan-kok-bisa/. Accessed 28 Dec 2018

Iqbal D (2018) Here is the condition of mangrove in north coast. http://www.mongabay.co.id/2017/01/03/begini-kondisi-mangrove-pantura-jabar/. Accessed 27 Dec 2018

Ji L, Zhang L, Wylie B (2009) Analysis of dynamic thresholds for the Normalized Difference Water Index. Photogramm Eng Remote Sens 75:1307–1317. doi: 10.14358/PERS.75.11.1307

Jonah FE, Boateng I, Osman A, Shimba MJ, Mensah EA, Adu-Boahen K, Chuku EO, Effah E (2016) Shoreline change analysis using end point rate and net shoreline movement statistics: An application to Elmina, Cape Coast and Moree section of Ghana’s coast. Reg Stud Mar Sci 7:19–31. doi: 10.1016/j.rsma.2016.05.003

Kiswanto H (2015) The environmental caracteristics of intercropping pond in Subang, West Java as a Reference for The Mud Crabs Pond Aquaculture Development. Bogor Agircultural University [Academic Thesis] Pp:1-20 [In Indonesian with English summary]

Kotasubang.com (2014) Cegah Abrasi , Preventing Abrasion: Facebook's Users in Subang planted mangrove at Cirewang Beach. https://www.kotasubang.com/3816/cegah-abrasi-facebooker-subang-tanam-mangrove-di-pantai-wisata-cirewang. Accessed 28 Dec 2018

Kusumaningtyas R, Chofyan I (2012) Forest management in solving forest land conversion in Subang. J City Area Plan 13:1–11 [In Indonesian]

Li W, Du Z, Ling F, Zhou D, Wang H, Gui Y, Sun B, Zhang X (2013) A comparison of land surface water mapping using the normalized difference water index from TM, ETM+ and ALI. Remote Sens 5:5530–5549. doi: 10.3390/rs5115530

Lichter M, Vafeidis AT., Nicholls RJ., Kaiser G (2011) Exploring data-related uncertainties in analyses of land area and population in the " Low-Elevation Coastal Zone" (LECZ). J Coast Res 27:757–768

Lira C, Taborda R (2014) Advances in Applied Remote Sensing to Coastal Environments Using Free Satellite Imagery. In: Remote Sensing and Modeling: Advances in Coastal and Marine Resources. http://link.springer.com/10.1007/978-3-319-06326-3, pp 77–102

Liu Y, Wang X, Ling F, Xu S, Wang C (2017) Analysis of coastline extraction from Landsat-8 OLI imagery. Water (Switzerland) 9:1–26. doi: 10.3390/w9110816

Loubersac L, Populus J (1986) The applications of high resolution satellite data for coastal management and planning in a pacific coral island. Geocarto Int 1:17–31. doi: 10.1080/10106048609354036

McFeeters SK (1996) The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. Int J Remote Sens 17:1425–1432. doi: 10.1080/01431169608948714

McGranahan G, Balk D, Anderson B (2007) The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones. Environ Urban 19:17–37. doi: 10.1177/0956247807076960

Miladan N (2009) Study of climate change vulnerability of the coastal area of Semarang. Dipenogoro University [Academic Thesis] 15 PP [In Indonesian]

Mills M, Leon JX, Saunders MI, Bell J, Liu Y, O'Mara J, Lovelock CE, Mumby PJ, Phinn S, Possingham HP, Tulloch VJD, Mutafoglu K, Morrison T, Callaghan DP, Baldock T, Klein CJ, Hoegh-Guldberg O (2016) Reconciling development and conservation under coastal squeeze from Rising Sea Level. Conserv Lett 9:361–368. doi: 10.1111/conl.12213

Munibah K, Iswati A, Tjahjono B (2010) Coastline changes and regulation of new land management at Cipunagara Delta, Subang, West Java. Globe 12:151–159 [In Indonesian with English summary]

Mutaqin BW (2017). Shoreline changes analysis in Kuwaru coastal area, Yogyakarta, Indonesia: an application of the Digital Shoreline Analysis System (DSAS). International Journal of Sustainable Development and Planning 12(7):1203-1214

Novianty R, Sastrawibawa S, Prihadi DJ (2012) Identification of damages and rehabilitation efforts mangrove ecosystem in North Coast in the Subang Dustrict. J Fish Mar Sci 3:41–47. doi: 10.4135/9781412950589.n774 [In Indonesian with English summary]

Otsu N (1979) A tlreshold selection method from gray-level histograms. IEEE Trans Syst Man Cybern 9:62–66

Oyedotun TDT (2014) Shoreline geometry: DSAS as a tool for historical trend analysis. Geomorphol Tech (online Ed) 2:1–12

Pawitro U, Indahingtyas W, Subekti B (2015) Fishermen residence in Blanakan Subang and empowerment of poor society in their residential area. SNST Proceeding 6:5-10 [In Indonesian]

Rouse JW, Hass RH, Schell JA, Deering DW (1973) Monitoring vegetation systems in the great plains with ERTS. Third Earth Resour Technol Satell Symp 1:309–317. doi: citeulike-article-id:12009708

Sakuntaladewi N, Sylviani (2014) Vulnerability and adaptation of community at the coastal area to climate change. J Soc Study For Econ 11:281–293 [In Indonesian with English summary]

Sipayung SB (2009) Rainfall analysis based on climate prediction zone in Subang and Tasikmalaya 1980-2005. J Aerosp Sci Technol 2:67–74 [In Indonesian with English summary]

Story M, Congalton RG (1986) Accuracy assessment: a user's perspective. Photogrammetric Engineering and remote sensing 52(3):397-399

Subang Statistics Agency (2010) Subang in Figure 2010. Subang [In Indonesian with English summary] https://subangkab.bps.go.id/publication/2010/12/09/1f95dbf714d659ea30a873cc/kabupaten-subang-dalam-angka-2010.html. Accessed 28 Dec 2018

Subang Statistics Agency (2017) Gross regional domestic product of Subang Regency by industry 2013-2017. Subang [In Indonesian with English summary] https://subangkab.bps.go.id/publication/2018/08/10/3d0b741329f3456676063e26/produk-domestik-regional-bruto-kabupaten-subang-menurut-lapangan-usaha-2013-2017.html. Accessed 28 Dec 2018

Subang Statistics Agency (2018) Subang in Figure 2018. Subang [In Indonesian with English summary] https://subangkab.bps.go.id/publication/2018/08/16/fbf586fd952afd9aa9db7052/kabupaten-subang-dalam-angka-2018.html

Takashima F (2000) Silvofishery : an aquaculture system harmonized with the environment Silvofishery : an aquaculture system harmonized with the environment. In: Primavera JH, Garcia LMB, Castaños MT, Surtida MB (eds) Proceedings of the Workshop on Mangrove-Friendly Aquaculture organized by the SEAFDEC Aquaculture Department, January 11-15, 1999, Iloilo City, Philippines. Southeast Asian Fisheries Development Center, Aquaculture Department, Tigbauan, Iloilo, Philippines, pp 13–19

Taofiqurohman A (2014) The modelling of wave height fluctuation effected by mangrove forest in Mayangan Village, Subang District. J Akuatika V:1–7 [In Indonesian with English summary]

Taofiqurohman A, Ismail MFA (2012) Spatial analysis of shoreline changes in the coastal of Subang District, West Java. J Trop Mar Sci Technol 4:81–87. doi: 10.1007/s13398-014-0173-7.2 [In Indonesian with English summary]

Thieler ER (2005) User guide & tutorial for the digital shoreline analysis system. USGS, Woods Hole, MA https://cmgds.marine.usgs.gov/publications/DSAS/of2008-1278/

Vina A (2011) Physical vulnerability zonation of Subang Coast West Java. Padjadjaran University [Academic Thesis] 80 PP [In Indonesian with English summary]

Wong PP (2003) Where have all the beaches gone? Coastal erosion in the tropics. Singap J Trop Geogr 24:111–132. doi: doi:10.1111/1467-9493.00146

Xu H (2006) Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int J Remote Sens 27:3025–3033. doi: 10.1080/01431160600589179

Xue Z, Feng A, Yin P, Xia D (2009) Coastal erosion induced by human activities: A Northwest Bohai Sea Case Study. J Coast Res 253:723–733. doi: 10.2112/07-0959.1

Zhu M, Xi X, Hoctor TS, Volk M (2015) Integrating conservation costs into sea level rise adaptive conservation prioritization. Glob Ecol Conserv 4:48–62. doi: 10.1016/j.gecco.2015.05.007

Table and Figure Captions

Tables

Table 1. Accuracy of the land cover classification using the 1990 images.

Table 2. Accuracy of the land cover classification using the 2018 images.

Figures

Fig. 1. Study site in Subang Regency, Indonesia. The smaller map shows the western part of Java; the grey area is Subang Regency. The study site was the coastal area of Subang Regency, indicated by the hatch marks in the larger map. The black dots indicate the Blanakan and Legonkulon Sub-districts.

Fig. 2. Analysis procedure used to detect coastline and land use and cover changes. Landsat satellite images were used to produce the modified normalized difference water index (MNDWI) and were converted into binary images using Otsu segmentation (Otsu 1979) to extract the coastline. The land use and cover were investigated using the red, green, and blue band of the Landsat images, as well as the normalized difference vegetation index (NDVI) of the images.

Fig. 3. The results of coastline extraction from 1990 and 2018 images. The black line shows the coastline of Subang in 1990, and the dashed line shows the coastline in 2018. The hatched

area is the land accretion in the coastal area of Subang from 1990 to 2018, and the grey area is the eroded land from 1990 to 2018.

Fig. 4. Land use and cover in 1990 detected from Landsat-5 TM images applying object-based image classification.

Fig. 5. Land use and cover in 2018 detected from Landsat-8 OLI images applying object-based image classification.

Fig. 6. Land use and cover affected by accretion and erosion from 1990 to 2018.

Table 1. Accuracy of the land cover classification using the 1990 images.

		Interpretation on Google Earth					Total	User accuracy (%)
		Fishpond	Ricefield	Built up	Vegetation	Water		
Testing data	Fishpond	48	0	0	0	5	53	90.5
	Ricefield	2	46	5	16	0	69	66.6
	Builtup	0	4	45	0	0	49	91.8
	Vegetation	0	0	0	34	0	34	100.0
	Water	0	0	0	0	45	45	100.0
	Total	50	50	50	50	50	250	
	Producer accuracy (%)	96.0	92.0	90.0	68.0	90.0		

Overall accuracy (%) 87.2 % Kappa 0.84

Table 2. Accuracy of the land cover classification using the 2018 images.

		Interpretation on Google Earth					Total	User accuracy (%)
		Fishpond	Ricefield	Built up	Vegetation	Water		
Testing data	Fishpond	50	4	0	5	30	89	56.1
	Ricefield	0	46	3	0	1	50	92.0
	Builtup	0	0	42	0	0	42	100.0
	Vegetation	0	0	0	45	0	45	100.0
	Water	0	0	0	0	19	19	100.0
	Total	50	50	45	50	50	245	
	Producer accuracy (%)	100.0	92.0	93.3	90.0	38.0		

Overall accuracy (%) 80.8 % Kappa 0.78

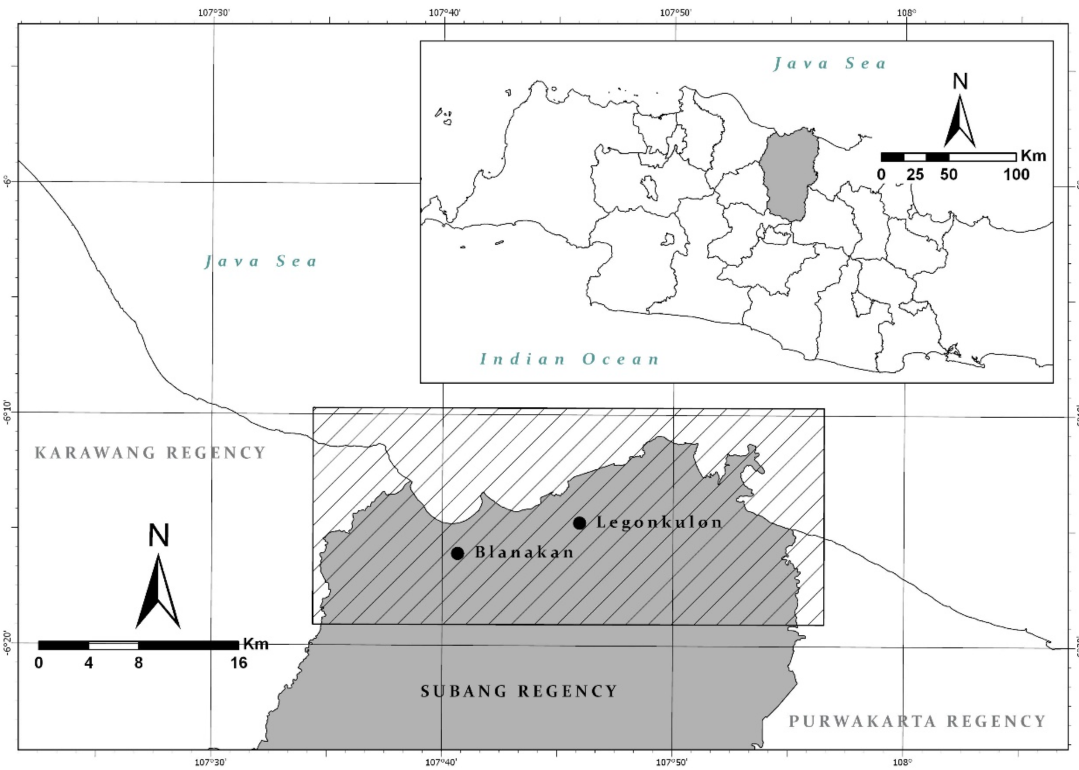

Fig. 1. Study site in Subang Regency, Indonesia. The smaller map shows the western part of Java; the grey area is Subang Regency. The study site was the coastal area of Subang Regency, indicated by the hatch marks in the larger map. The black dots indicate the Blanakan and Legonkulon Sub-districts.

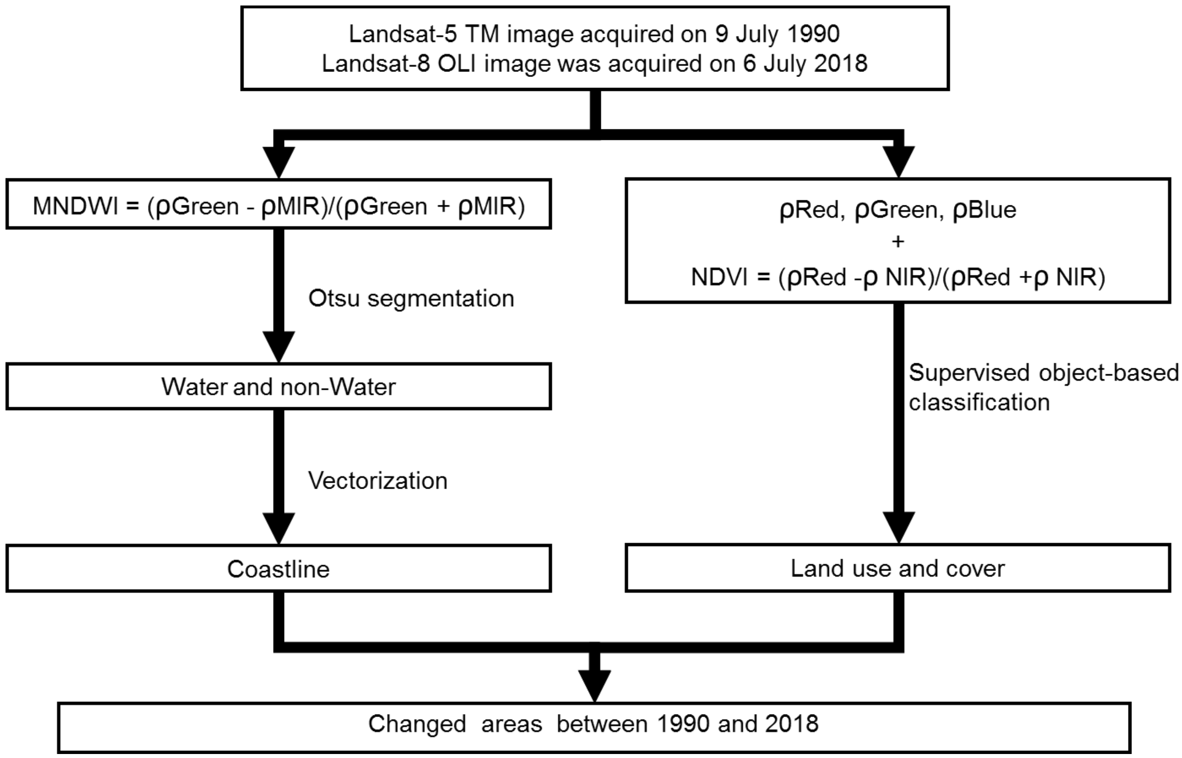

Fig. 2. Analysis procedure used to detect coastline and land use and cover changes. Landsat satellite images were used to produce the modified normalized difference water index (MNDWI) and were converted into binary images using Otsu segmentation (Otsu 1979) to extract the coastline. The land use and cover were investigated using the red, green, and blue band of the Landsat images, as well as the normalized difference vegetation index (NDVI) of the images.

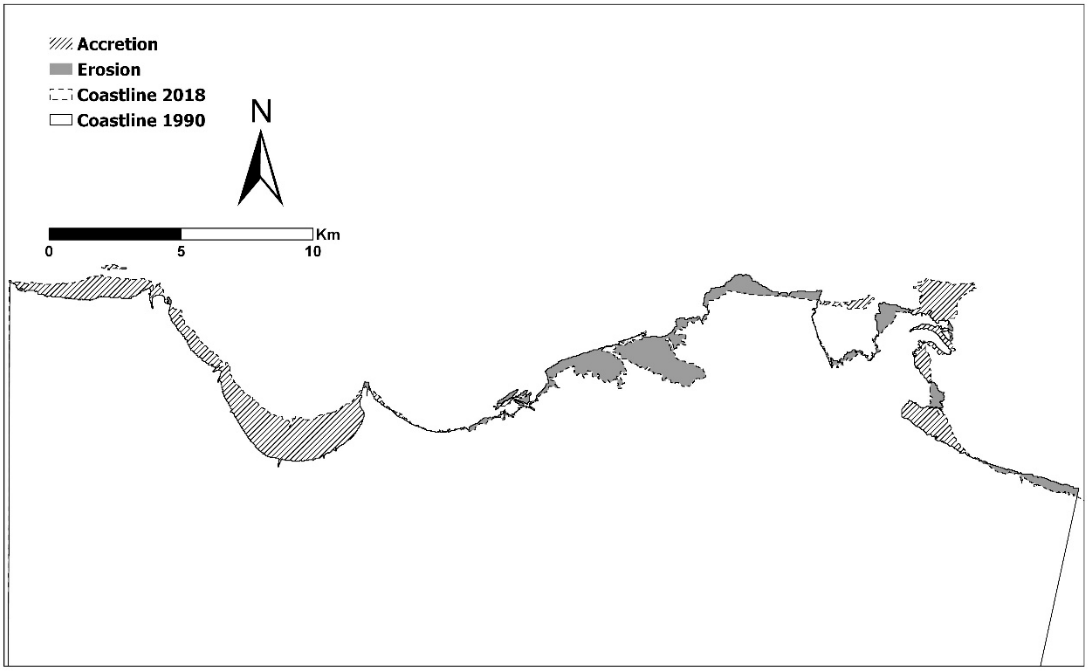

Fig. 3. The results of coastline extraction from 1990 and 2018 images. The black line shows the coastline of Subang in 1990, and the dashed line shows the coastline in 2018. The hatched area is the land accretion in the coastal area of Subang from 1990 to 2018, and the grey area is the eroded land from 1990 to 2018.

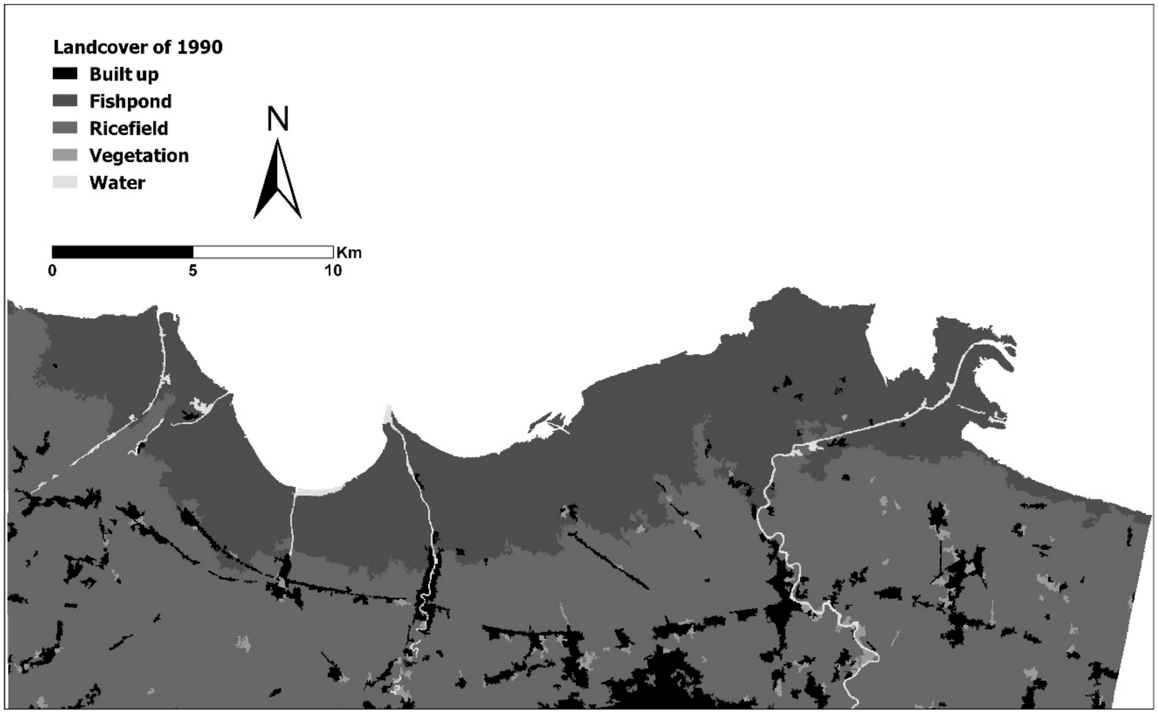

Fig. 4. Land use and cover in 1990 detected from Landsat-5 TM images applying object-based image classification.

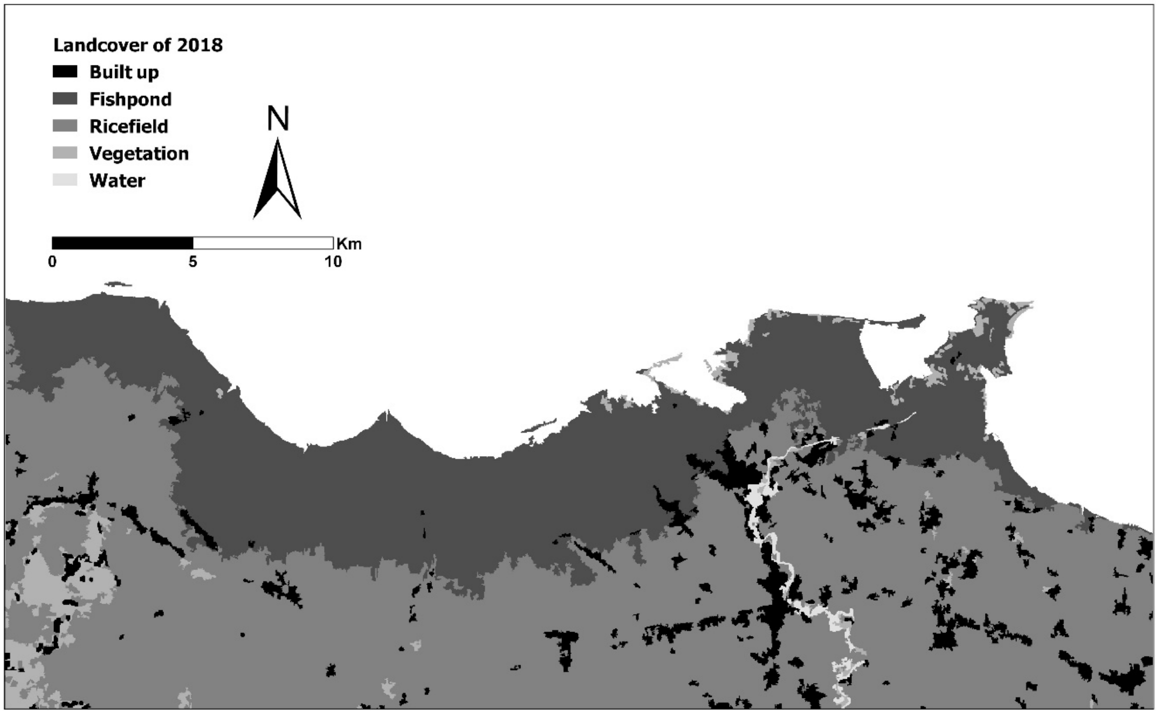

Fig. 5. Land use and cover in 2018 detected from Landsat-8 OLI images applying object-based image classification.

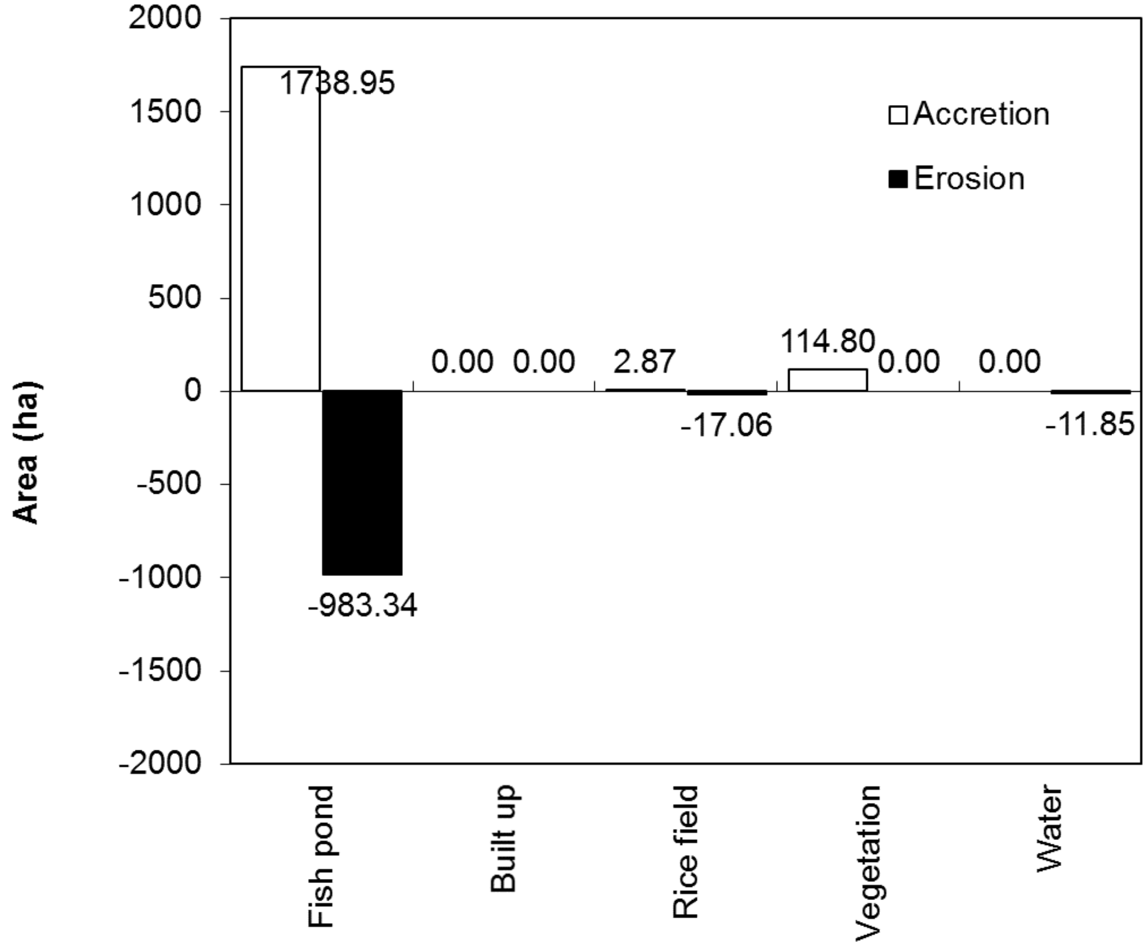

Fig. 6. Land use and cover affected by accretion and erosion from 1990 to 2018.

3. Identifying priority regencies for coastal protection around Java, Indonesia

Abstract

Climate change-induced sea level rise will likely increase the severity of ongoing coastal disasters in Indonesia. The selection and concentration approach should be applied to minimize the costs of conservation when budgets are limited. Prioritizing is then effective in terms of cost effectiveness. We aimed to identify priority areas for coastal protection against sea level rise around Java, Indonesia, using the Marxan model. The model uses systematic planning to select prioritized areas for coastal protection. Three scenarios were developed based on ecological, economic, and disaster elements that were exacerbated by sea level rise. A scenario is defined as a particular simulation circumstance based on assumptions about extrinsic drivers, parameters, and the structure of the model. Coastline length, mangrove coverage, low-elevation area, fishpond area, human settlement area, and the area of zones with the potential for annual rainfall increases acquired from DIVA-GIS and WorldClim were set as environmental factors. There were 60 areas facing the coast among 117 areas. For those protection, it would be fairly costly. We were able to narrow that number down from 18.8% to 62.4% from 117 areas using our method. This might become very cost effective. The most prioritized areas were located in the northern region of Java. These areas can be a focus of preferential effort and funding for conservation. The results of this study will help to make the protection strategy based on not only the magnitude of damage but also the total perspective using public data that is relatively easy to obtain.

Keywords: Aquaculture, Erosion, Low elevation area, Mangrove, Marxan

Introduction

Climate change and associated disasters are among the most serious global issues facing humanity. Sea level rise created by climate change will increase the rates and severity of coastal flooding, degrade coastal fresh water supplies, accelerate coastal erosion, and magnify the impacts of other coastal and marine hazards (Nicholls et al., 2011). Sea level rise may also change the spatial distribution of vulnerable coastal ecosystems, such as mangroves and saltmarshes, and their provision of ecosystem goods and services (Arkema et al., 2013). Oppenheimer et al. (2019) showed that the global mean sea level is rising and the process is accelerating. Observations made with tide gauges and altimetry demonstrated an increase of 1.4 mm/year from 1901 to 1990, 2.1 mm/year from 1970 to 2005, and 3.6 mm/year from 2006 to 2015. Relative to levels for the period 1986–2005, the sea level is projected to rise through the end of the century by 0.43 m (0.29–0.59 m) under Representative Concentration Pathway (RCP) 2.6, and by 0.84 m (0.61–1.10 m) under RCP8.5 (Oppenheimer et al., 2019). Even though sea level rise is not always a direct trigger of coastal erosion, rising water levels undoubtedly lead to more extensive, and oftentimes more rapid, erosion (Bird, 1996).

Sea level rise will also likely submerge coastal areas, especially those in low-elevation coastal zones (McGranahan et al., 2007) or alongside riverbanks (Yasuhara et al., 2011). Coastal zones have historically attracted large human populations and their associated activities because of easy access to water transport and fishing grounds, their esthetic values, and the diverse ecosystem services that they provide (Luijendijk et al., 2018). Several studies have shown that the population in low-elevation coastal zones (defined as coastal areas < 10 m above sea level, a.s.l.)

will likely increase from 640–700 million people in 2000 to over one billion in 2050 (Merkens et al., 2016). Hinkel et al. (2014) provided estimates showing that with sea levels set to rise by 25–123 cm through 2100, as much as 0.2–4.6% of the global human population would experience flooding annually, with associated annual damages amounting to 0.3–9.3% of the gross domestic product (GDP).

Indonesia is an archipelagic country with many small islands that are very vulnerable to sea level rise (Ministry of National Development and Planning 2014). Sea level in Indonesian waters is projected to rise by 80.0 ± 5.0 cm by 2100 (Indonesia Climate Change Sectoral Roadmap - ICCSR Scientific, 2010). This rise is expected to influence coastal areas of Indonesia in at least two ways: (a) an increase in the inundation area of coastal zones as the coastlines move, and (b) an areal increase in the zone affected by saltwater intrusions via river mouths and ground water (Ministry of National Development and Planning, 2014). Moreover, coastal areas in Indonesia have experienced severe erosion; 29,261 ha of the coastal zone has been eroded over 15 years (Siry, 2018). According to Climate Central (2019), coastal flooding triggered by sea level rise will affect around 23 million people living in the coastal zones of Indonesia by 2050, with land losses worth US$ 151 million globally. The Indonesian Government has repeatedly attempted to protect the coastal zone from the danger of erosion and flooding (Siry, 2018). In 2017, the government built 15 km of coastal protection structures using various procedures, such as the hard-engineering application of concrete, hybrid engineering using both hard structures and mangroves, and soft engineering using mangroves (Ministry of Marine Affairs and Fisheries, 2017). However, these efforts are not adequate given that the coastal areas affected by erosion are increasing in extent by about 420 km/year (Siry, 2018). Adaptation or adjustment that can be done to respond the impact of climate change-induced coastal disaster generally can be divided into four options: defense, accommodate, managed retreat and sacrifice (Williams et al., 2018). Defense differs from adaptation (accommodate) in the sense that adaptation refers to passive steps taken by humans in response to the approaching sea, while protection refers to an aggressive collection of policies aimed at preventing the sea from encroaching on land (McGuire, 2013). Defense focuses on preserving vulnerable areas, especially population centers, economic activities and natural resources using hard structures and/or soft protection measures (Rangel-Buitrago et al., 2018) such as seawall, bulkhead, groynes etc. (Bush et al., 1999) and soft structures including the use of mangroves as green belts, bamboo fences, sand dunes, and ecosystem-based coastal erosion management (Gracia et al., 2018). Its focus on the strategic displacement of human dwellings and villages from the coastal region as the sea moves landward distinguishes retreat from remaining in the coastal area (Nicholls, 2002). Another response to climate change impact in the coastal area is sacrifice, which means no active intervention to prevent or managed the impact and letting the nature to takes its courses (Williams et al., 2018). Techniques, expertise, facilities, and institutional resources must all be included in management strategies to reduce or eliminate coastal erosion-related impacts. Sometimes coastal protection strategies have been poorly planned and hastily constructed to reduce the impact of the erosion process, resulting in a coastal protection structure that is not fit for purpose (Rangel-Buitrago et al., 2018).

Conservation practitioners frequently face the fact that the cost of maintaining global biodiversity far exceeds available financial and human resources (Mace and Possingham, 2006). In fact, the Government had to relocate some communities where the villages are heavily eroded such as Demak and Pekalongan, in Central Java Province (Asiyah et al., 2015), which was involved substantial funding (Jolliffe, 2016). Therefore, it is important to determine the appropriate sequence of intensive maintenance procedures for maximum benefit. This is an urgent task to protect the coast of Indonesia, which is surrounded by the sea. Spatial prioritization of conservation action has been particularly valuable for conservation planning (Wilson et al., 2009), it has been applied in a lot of studies on conservation (Moilanen et al., 2011; Lehtomäki & Moilanen, 2013; Mendoza-Ponce et al., 2020). Prioritization methods can be divided into two main categories: scoring-based and complementarity-based approaches (Ferrier & Wintle, 2009). In the approach based on scoring, for example, Singh et al. (2021) scored lakes based on four characteristics such as ecological lake characteristics, lake catchment characteristics, threat to the lake ecosystem, conservation and management policy. The complementarity approach (Leathwick et al., 2010; Kullberg et al., 2015; Monroy-Gamboa et al., 2019) chooses areas of complementary richness areas that in combination have the highest species richness. Marxan as complementarity approach have been used for conservation plans (Ban et al., 2013; Pasnin et al., 2016), such as design and establishment of conservation areas (Henriques et al., 2017). Several marine spatial planning tools including visual gradient overlay, categorical classification, Marxan as the target-based site optimization algorithm, and zonation conservation priority ranking were compared, Marxan proven to show better result (Allnutt et al., 2011).

The purpose of this study was to identify priority areas (administrative units below the provincial level) for coastal protection against sea level rise on Java Island, Indonesia, using the Marxan model as the complementarity approach. By detecting priority areas for protection, the Governments and NGOs will be able to invest funds and human resources efficiently and effectively.

Materials and Methods

Study area

The study area was on Java Island, Indonesia (5°52′S–8°52′S, 105°7′E–114°37′E) (Figure 1). The terrestrial landscape of Java Island occupies about 150,000 km2 (Ministry of Public Works and Housing, 2017). The area is divided into six provinces: Banten, Special Capital Region of Jakarta, West Java (Jawa Barat), Central Java (Jawa Tengah), Special Region of Yogyakarta, and East Java (Jawa Timur). Java Island is bordered by the Java Sea to the north, by the Indian Ocean to the south, by the Sunda Strait to the west, and the Bali and Madura Straits to the east. The average temperature on Java Island is in the range 22–29°C; the average humidity is about 75% (climate-data.org, 2019). The coastal area of East Java, however, can be warmer, reaching about 35°C during the dry season in October (Statistics of East Java Province, 2018). The average annual rainfall is 2100 mm (Climate-data.org, 2019), with the highest precipitation falling on the Parahyangan highland (4000 mm; Statistics of West Java Province, 2018), and the lowest falling on the north coast of East Java (900 mm; Statistics of East Java Province, 2018).

The ocean waves off Java Island track seasonal patterns that are influenced by wind speed, wind period, and wind fetch, which is dependent on the coastal topographic configuration. The coastal areas of Gresik and Tuban in East Java have been categorized as semi-closed waters because they are connected directly to the coastal area of Borneo Island and Madura Island (Fisheries Agency of East Java, 2016). The Indramayu region has the largest waves that can reach heights > 1.7 m; the smallest waves reach heights < 0.3 m. The south coast of Java Island has largest wave heights of 2–5 m in offshore waters (Environmental Agency of West Java, 2008).

Data collection

Ground surface attributes as input data for Marxan were mangrove areas, low-elevation areas, areas of increasing annual precipitation, fishpond areas, and watershed settlements. The mangrove, fishpond, and settlement area data were extracted from the Global Forest Watch Data website (http://data.globalforestwatch.org/), which uses land cover and land use data released by the Ministry of Environment and Forestry of Indonesia. The primary and secondary mangrove forest fields were extracted as designated mangrove areas. A 1-km buffer zone was created along the outlines of coasts and rivers; settlement areas were extracted and designated as watershed settlements. Low-elevation areas were calculated using the digital elevation model (spatial resolution of 30 m) obtained from the Aster GDEM website (https://ssl.jspacesystems.or.jp/); areas that were < 10 m a.s.l. were isolated. Areas with potential annual increases in precipitation were identified using current and future annual precipitation estimates obtained from the WorldClim website (https://www.worldclim.org/). Current annual precipitation was obtained from interpolations in observed data that were representative of the period 1960–1990. The future annual precipitation was obtained from estimations made under the RCP8.5 scenario in 2070. The differences between current and future precipitations were calculated, and areas with more than 100 mm difference were categorized as those with potential increases in rainfall.

Figure 2 (a) shows the distribution of mangrove forests (primary and secondary) on Java. The total mangrove area on the island was 27,344.82 ha. Of 117 areas, 22 had mangals. The largest coverage occurred in Sumenep Regency, East Java (11,409.02 ha), followed in rank order by Cilacap Regency (7,409.55 ha) in the southern part of Central Java. Lebak Regency in Banten

Province had the smallest mangrove cover (3.43 ha). Figure 2 (b) shows the distribution of coastal and riverside settlements on Java. These settlements occupied 558,646.38 ha. Tangerang Regency in Banten had the largest coastal and riverside settlement area (13,201.03 ha). The smallest settlement area occurred in Kepulauan Seribu Regency (31.35 ha). Of 117 areas, three had no coastal or riverside settlements: Cimahi City in West Java, Salatiga City in Central Java, and Blitar Regency in East Java. These three areas did not have coastlines or river channels. Figure 2 (c) shows the distribution of the low-elevation areas (< 10 m a.s.l.), which occurred mostly in northern Java. The north coast of Java is low and flat, in contrast to the south coast, which is dominated by cliffs (Environmental Agency of West Java, 2008). The total low-elevation area occupied 1,144,830.93 ha. The largest low-elevation area occurred in Karawang Regency, West Java (89,080.48 ha). Jombang Regency in East Java had few low-elevation areas (7.74 ha), and 39 areas had no low-elevation areas. Figure 2 (d) shows the distribution of fishpond coverage on Java. The ponds occupied 189,377.27 ha, with most located in the northern part of West Java, where they occupied 76,852.74 ha.

Indramayu Regency had largest fishpond coverage among areas (27,265.36 ha). Lebak Regency in Banten had the smallest fishpond coverage (2.19 ha). Only 48 of 117 areas had fishponds. Figure 2 (e) shows the distribution of areas in which the annual precipitation was projected to increase above current levels. The total area with projected precipitation increases of > 100 mm by 2070 covered 5,102,288.51 ha, with the greatest concentrations in central to western Java. Sukabumi Regency in West Java and Purwokerto Regency in Central Java had the largest (413,463.27 ha) and smallest (676.10 ha) areas with projected rainfall increases, respectively.

Identification of priority areas for coastal protection using Marxan

We used Marxan software to identify priority areas for coastal protection. The model uses systematic planning to select prioritized areas for coastal protection (Mills *et al*., 2016). Marxan selects planning units for protection at a minimum total cost, while allowing for more or less emphasis on the spatial clustering of the selected planning units (Ball *et al*., 2009). Marxan estimations are controlled mainly by cost, target features, boundary, and status given for each ground surface attribute, which are incorporated in the following formula (Göke *et al*., 2018):

$$\sum\nolimits_{\boldsymbol{PUs}} \boldsymbol{Cost} + (\boldsymbol{BLM} * \sum\nolimits_{\boldsymbol{PUs}} \boldsymbol{Boundary\ length}) + (\sum\nolimits_{\boldsymbol{Target\ Features}} \boldsymbol{Penalty} * \boldsymbol{FPF})$$

Here, *PUs* are the planning units that are potential parcels of land or sea to be included in the reserve or conservation network in a planning region (Game and Grantham, 2008). *Cost* is the cost of including the sets of planning units into the configuration or conservation network (Morrell *et al*., 2015). *Target Features* is the object for conservation, and the target amount of each conservation feature is included in the solutions (Game and Grantham, 2008). The *Boundary length* of the reserve system is a means of quantifying the connectivity of a configuration of planning units (Morrell *et al*., 2015). *BLM* is boundary length modifier which is a variable used to determine how much emphasis is placed on minimizing the overall reserve system boundary length (Game & Grantham, 2008). *Penalty* is the difference between the target set and the selected amount. *FPF* is the feature penalty factor, which is the penalty factor applied for not reaching the target for the feature (Göke *et al*., 2018). The Marxan algorithm uses iterations to optimize this equation. In our study, Marxan ran 100 different iterations to find the best solution. The best solution file lists the reserve or conservation network with the lowest score across all good reserve networks generated (Ball *et al*., 2009).

A scenario is usually defined as a particular simulation circumstance based on assumptions about extrinsic drivers, parameters, and the structure of the model (Peterson *et al*., 2003). In this study, we developed three scenarios based on the main target of conservation (Table 1). In the strategy of selection and concentration, scenario 1 focused on the mangrove ecosystem. Mangrove areas in Java have been converted into brackish water fish and shrimp ponds on a large scale. The method of intensive shrimp farming introduced in 1970 coincided with the strong market demand and prices for shrimp at the time, resulting in a significant transformation of mangroves (Wouthuyzen *et al*., 2014). The loss due to this conversion is estimated at 1.6 million ha. Conversion of mangrove areas in 1980s was 155,081 ha, mostly taking place in Java, Sumatra and Sulawesi and increased to 285,500 ha in the 1990s (Nusantara *et al*., 2015). On the other hand, these conversion of mangrove areas has weakened or even eliminate the ability of mangrove areas to provide ecosystem services in terms of coastal protection, water purification, as well as carbon sequestration (Van Oudenhoven, 2015). We identified those areas where more effort and funding can be allocated for conserving and maintaining mangrove ecosystems by selecting areas based on the distribution of mangals and low-elevation zones. Because the mangrove ecosystem is important for reducing coastal erosion (Máñez *et al*., 2014) and the area occupied by mangals is decreasing (Siry, 2018), we need to conserve existing mangrove zones. Combined with other structures, mangroves could also be planted in low-elevation areas to protect coastal zones (Tonneijck *et al*., 2015). Under scenario 1, the goal was to protect 80% of both existing mangals and low-elevation areas with the potential for mangrove planting. The aim was also to protect 50% of the fishpond area because fish farmers sometimes plant mangroves to supply nutrients to the ponds and maintain the water quality.

Aquaculture is one of the main industries on Java; in 2017, it generated 8–9% of the GDP, and it has become one of the main livelihoods. About 150,000 households engage in this region (Ministry of Marine Affairs and Fisheries, 2018; Statistics of West Java Province, 2018). The investment in fisheries industries in Java, especially in Central Java, East Java, and West Java, is very high, representing about 34% of total investment in 2017, i.e., about 1.6 trillion IDR (Siry, 2018). Scenario 2 focused on fish farmers' livelihoods. The aquaculture area in Java including fish and shrimp ponds is under immediate threat, which is coastal erosion. For example, in Subang, a regency in West Java Province, 97.14% of fishponds have disappeared due to coastal erosion and flooding from 1990-2018 (Kalther & Itaya, 2020). Severe coastal erosion was also found in several neighboring regions such as Karawang (Azhar, 2012), Semarang (Marfai, 2011), and Demak (Sasmito & Suprayogi, 2017), which were mainly covered by aquaculture area according to the land use map. In addition, most people engaged in this industry, especially the small-scale fish farmers, are living under poverty (Natalia & Alie, 2014). These facts offer a strong reason for protecting the aquaculture area. We identified those areas where more effort and funding can be allocated to maintain fish farmers' livelihoods by selecting areas according to the distribution of fishponds. The goal of this scenario was to protect 80% of fishponds. It also aimed to protect 50% of low-elevation areas and watershed settlements because they are target areas for fishing and daily livelihoods of fish farmers.

Scenario 3 focused on residential area. We identified those areas where more effort and funding can be allocated for flood protection by selecting areas based on the distribution of low-elevation zones and watershed settlements. With a population of over 141 million on Java Island, or 145 million including the inhabitants of the surrounding islands, Java supports 56.7% of the Indonesian population and is the world's most populous island (BPS - Statistics Indonesia, 2013). Recent reports show that about 65% of Java's population inhabits the coastal zone. Coastal flooding is a serious threat to coastal areas around the world. It is responsible for billions of dollars worth of damage to property and infrastructure, and it threatens the lives of millions of people (Dasgupta *et al*., 2009). The coastal zones of Jakarta and Semarang in Central Java already have acute coastal flooding problems that create immense difficulties for many people in Indonesia (Miladan, 2009; Ward *et al*., 2011). Several coastal cities in such as Semarang (Ramadhany *et al*., 2012) and Demak (Sasmito & Suprayogi, 2017) are regularly flooded during high tide, which affects the social and economic activities of coastal communities as well as the sustainability of coastal ecosystem (Marfai, 2011). Moreover, most coastal communities in these areas live below the poverty line, making them highly vulnerable to coastal flooding and other forms of coastal disasters (Miladan, 2009; Ramadhany *et al*., 2012). Under scenario 3, the goal was to protect 80% of low-elevation areas and watershed settlements where flooding is a possibility. Another goal was to protect 50% of mangal coverage and areas where precipitation is expected to increase in the future because these are flood-sensitive areas.

The planning units in this study were generated based on regencies in Java obtained from the DIVA-GIS (https://www.diva-gis.org/gdata) database. Regencies belonging to West Java, Central Java, East Java, the Special Region of Yogyakarta, Banten, and the Special Capital Region of Jakarta were separated from the original data. We included 117 planning units (PUs) in our analysis and used status to lock planning units into or out of the reserve system. The total coastline length of Java is 6223.36 km. Of 117 areas on the island, 60 have coastlines. Sumenep Regency in East Java has the longest coastline (1055.27 km). Cirebon City in West Java has the shortest coastline (3.72 km).

A PU with status 0 indicated that it was not guaranteed inclusion in the initial or seed reserve; however, the possibility still existed. The chance of being included in the initial reserve was the starting proportion from the parameter input file. A PU with status 3 indicated that it was fixed outside of the reserve. It was not included in the initial reserve and could not be added. We defined status based on the lengths of coastlines and river channels. The lengths of coastlines and river channels were used as the cost value for each PU in scenarios 1 and 3, whereas we used only the length of coastline as the cost value for scenario 2. The outlines of coasts and rivers were obtained from the DIVA-GIS database. BLM was set to 0, meaning the algorithm ignored boundary length, based on the assumption that the large size of individual planning units is effective for coastal protection and that compactness is not critical for reserve design given our research question (Drever *et al.*, 2019). The FPF was set to 1, as we do not prioritize one conservation features over another.

Under our scenarios, 80% of the total area of the features in highly important targets would be protected. For fairly important targets, 50% of the total area of the features would be protected. For less important targets, only 10% of the total area of the features would be protected.

Results and Discussion

Climate change-induced sea level rise will likely increase the severity of ongoing coastal disasters in Indonesia. These disasters include coastal erosion, coastal flooding, and loss of important ecosystems and activities in the coastal zone. The selection and concentration approach should be applied to minimize the costs of conservation when budgets are limited. Prioritizing is then effective in terms of cost effectiveness. Although conservation priorities and management actions in marine systems have been mapped using scoring-based and complementarity-based approaches (Lourie & Vincent, 2004; Sala *et al*., 2002; Ball *et al*., 2009; Leathwick *et al*., 2008), some reports have shown that Marxan as complementarity-based approach is more able than other methods in terms of accuracy (e.g. Allnutt *et al*., 2012). Marxan was applied to solve problems encountered in marine conservation network planning to protect diverse components of biodiversity (Ball *et al*., 2009). For instance, Mills *et al*. (2016) used Marxan to identify appropriate methods for adapting to sea level rise. Henriques *et al*. (2017) used Marxan to select the best areas for aquaculture management. The model uses systematic planning to select prioritized areas for coastal protection. Therefore, using the Marxan we aimed to identify priority areas for coastal protection against sea level rise around Java, Indonesia.

Three scenarios were developed based on ecological, economic, and disaster elements that were exacerbated by sea level rise. A scenario is defined as a particular simulation circumstance based on assumptions about extrinsic drivers, parameters, and the structure of the model. Coastline length, mangrove coverage, low-elevation area, fishpond area, human settlement area, and the area of zones with the potential for annual rainfall increases acquired from DIVA-GIS and WorldClim were set as environmental factors.

Marxan software identified the regencies in which more effort and funding can be provided for conserving and maintaining the mangrove ecosystem (Figure 3 (a)). Of the 117 regencies, 22 (18.8%) were selected as priority areas. Most of the selected regencies were located in northern Java, except for Cilacap Regency located in southern Java. Sumenep Regency and Cilacap Regency had the largest and second largest mangrove forests. Scenario 1 focused on mangrove ecosystems. Multiple studies have shown that mangals are important natural barriers in coastal areas (Danielsen *et al*., 2005; Gedan *et al*., 2011; Máñez *et al*., 2014; Spalding *et al*., 2014). Mangrove roots stabilize shoreline sediments to protect against erosion, and the aboveground organs of the trees function to dampen the forces of wind and waves (Danielsen *et al*., 2005). Mangroves have economic benefits for coastal communities, directly through the provision of timber and fuel, and indirectly by providing habitat and nursery areas for fish and other animals (Máñez *et al*., 2014). Unfortunately, the mangal cover in Indonesia has been declining steadily, particularly on Java. Between 2010 and 2015, the annual cover loss was about 41,055 ha (Siry, 2018). The main driver behind mangrove loss is conversion to fish or shrimp ponds (Novianty *et al*., 2012). The extensive coastlines and long river channels in the 22 selected areas will require expanded effort and funding to protect the mangrove forests in balance with the fishery sector. The mangrove forest in the selected areas occupied 19,728.27 ha, representing 72% of the total mangrove area on Java. The extensive coastlines and long river channels in the 22 selected areas will require expanded effort and funding to protect the mangrove forests in balance with the fishery sector. A mechanism called "Tambak Tumpangsari" or silvofishery may be an option that can meet both needs (Kiswanto, 2015). It is a unique aquaculture method that allows both aquatic animals and mangrove trees to be reared in the same pond (Takashima, 2000). In terms of protection strategies for sustaining the mangrove forest, various activities such as mangrove restoration or replanting activities (Setyawan *et al*., 2002) and protection of mangrove seedlings with bamboo fences have been implemented (Nusantara *et al*., 2015). In 2017, the Indonesian government planted mangroves in at least 5 kilometers of the critical coastal area in Java as a coastal protection measure (Ministry of Marine Affairs and Fisheries, 2017). The outcome of scenario 1 can provide insight on where next coastal protection can be implemented focusing on the mangrove ecosystem.

Figure 3 (b) shows the regencies selected under scenario 2 to which increased effort and funding can be directed to maintain fish farmers' livelihoods. Among the 117 regencies, 34 (29.1%) identified for inclusion in the priority area were concentrated mostly in northern Java. Only eight were located in southern Java. Except for Cirebon Regency, all regencies in northern West Java, where most fishponds were located, were selected for inclusion in the priority area. Scenario 2 focused on fish farmers' livelihoods. The fishery sector on Java is very important economically. In West Java, the fishery sector generated 8–9% of the GDP in 2017 (Statistics of West Java Province, 2018). In East Java, around 311,000 tons of fishery products were produced by brackish water aquaculture (Statistics of East Java Province, 2018). Therefore, it was unsurprising that the output of Marxan analysis was focused strongly in the northern part of West Java and East Java under scenario 2. If fishponds and low-elevation areas become inundated due to sea level rise, it would cause great damage to the fishery industry. However, the extensive coastlines would certainly complicate any programs aiming to increase effort and funding. Additional effort and funding to maintain fish farmers' livelihoods might be better to allocate to the 34 areas selected. The fishpond area in the areas selected under this scenario occupied 151,671.08 ha, or about 80% of the total fishpond area on Java. Under the status established for this scenario, Marxan needs to identify more than half of all areas available for selection in order to satisfy the conservation target. It is possibly due to the distribution of fishpond area, which mostly scattered in the northern part of Java. In contrast, for low-lying areas and watershed settlements, the target achievement is 65% and 28% respectively. The target for the low-lying areas is met by Marxan (the target is 50%), while the target for the coastal and watershed settlements is not met (the target is 50%). This was likely influenced by the distribution of coastal settlements within the planning units where fishponds dominate. Coastal and watershed settlements were extracted from settlements within a 1-km buffer area from the shoreline and rivers. On the other hand, in the planning units where fishponds predominate, the 1-km buffer zones were mostly covered by fishponds and only few settlements were found. Thus, when Marxan attempts to meet the targets for fishpond area, it sacrifices the watershed settlement target.

Figure 3 (c) shows the regencies to which effort and funding can be directed based on scenario 3 to increase protection against flooding. Under this scenario, 73 of 117 regencies (62.4%) were selected for inclusion in the priority areas. Scenario 3 focused on protecting people from flooding. Coastal flooding has occurred frequently in many large Indonesian coastal cities (Marfai & King, 2007). Some areas, such as Karawang (Azhar, 2012), Semarang (Marfai, 2011), and Demak (Sasmito & Suprayogi, 2017), have already experienced severe coastal erosion. Semarang (Ramadhany *et al*., 2012) and Demak (Sasmito & Suprayogi, 2017) also regularly experience coastal floods. The extensive coastlines and long river channels increase the extent of area sensitive to flooding, thereby increasing the demands on effort and funding programs. The extra effort and funding to increase protection from flooding might be better to allocate to the 73 areas selected. The selected areas occupy 403,317.50 ha, or 72% of total watershed settlement on Java. The number of selected areas in scenario 3 is much higher compared to the other scenarios. This is probably due to the target set for this scenario rather high. However, in this scenario, all the conservation targets were met by Marxan except for the mangrove areas, which represent only 41% (the target is 50%). It is also interesting to note that although the target for fishpond area is only 10%, the percentage of fishpond cover within the selected areas is 89%. This scenario focuses on flood-prone areas; therefore, the primary target is the low-elevation area. When Marxan attempts to meet the low elevation area's target, the fishpond area's target will also be achieved since most of the low elevation areas are covered by or used as fishpond.

There were 60 areas facing the coast among 117 areas. For those protection, it would be fairly costly. We were able to narrow that number down from 12.3% to 62.4% from 117 areas using our method. This might become very cost effective. The most prioritized areas were located in the northern region of Java. These areas can be a focus of preferential effort and funding for conservation. The results of this study will help to make the protection strategy based on not only the magnitude of damage but also the total perspective using public data that is relatively easy to obtain. To ensure the sustainability of coastal ecosystems and all activities within them, diverse procedures have been implemented by both by the Indonesian Government and the local communities (Azhar, 2012; Ministry of Marine Affairs and Fisheries, 2017). In 2017, the government built about 15 km of coastal protection using hard, soft, and hybrid structures (Ministry of Marine Affairs and Fisheries, 2017). Based on the trend in budget allocation for coastal protection in the past, the limited funding allocated by the government will be sufficient to protect only 10–20 km of the coastal zone annually. By providing effectiveness insights, our study supports decision making by planners choosing sites for the construction of coastal protection structures or coastal forest rehabilitation programs. The combination of manufactured structures with natural mangal barriers is one of the best available options to minimize the cost of coastal protection (Tonneijck *et al*., 2015).

Conclusions

Using the Marxan model, we identified areas in Indonesia that can be the focus of increased effort and funding to deal with the rising sea level crisis. The selection of concentrated areas targeted for conservation is important because the budgets available for such programs are limited. With focuses on ecological, economic, and disaster elements, scenarios 1, 2, and 3 selected 22, 34, and 73 areas, respectively, among 117 on Java. We were able to narrow that number down from 12.3% to 62.4% from 117 areas using our method using public data that is relatively easy to obtain. By providing effectiveness insights, our study supports decision making by planners choosing sites for the construction of coastal protection structures or coastal forest rehabilitation programs. Thus, our findings can support the fisheries sector in the study area as the main livelihood of coastal communities and the areas' main source of GDP as well as their settlement areas by considering their sustainability in the selection of priority areas for coastal protection as a social and economic contribution, and in terms of environmental contribution, it supports the protection of important coastal habitat, mangrove areas, which is not only essential as natural barriers of coastal areas from waves but also provide an immense amount of ecosystem services to coastal communities.

Acknowledgments

We would like to express our great appreciation to Prof. Ishikawa, who provided helpful comments and suggestions. We would also like to thank the Japanese Ministry of Education, Culture, Sports, Science and Technology for a scholarship that made it possible to complete this study.

References

Allnutt, T.F., McClanahan, T.R., Andréfouët, S., Baker, M., Lagabrielle, E., McClennen, C., Rakotomanjaka, A.J.M., Tianarisoa, T.F., Watson, R., & Kremen C (2012). Comparison of marine spatial planning methods in Madagascar demonstrates value of alternative approaches. *PLoS One*. doi: 10.1371/journal.pone.0028969.

Arkema, K.K., Guannel, G., Verutes, G., Wood, S.A., Guerry, A., Ruckelshaus, M., Kareiva, P., Lacayo, M., & Silver, J.M. (2013). Coastal habitats shield people and property from sea-level rise and storms. *Nat Clim Chang*. 3, 913–918. doi: 10.1038/nclimate1944.

Asiyah, S., Rindarjono, M.G., & Muryani, C. (2015). (In Indonesian). Analysis of Settlement Changes and Characteristics of Slum Settlements Due to Abrasion and Inundation in the Coastal of Sayung District, Demak Regency 2003 - 2013. *J GeoEco*. 1, 83–100.

Azhar, R.M. (2012). (In Indonesian with English summary). Physical vulnerability of the coastal zone on the north coastal of Karawang in West Java. *Undergraduate Thesis*, Universitas Padjadjaran.

Ball, I.R., Possingham, H.P., & Watts, M.E. (2009). Marxan and relatives: software for spatial conservation prioritization. In: Moilanen, A., Wilson, K.A., & Possingham, H.P. (eds) Spatial conservation prioritization. Quantitative methods & computational tools. Oxford University Press, United Kingdom, pp 185–195.

Ban, N.C., Bodtker, K.M., Nicolson, D., Robb, C.K., Royle, K., & Short, C. (2013). Setting the stage for marine spatial planning: Ecological and social data collation and analyses in Canada's Pacific waters. *Mar Policy* 39, 11-20. doi: 10.1016/j.marpol.2012.10.017.

Bird, E.C.P. (1996). Coastal erosion and rising sea-level. In: Milliman JD, Haq (Eds.) BU (eds) Sea-Level Rise and Coastal Subsidence. Springer, Dordecht, The Netherlands, pp 87–103, doi: 10.1007/978-94-015-8719-8_5.

BPS-Statistics Indonesia (2013). Indonesia population projection 2010-2035 [In Indonesian and English]. Ministry of National Development and Planning, Jakarta, BPS-Statistics Indonesia, pp. 470.

Bush, D.M., Neal, W.J., Young, R.S., & Pilkey, O.H. (1999). Utilization of geoindicators for rapid assessment of coastal-hazard risk and mitigation. *Ocean Coast Manag*. doi: 10.1016/S0964-5691(99)00027-7.

Climate-data.org (2019). Climate of Java. https://en.climate-data.org/asia/indonesia/west-java-2408/. Accessed 15 Oct 2019.

Climate Central (2019). Flooded future: global vulnerability to sea level rise worse than previously understood. Climate Central, Jakarta, pp. 12

Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A., & Suryadiputra, N. (2005). The Asian Tsunami: a protective role for coastal vegetation. *Sceince* 310:643. doi: 10.1126/science.1118387.

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D., & Yan, J. (2009). The impact of sea level rise on developing countries: a comparative analysis. *Clim Change* 93, 379-388. doi: 10.1007/s10584-008-9499-5.

Drever, C.R., Hutchison, C., Drever, M.C., Fortin, D., Johnson, C.A., & Wiersma, Y.F. (2019). Conservation through co-occurrence: Woodland caribou as a focal species for boreal biodiversity. *Biological Conservation* 232, 238-252.

Ferrier, S., & Wintle, B.A. (2009). Quantitative approaches to spatial conservation prioritization: matching the solution to the need. In Spatial Conservation Prioritization (eds Moilanen, A., Wilson, K. A., & Possingham, H. P.), pp. 1– 15. Oxford University Press, Oxford.

Environmental Agency of West Java (2008). (In Indonesian with English summary) Environmental status of West Java 2008. Environmental Agency of West Java, Bandung, http://dlh.jabarprov.go.id/index.php/layanan/dokumen/kegiatan/slhd/tahun-2008. Accessed 15 Oct 2019.

Fisheries Agency of East Java (2016). (In Indonesian) Profile of coastal village in East Java Volume 1 (North Coast). Fisheries Agency of East Java, Surabaya pp. 89.

Game, E.T., & Grantham, H.S. (2008). Marxan user manual. University of Queensland, St. Lucia, Queensland, Australia, and Pacific Marine Analysis and Research Association, Vancouver, British Columbia, Canada, pp. 135.

Gedan, K.B., Kirwan, M.L., Wolanski, E., Barbier, E.B., & Silliman, B.R. (2011). The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm. *Clim Change* 106, 7-29. doi: 10.1007/s10584-010-0003-7.

Göke, C., Dahl. K, & Mohn, C. (2018). Maritime spatial planning supported by systematic site selection: applying Marxan for offshore wind power in the Western Baltic Sea. *PLoS One* 13:e0194362, doi: 10.1371/journal.pone.0194362.

Gracia, A., Rangel-Buitrago, N., Oakley, J.A., & Williams, A.T. (2018). Use of ecosystems in coastal erosion management. *Ocean Coast Manag* 156, 277–289. doi: 10.1016/j.ocecoaman.2017.07.009.

Henriques, N.S., Monteiro, P., Bentes, L., Oliveira, F., Afonso, C.M.L., & Gonçalves, J.M.S. (2017). Marxan as a zoning tool for development and economic purposed areas - Aquaculture Management Areas (AMAs). *Ocean Coast Manag* 141, 90-97. doi: 10.1016/j.ocecoaman.2017.03.016.

Hinkel, J., Lincke, D., Vafeidis, A.T., Perrette, M., Nicholls, R.J., Tol, R.S.J., Marzeion, B., Fettweis, X., Ionescu, C., Levermann, A. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proc Natl Acad Sci* 111, 3292-3297. doi: 10.1073/pnas.1222469111.

Indonesia Climate Change Sectoral Roadmap - ICCSR Scientific (2010). Scientific Basis: Analysis and projection of sea level rise and extreme weather event. Ministry of National Development and Planning, Jakarta, pp. 89.

Jolliffe, J. (2016). Economic dimensions of relocation as an adaptation strategy to climate change: A case study of the Narikoso Relocation Project, Fiji. Pacific Community, Suva, pp. 55.

Kalther, J, & Itaya, A. (2020). Coastline changes and their effects on land use and cover in Subang, Indonesia. *J Coast Conserv*. doi: 10.1007/s11852-020-00736-w.

Kiswanto, H. (2015). (In Indonesian with English Summary) The Environmental Characteristics of Intercropping Pond in Subang, West Java as a Reference for The Mud Crabs Pond Aquaculture Development. *Thesis*, Bogor Agricultural University pp. 20.

Kullberg, P., Toivonen, T., Pouzols, F.M., Lehtomäki, J., Di Minin, E., & Moilanen, A. (2015). Complementarity and area-efficiency in the prioritization of the global protected area network. *PLoS One*. doi: 10.1371/journal.pone.0145231.

Leathwick, J., Moilanen, A., Francis, M., Elith, J., Taylor, P., Julian, K., Hastie, T., Duffy, C. (2008). Novel methods for the design and evaluation of marine protected areas in offshore waters. *Conserv Lett*. doi: 10.1111/j.1755-263x.2008.00012.x.

Leathwick, J.R., Moilanen, A., Ferrier, S., & Julian, K. (2010). Complementarity-based conservation prioritization using a community classification, and its application to riverine ecosystems. *Biol Conserv*. doi: 10.1016/j.biocon.2010.01.012.

Lehtomäki, J., & Moilanen, A. (2013). Methods and workflow for spatial conservation prioritization using Zonation. *Environ Model Softw*. doi: 10.1016/j.envsoft.2013.05.001.

Lourie, S.A., & Vincent, A.C.J. (2004). Using biogeography to help set priorities in marine conservation. *Conserv. Biol*. 18, 1004-1020. doi: 10.1111/j.1523-1739.2004.00137.x.

Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., & Aarninkhof, S. (2018). The State of the World's Beaches. *Sci Rep* 8, 1–11. doi: 10.1038/s41598-018-24630-6.

Mace, G.M., & Possingham, H.P. (2006). Prioritizing choices in conservation. In: Macdonald, D., & Service, K. (eds) Key Topics in Conservation Biology, 1st edn. Willy-Blackwell, New Jersey, pp 17-34.

Máñez, K.S., Krause, G., Ring, I., & Glaser, M. (2014). The Gordian knot of mangrove conservation: Disentangling the role of scale, services and benefits. *Glob Environ Chang* 28, 120-128. doi: 10.1016/j.gloenvcha.2014.06.008.

Marfai, M.A. (2011). The hazards of coastal erosion in Central Java, Indonesia: an overview. Malaysian. *J Soc Sp* 7, 1-9.

Marfai, M.A., & King, L. (2007). Monitoring land subsidence in Semarang, Indonesia. *Environ Geol* 53, 651–659. doi: 10.1007/s00254-007-0680-3.

McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones. *Environ Urban* 19, 17–37. doi: 10.1177/0956247807076960.

McGuire, C.J. (2013). Adapting to Sea Level Rise in the coastal zone: Law and Policy Considerations, Taylor & Francis Group, Boca Raton, FL, US pp. 222, doi: 10.4324/9781315097572.

Mendoza-Ponce, A.V., Corona-Núñez, R.O., Kraxner, F., & Estrada, F. (2020). Spatial prioritization for biodiversity conservation in a megadiverse country. *Anthropocene* doi: 10.1016/j.ancene.2020.100267.

Merkens, J., Reimann, L., Hinkel, J., & Vafeidis, A.T. (2016). Gridded population projections for the coastal zone under the Shared Socioeconomic Pathways. *Glob Planet Change* 145, 57–66. doi: 10.1016/j.gloplacha.2016.08.009.

Miladan, N. (2009). (In Indonesian) Study of climate change vulnerability of the Coastal Area of Semarang. *Master Thesis*, Dipenogoro University, pp. 16

Mills, M., Leon, J.X., Saunders, M.I., Bell, J., Liu, Y., O'Mara, J., Lovelock, C.E., Mumby, P.J., Phinn, S., Possingham, H.P., Tulloch, V.J.D., Mutafoglu, K., Morrison, T., Callaghan, D.P., Baldock, T., Klein, C.J., & Hoegh-Guldberg, O. (2016). Reconciling development and conservation under coastal squeeze from rising sea level. *Conserv Lett* 9, 361-368. doi: 10.1111/conl.12213.

Ministry of Marine Affairs and Fisheries (2017). (In Indonesian) Annual Report of 2017. Ministry of Marine Affairs and Fisheries, Jakarta pp. 35.

Ministry of Marine Affairs and Fisheries (2018). (In Indonesian and English) Marine and Fisheries in Figures 2018. Ministry of Marine Affairs and Fisheries, Jakarta, http://sidatik.kkp.go.id/files/src/023dfaa957829d846cfb59164b6c5774.pdf. Accessed 15 Oct 2019.

Ministry of National Development and Planning (2014). (In Indonesian) National action plan on climate change adaptation. Ministry of National Development and Planning, Jakarta, pp. 204.

Ministry of Public Works and Housing (2017). Statistical Information Book 2017. Ministry of Public Works and Housing, Jakarta, pp. 113

Moilanen, A., Leathwick, J.R., & Quinn, J.M. (2011). Spatial prioritization of conservation management. *Conserv Lett*. doi: 10.1111/j.1755-263X.2011.00190.x.

Monroy-Gamboa, A.G., Briones-Salas, M.Á., Sarkar, S., & Sánchez-Cordero, V. (2019). Terrestrial vertebrates as surrogates for selecting conservation areas in a biodiversity hotspot in Mexico. *Conservation Science and Practice* 1 (3), e12. doi: https://doi.org/10.1111/csp2.12.

Morrell, N., Schuster, R., & Arcese, P. (2015). Marxan tutorial for the coastal Douglas-Fir and conservation partnership study area. University of British Columbia, British Columbia, pp. 26.

Natalia, M., & Alie, M.M. (2014). (In Indonesian with English Summary) Coastal poverty assessment in Semarang City (case study: Tambak Lorok Fisherman Village). *J Tek PMW* 3, 50-59.

Nicholls, R.J. (2002). Rising sea levels: potential impacts and responses. In: Hester, R.E., & Harrison, R.M. (eds) Global Environmental Change. The Royal Society of Chemistry, pp 83-108. doi: 10.1039/9781847550972-00083.

Nicholls, R.J., Marinova, N., Lowe, J.A., Brown, S., Vellinga, P., Gusmão, D de., Hinkel, J., & Tol, R.S.J. (2011). Sea-level rise and its possible impacts given a "beyond 4°C world" in the twenty-first century. *Phil Trans R Soc A* 369:161-181. doi: 10.1098/rsta.2010.0291.

Novianty, R., Sastrawibawa, S., & Prihadi, D.J. (2012). (In Indonesian with English summary) Identification of damages and rehabilitation efforts mangrove ecosystem in North Coast in the Subang Dustrict. *J Fish Mar Sci* 3, 41-47. doi: 10.4135/9781412950589.n774.

Nusantara, M.A., Hutomo, M., Purnama, H. (2015). Evaluation and planning of mangrove restoration programs in Sedari Village of Kerawang District, West Java: Contribution of PHE-ONWJ Coastal Development Programs. *Procedia Environ Sci* 23, 207-214. doi: 10.1016/j.proenv.2015.01.032.

Oppenheimer, M., Glavovic, B.C., Hinkel, J., Wal, R. van de., Magnan, A.K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R.M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., & Sebesvari, Z. (2019). Chapter 4: Sea Level Rise and Implications for Low Lying Islands, Coasts and Communities [Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, M. Tignor, P., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., & Weyer, N.M. (eds.)]. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, Cambridge University Press, Cambridge, UK, pp 321-446.

Pasnin, O., Attwood, C., & Klaus, R. (2016). Marine systematic conservation planning for Rodrigues Island, western Indian Ocean. *Ocean Coast Manag* 130, 213-220. doi: 10.1016/j.ocecoaman.2016.06.014.

Peterson, G.D., Cumming, G.S., & Carpenter, S.R. (2003). Scenario Planning: a Tool for Conservation in an Uncertain World. *Conserv Biol* 17, 358-366. doi: 10.1046/j.1523-1739.2003.01491.x.

Ramadhany, A.S., Agus, D.S. A., & Subardjo, P. (2012). (In Indonesian with English summary) Coastal flood prone area in Semarang. *J Mar Res* 1, 174-180. doi: 10.14710/jmr.v1i2.2035.

Rangel-Buitrago, N,. Williams, A.T., & Anfuso, G. (2018). Hard protection structures as a principal coastal erosion management strategy along the Caribbean coast of Colombia. A chronicle of pitfalls. *Ocean Coast Manag* 156, 58-75. doi: 10.1016/j.ocecoaman.2017.04.006.

Sala, E., Aburto-Oropeza, O., Paredes, G,. Parra, I., Barrera, J.C., & Dayton, P.K. (2002). A general model for designing networks of marine reserves. *Science* 298(5600), 1991-1993. doi: 10.1126/science.1075284.

Sasmito, B., & Suprayogi, A. (2017). (In Indonesian with English summary) Coastal ecosystem vulnerability assessment in Demak district based on coastline change using remote sensing technology and geographic information system. *Teknik* 38, 13-20. doi: 10.14710/teknik.v38n1.12181.

Setyawan, A.D., Winarno, K., & Purnama, P.C. (2002). (In Indonesian with English Summary) Mangrove ecosystem in Java: 2. *Restoration. Biodiversitas* 5, 105-118. doi: 10.13057/biodiv/d050212.

Singh, P., Kumar, A., & Mishra, S. (2020). Performance evaluation of conservation plan for freshwater lakes in India through a scoring methodology. *Environment, Development and Sustainability* 23, 3787-3810.

Siry, H.Y. (2018). (In Indonesian) Policy and disaster mitigation in small islands [Presentation]. In: Diskusi Pojok Iklim, Tanggap Darurat Bencana Iklim. Ministry of Environment and Forestry, Jakarta, http://simlit.puspijak.org/files/other/Bahan_Direktur_P4K_Ditjen_PRL_@_Pojok_Iklim.pdf. Accessed 15 Oct 2019.

Spalding, M.D., McIvor, A., Tonneijck, F.H., Tol, S., & van Eijk, P. (2014). Mangroves for coastal defense: guidelines for coastal managers and policy makers. Wageningen, The Netherlands, Wetlands International and The Nature Conservancy, http://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf. Accessed 15 Oct 2019.

Statistics of East Java Province (2018). (In Indonesian and English) East Java in Figures 2018. Statistics of East Java Province, Surabaya, https://jatim.bps.go.id/publication/2018/08/16/9999b727d316c006ee2fd7e7/provinsi-jawa-timur-dalam-angka-2018.html. Accessed 15 Oct 2019.

Statistics of West Java Province (2018). (In Indonesian and English) West Java in Figures 2018. Statistics of West Java Province, Bandung, https://jabar.bps.go.id/publication/2018/08/16/d8b96de222796402938666e4/provinsi-jawa-barat-dalam-angka-2018.html. Accessed 15 Oct 2019.

Takashima, F. (2000). Silvofishery: an aquaculture system harmonized with the environment Silvofishery: an aquaculture system harmonized with the environment. In: Primavera, J.H., Garcia, L.M.B., Castaños, M.T., & Surtida, M.B. (eds) Proceedings of the Workshop on Mangrove-Friendly Aquaculture organized by the SEAFDEC Aquaculture Department, January 11-15, 1999, Iloilo City, Philippines. Southeast Asian Fisheries Development Center, Aquaculture Department, Tigbauan, Iloilo, Philippines, 13-19.

Tonneijck, F., Winterwerp, H., Weesenbeeck, B. van., Bosma, R., Debrot, D., Noor, Y.R., & Wilms, T. (2015). Building with Nature Indonesia Securing Eroding Delta Coastlines. Ecoshape, Dordecht, The Netherlands, https://edepot.wur.nl/377873. Accessed 15 Oct 2019.

Van Oudenhoven, A.P., Siahainenia, A.J., Sualia, I., Tonneijck, F.H., van der Ploeg, S., de Groot, R.S., & Leemans, R. (2015). Effects of different management regimes on mangrove ecosystem services in Java, Indonesia. *Ocean & Coastal Management* 116, 353-367.

Ward, P.J., Marfai, M.A., Yulianto, F., Hizbaron, D.R., & Aerts, J.C.J.H. (2011). Coastal inundation and damage exposure estimation: a case study for Jakarta. *Nat Hazards* 56, 899–916. doi: 10.1007/s11069-010-9599-1.

Williams, A.T., Rangel-Buitrago, N., Pranzini, E., & Anfuso, G. (2018). The management of coastal erosion. *Ocean Coast Manag* 156, 4-20. doi: 10.1016/j.ocecoaman.2017.03.022.

Wilson, K.A., Cabeza, M., Klein, C.J. (2009). Fundamental concepts of spatial conservation prioritization. Spatial conservation prioritization: quantitative methods and computational tools. Oxford University Press, New York, 16-27.

Wouthuyzen, S., Melati, F., Fachrul, B., Hakim, R., Hukom, F.D., & Purnama, H. (2014). Long-term monitoring of Mangroves conversion along the Nothern Coast of West Java Province, Indonesia using multi-temporal Landsat satellite images. In: GISUP2014 (International) The 16th International Symposium of Geospatial Information Science and Urban Planning. pp 3-13 https://hdl.handle.net/20.500.12690/RIN/PH3UOK. Accessed 15 Oct 2019.

Yasuhara, K., Komine, H., Yokoki, H., Suzuki, T., Mimura, N., Tamura, M., & Chen, G. (2011). Effects of climate change on coastal disasters: New methodologies and recent results. *Sustain Sci* 6, 219–232. doi: 10.1007/s11625-011-0127-3.

Tables

Table 1. Three scenarios developed for Marxan analysis based on ecological, economic, and disaster components impacted by sea level rise. Coastline length, mangrove coverage, low-elevation area, fishpond area, human settlement area, and the area with potential annual rainfall increases were selected as environmental factors.

Figures

Figure 1. The island of Java with the Indian Ocean to the south and the Java Sea to the north. Java is divided into four administrative provinces (West Java, Central Java, East Java, and Banten), and two special regions (Jakarta and Yogyakarta). With a combined population of 145 million in the 2015 census, Java is the most populous island in the world; it is home to 57% of Indonesia's population. Regency boundaries on Java bounded were shown by thin lines. The coastline of the island is bounded by a thick line. Regencies were the units of analysis.

Figure 2. Attributes of land surface. Mangrove forest (primary and secondary) distribution on Java (obtained from Global Forest Watch; Land Cover Indonesia in 2017, (a)). Watershed settlement. Settlement area data were obtained from Global Forest Watch (Settlement area from Land Cover Indonesia in 2017). A 1-km buffer zone was created back from the line of coasts and rivers obtained from the DIVA-GIS Inland water database. Settlement areas were extracted and designated as watershed settlements (b). Low-elevation areas < 10 m

above sea level calculated from ASTER GDEM data (c). Fishpond area obtained from Global Forest Watch data (Fishpond from Land Cover Indonesia in 2017, (d)). Areas in which the annual precipitation in 2070 is expected to exceed current levels (e). The 2070 projection was provided by the MIROC-ESM model under scenario RCP8.5 (WorldClim).

Figure 3. Areas (identified by Marxan software) where effort and funding supports will be effective for the best conservation and maintenance of the mangrove ecosystem (black area in (a)). Areas to which effort and funding will be effective to direct to best maintain fish farmers' livelihoods (black area in (b)). areas to which effort and funding will be effective to direct to provide the best protection against flooding (black area in (c)).

Table 1. Three scenarios developed for Marxan analysis based on ecological, economic, and disaster components impacted by sea level rise. Coastline length, mangrove coverage, low-elevation area, fishpond area, human settlement area, and the area with potential annual rainfall increases were selected as environmental factors.

	Scenario 1	Scenario 2	Scenario 3
Scenario	Which areas should be allocated more effort and funding for conserving and maintaining the mangal ecosystem?	Which areas should be allocated more effort and funding to maintain fish farmers' livelihoods?	Which areas should be allocated more effort and funding for protection from flooding?
Planning unit	Regencies in Java	Regencies in Java	Regencies in Java
Status	Length of coastline and river channels = 0, status = 3. Lengths of coastline and river channels > 0, status = 0	Length of coastline = 0, status = 3 Lengths of coastline and river channels > 0, status = 0	Length of coastline and river channels = 0, status=3 Length of coastline and river channels > 0, status = 0
Cost	Lengths of coastline and river channels	Length of coastline	Lengths of coastline and river channels
Boundary length	0	0	0

Target and proportion	Area of mangal 80%. Area of low-elevation zone 80%. Increase in annual precipitation 10%. Area of fishponds 50%. Area of watershed settlements 10%.	Area of mangal 10%. Area of low-elevation zone 50%. Increase in annual precipitation 10%. Area of fishponds 80%. Area of watershed settlements 50%.	Area of mangal 50%. Area of low-elevation zone 80%. Increase in annual precipitation 50%. Are of fishponds 10%. Area of watershed settlements 80%.

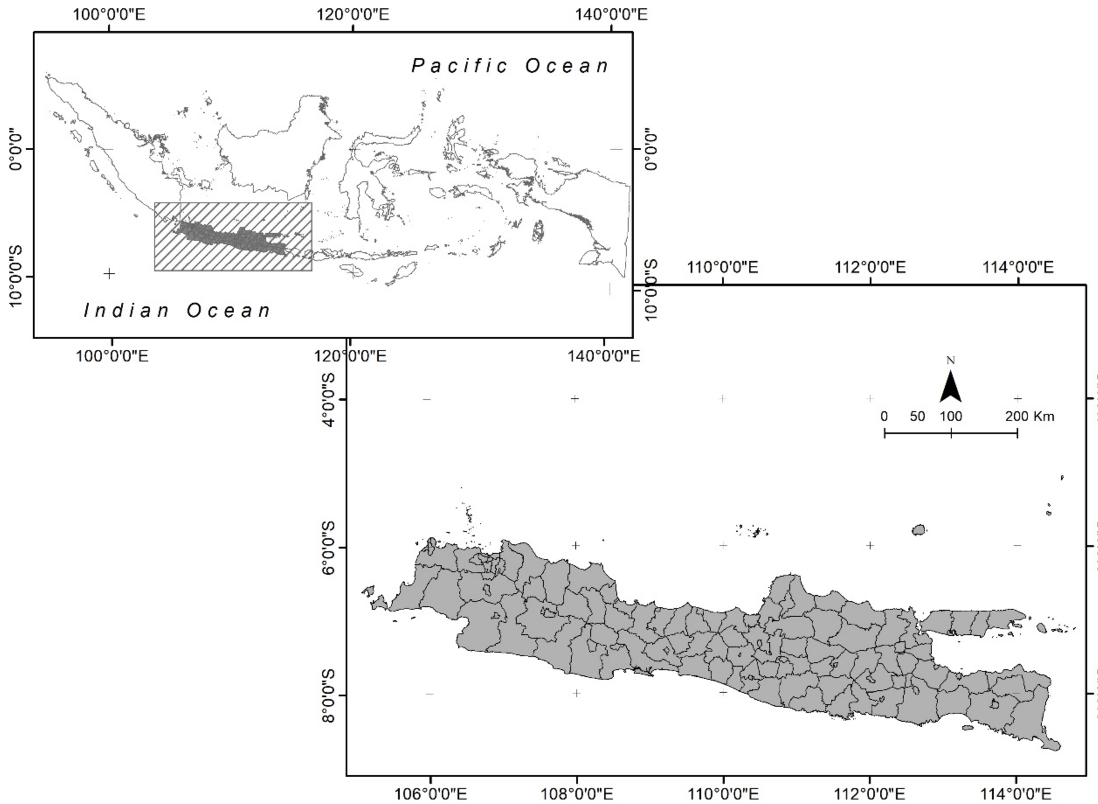

Figure 1. The island of Java with the Indian Ocean to the south and the Java Sea to the north. Java is divided into four administrative provinces (West Java, Central Java, East Java, and Banten), and two special regions (Jakarta and Yogyakarta). With a combined population of 145 million in the 2015 census, Java is the most populous island in the world; it is home to 57% of Indonesia's population. Regency boundaries on Java bounded were shown by thin lines. The coastline of the island is bounded by a thick line. Regencies were the units of analysis.

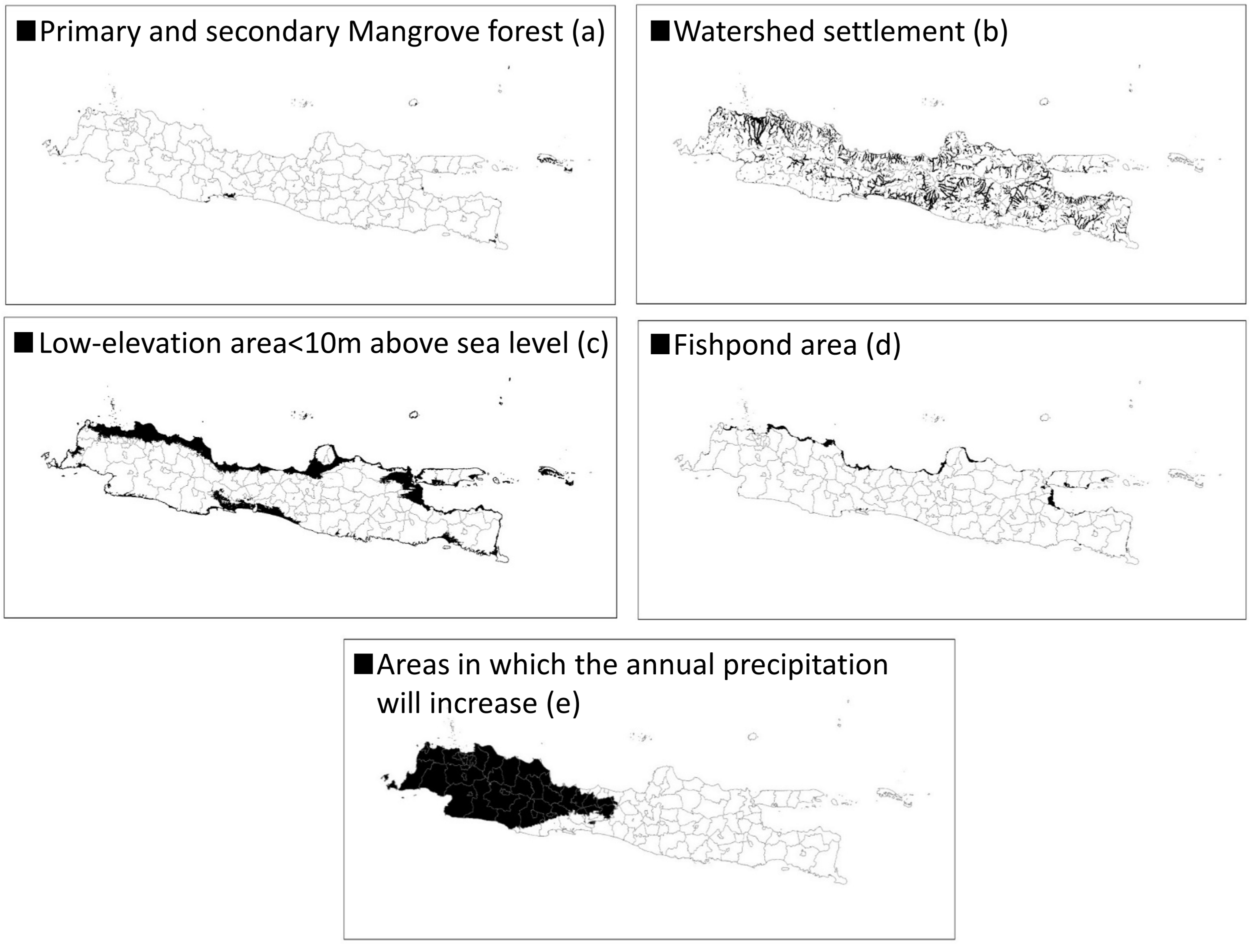

Figure 2. Attributes of land surface. Mangrove forest (primary and secondary) distribution on Java (obtained from Global Forest Watch; Land Cover Indonesia in 2017, (a)). Watershed settlement. Settlement area data were obtained from Global Forest Watch (Settlement area from Land Cover Indonesia in 2017). A 1-km buffer zone was created back from the line of coasts and rivers obtained from the DIVA-GIS Inland water database. Settlement areas were extracted and designated as watershed settlements (b). Low-elevation areas < 10 m above sea level calculated from ASTER GDEM data (c). Fishpond area obtained from Global Forest Watch data (Fishpond from Land Cover Indonesia in 2017, (d)). Areas in which the annual precipitation in 2070 is

expected to exceed current levels (e). The 2070 projection was provided by the MIROC-ESM model under scenario RCP8.5 (WorldClim).

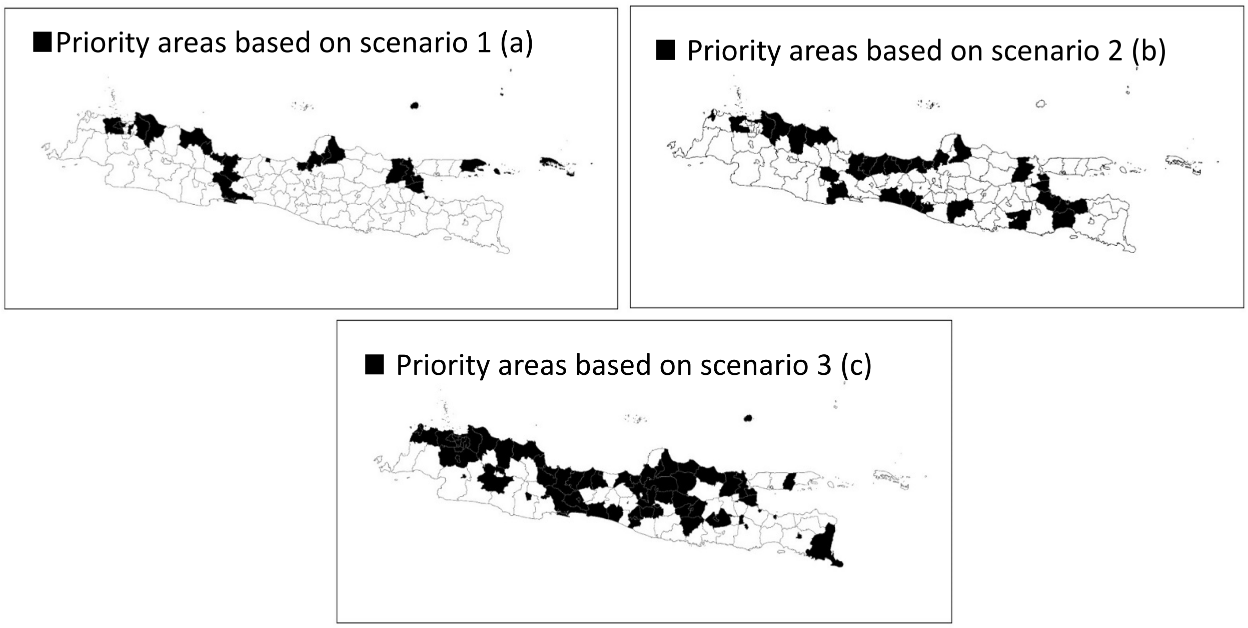

Figure 3. Areas (identified by Marxan software) where effort and funding supports will be effective for the best conservation and maintenance of the mangrove ecosystem (black area in (a)). Areas to which effort and funding will be effective to direct to best maintain fish farmers' livelihoods (black area in (b)). areas to which effort and funding will be effective to direct to provide the best protection against flooding (black area in (c)).

4. General Conclusion

Coastal areas, in Indonesia in particular, are at risk of various disasters that will be exacerbated by climate change, such as coastal erosion and coastal flooding. This study evaluated both the severity of the aforementioned disasters and suggested the best solution for their safety.

In the first study, we detected the coastline change and the land cover and use change using Landsat images. It turned out that this area experienced both erosion and accretion. The largest eroded land was found in Legonkulon which were mostly covered by fishponds in the past. Since fish farming were the main livelihood for the local communities in this area, the erosion likely influenced their social economic condition. Meanwhile, the largest accretion happened in Blanakan where most of the accreted area were used as fishponds. It was conceded that the cause of erosion in Subang was a decline in the mangrove ecosystem, in terms of both coverage and density mainly due to conversion into unsustainable fish and shrimp ponds. Although several mangrove planting activities have carried out, most were unsuccessful due to a lack of proper maintenance and monitoring. A long-term planting strategy is needed.

Based on the results of the first study, we recognize that coastal disasters, in particular coastal erosion, are threatening coastal areas. Further literature review also showed that this is not only taking place in Subang-Indonesia, the first study area, but also around Java Island in general. However, it is impossible to protect the entire coastal area of Java. Using the Marxan model, we identified areas in Indonesia that can be the focus of increased effort and funding to deal with the rising sea level crisis in Java Island. With focuses on ecological, economic, and disaster elements, scenarios 1, 2, and 3 selected 22, 34, and 73 areas, respectively, among 117 on Java. We were able to narrow that number down from 12.3% to 62.4% from 117 areas using our method using public data that is relatively easy to obtain. By providing effectiveness insights, our study supports decision making by planners choosing sites for the construction of coastal protection structures or coastal forest rehabilitation programs which can support the fisheries sector in the study area as the main livelihood of coastal communities as well as important coastal habitat such as mangrove areas, which is not only essential as natural barriers of coastal areas from waves but also provide an immense amount of ecosystem services to coastal communities.