Land suitability analysis for global mangrove rehabilitation in Indonesia

Luri N Syahid\textsuperscript{1,2,*}, Anjar D. Sakti\textsuperscript{1,2}, Riantini Virtriana\textsuperscript{1,2}, Wiwin Windupranata\textsuperscript{3}, Sonny A Sudhana\textsuperscript{1,2}, Felia N Wilwatikta\textsuperscript{1,2}, Adam I Fauzi\textsuperscript{4}, Ketut Wikantika\textsuperscript{1,2}

\textsuperscript{1}Center for Remote Sensing, Institut Teknologi Bandung, Bandung 40132, Indonesia
\textsuperscript{2}Remote Sensing and Geographic Information Science Division, Faculty of Earth Science and Technology, Institut Teknologi Bandung, Bandung 40132, Indonesia
\textsuperscript{3}Hydrography Division, Faculty of Earth Science and Technology, Institut Teknologi Bandung, Bandung 40132, Indonesia
\textsuperscript{4}Department of Geomatics Engineering, Institut Teknologi Sumatera, Lampung 35365, Indonesia

e-mail: luri.nurlaila@students.itb.ac.id

Abstract: Mangrove has an important role not only for ecosystem services such as erosion control and water purification but also for human life. For instance, mangrove has been satisfactorily saving people from the ocean such as storm surge or tsunami. However, mangrove population has fallen for about a fifth over these 25 years. Therefore, rehabilitation and restoration of mangrove are essential to be taken to overcome mangrove loss. Nonetheless, in several areas, while doing the rehabilitation mangrove, some species of mangroves failed to survive due to several parameters that were not suitable for them to grow. Hence, this research aimed to determine suitable sites for mangrove life in Indonesia globally. This research used several parameters which were: elevation, slope, air temperature, and precipitation, to measure the suitable sites. The result shows that 62\% from the total area (99,773 ha) of coastline in Indonesia are suitable for mangrove to grow included 59\% is suitable class (95,347 ha) and 3\% is perfectly suitable class (4,427 ha), while the unsuitable class has 38\% (61,616 ha) from the total area. Furthermore, in some areas, the decreasing number of suitable land for mangrove was related to the increasing number of mangrove deforestation.

1. Introduction
Mangrove grows along the inter-tidal area in both tropical and subtropical countries [1], [2], and [3]. Moreover, Indonesia is the country that has 22.6\% mangrove area of the world in 2000 [4]. Furthermore, there are a lot of benefits from mangrove. One of the those is mangrove satisfactorily saving people from the ocean such as storm surge or tsunami [5], [6], and [7]. The other benefit is for ecosystem service like erosion control and water purification [5].

Nowadays, worldwide, mangrove has fallen about a fifth from 1980 to 2005 [8], whereas in Indonesia alone, the loss was about 155,000 ha in that years [8]. There are a lot of reasons that make the number of mangroves decreasing. One of the major reasons is the lands were clear-cutting for tannin export to Europe and US [9] and [10]. Furthermore, converting to the fishpond are the other causes of the extinction of mangrove [11], [12], [13], and [14].

Moreover, rehabilitation and restoration of mangrove are essential to be undertaken to overcome the mangrove loss [15]. However, while doing the mangrove rehabilitation some species of mangroves fail and have high mortality for life—the survival rates of mangrove decline at 10-20\%—due to several parameters that not suitable for them to grow such as soil types, the species of mangroves and waves.
Therefore, the objective of this research is to select the suitable land that has high potential to mangrove life in Indonesia using remote sensing and GIS (Geographical Information System).

2. Material and Methods

Selecting suitable sites for mangrove rehabilitation in this research uses Indonesia for its geographical focus. Indonesia located in Southeast Asia lying between the Indian Ocean and the Pacific Ocean. The study made in about 10 km over Indonesia’s coastline.

2.1. Data used

2.1.1. The distribution of mangrove global

Mangrove distribution used in this research is the data from [4] combined with [17]. This distribution mangrove is from Landsat that has a total area about 137,760 km² in year 2000 from 118 countries with the spatial resolution of 30 m. Then, this data is resampled to 250 m.

2.1.2. Air temperature

Mangrove could tolerate air temperature from 8°C to 42°C [18]. Additionally, the best range of temperature for mangrove life is from 28-30°C. Moreover, air temperature data used in this research is from European Centre for Medium-Range Weather Forecasts (ECMWF). This data is based on interpolating between the lowest model level and the Earth’s surface, taking account of the atmospheric conditions. Besides, the spatial resolution of temperature data is 0.125° represented with Kelvin degree unit.

2.1.3. Elevation

The elevation of mangrove habitat is approximately from -0.5 m to 2.8 m [19] [20]. Furthermore, the most suitable range from mangrove extent is from -0.25 m to 1.5 m [19] [20]. The Digital Elevation Model (DEMs) used in this research is derived from [21]. This DEMs developed from Shuttle Radar Topography Mission global coverage ~90m version 2 (SRTM3 v2.1) and Advance World 3D Map (AW3D) 30m version 1. Moreover, this data has eliminated the multiple error component from the actual topography signals and removed a combination of multiple satellite datasets and filtering techniques [21].

2.1.4. Slope

Mangrove lives in coastal areas that have slope about 0 – 3% [22]. Moreover, the best range of slope that is suitable for mangrove growth is from 0 – 2° [22]. The used in this research is derived from elevation data changed using slope tool.

2.1.5. Precipitation

The range of precipitation which is suitable for the mangrove growth is from 0 to 7500 mm per year while the best precipitation range for mangrove lives is 1400 – 3750 mm per year [23] [24]. The precipitation data used in this research is from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS) with 0.05° x 0.05° degree spatial resolution.

2.2. Data analysis

There are several steps used in this research. Firstly, all of the parameters are resampled into 250 m with raster format. Secondly, reclassifying the parameters (air temperature, elevation, slope, and precipitation) into four classes based on study literature (see Table 1) with scoring value of 0-1 that represents unacceptable to good respectively. Thirdly, multiplying each parameter to each weight. The weight used in this research is 0.25 each which means that the weight for all the parameters are assumed every parameter is equally important. Fourthly, selecting suitable sites for mangrove rehabilitation into four classes: 1 means extremely unsuitable, 2 means unsuitable, 3 means suitable, and 4 means perfectly suitable.
Table 1. Scoring parameters with their classification

| Parameter               | Unacceptable | Poor    | Fair    | Good   |
|-------------------------|--------------|---------|---------|--------|
| Air temperature (°C)    | < 6; > 44    | 6 – 8; 42 - 44 | 8 – 28; 30 – 42 | 28 - 30 |
| Elevation (m)           | < (-1.5); > 3.5 | (-1.5) – (-0.4) | (-0.4) – (-0.25) | (-0.25) - 1.5 |
| Slope (%)               | >4           | 3 - 4   | 2 - 3   | 0 - 2  |
| Precipitation (mm)      | >8500        | 7500 – 8500 | 0 – 1400; | 1400 – 3750 |

3. Result and Discussion
The mangrove land suitability of this study is identified using four parameters (air temperature, elevation, slope, and precipitation) with different range (table 1) resulted in the suitable sites map for mangrove rehabilitation in four classes (Figure 1). However, this map shows that there is no extremely suitable class in Indonesia because Indonesia is one of the tropical countries in the world. Therefore, mangrove easier lives and grow in Indonesia. According to the suitable sites map for mangrove, the total of the area in this study is 161,390 ha. Moreover, the area which suitable for mangrove grow is 62% from the total area (99,773 ha) included 59% is suitable class (95,347 ha) and 3% is perfectly suitable class (4,427 ha), while the unsuitable class has 38% (61,616 ha) from the total area.

3.1. Analysis based on mangrove distribution
Every island has different characteristics which make them have a different class in mangrove suitable sites map. Furthermore, we chose four areas which represent all of the areas in Indonesia. Choosing those areas was based on signification distribution of mangrove in Indonesia and the areas which have much perfectly suitable class. The four areas chosen are Bintuni in West Papua (Figure 2 and Figure 3), Kubu Raya in West Kalimantan (Figure 4 and Figure 5), Riau (Figure 6 and Figure 7), and East Surabaya in Java (Figure 8 and Figure 9). Bintuni located in West Papua has 20% suitable class and 23% perfectly suitable class. Moreover, Kubu Raya located in West Kalimantan has a suitable and perfectly suitable class of about 18% and 22% respectively.
Then, the Province of Riau has the highest number of both suitable and perfectly suitable class among others: 28% for a suitable class and 25% for perfectly suitable class. However, Surabaya located in East Java has the least percentage of suitable class (8%) and perfectly suitable class (8%) among four other places. Then, we validated the mangrove suitable sites map with the distribution of mangrove from [4]. The result shows that all of the mangrove distribution is overlapped with a suitable class. The suitable class overlapped with the distribution of mangrove is about 6%. Therefore, 94% of the land could be recommended for mangrove rehabilitation sites.
3.2. Analysis based on parameter

Land suitability analysis is obtained from overlaying four parameters affected the life of mangrove. Every parameter produces different classes (Table 2). Elevation has four classes and the majority elevation belong to the extremely unsuitable class (83.54%). Followed by a suitable class (8.26%) and the unsuitable class (4.43%) while the least is the perfectly suitable class (3.76%). This is because the elevation that is suitable for mangrove life has a range from -0.25 to 1.5 that means just the coastline area which will suitable for mangrove grow based on the elevation parameter. Furthermore, the slope parameter mostly included in perfectly suitable class (58.87%), whilst the extremely unsuitable, unsuitable and suitable class is 31.34%, 4.23%, and 5.56% respectively.

Additionally, the air temperature and the precipitation has just two classes that are suitable class (99.75%) and perfectly suitable class (0.25%) for air temperature parameter whereas the classes for the precipitation parameter are suitable class (99.96%) and extremely unsuitable class (0.04). Since Indonesia is a tropical country which has a stable temperature and just has two seasons (dry and rainy season), it makes the plants easy to grow included mangrove. Therefore, the majority precipitation class is a suitable class and the air temperature parameter just have suitable and perfectly suitable class.

| Parameter       | Class | Area (%) |
|-----------------|-------|----------|
| Elevation       | 0     | 83.54%   |
|                 | 1     | 4.43%    |
|                 | 2     | 8.26%    |
|                 | 3     | 3.76%    |
| Air Temperature | 2     | 99.75%   |
|                 | 3     | 0.25%    |
| Slope           | 0     | 31.34%   |
|                 | 1     | 4.23%    |
|                 | 2     | 5.56%    |
|                 | 3     | 58.87%   |

Figure 6. Suitable sites map for mangrove in Riau.

Figure 7. Mangrove distribution and suitable sites map for mangrove in Riau.

Figure 8. Suitable sites map for mangrove in East Java (Surabaya).

Figure 9. Mangrove distribution and suitable sites map for mangrove in East Java (Surabaya).
3.3. Analysis based on mangrove deforestation

As reported by [25] deforestation of mangrove happened in Southeast Asia. The reason of mangrove deforestation is that there are conversions from mangrove forest to other types of land use (Figure 10) [26]. There are eight types of land use causing deforestation of mangrove [26]. However, one of the eight types are named other which means the causing of mangrove deforestation in that sites not yet known. If we compared Figure 1 and Figure 2. then we found that there is the same pattern between unsuitable sites for mangrove with the causing of deforestation named other. For example, in Figure 10, we can see that Flores has the other type of conversion.

![Mangrove forest conversion in Southeast Asia](image)

**Figure 10.** Mangrove forest conversion in Southeast Asia [26].

![Suitable sites map for mangrove](image)

**Figure 11.** The suitable sites map for mangrove in East Nusa Tenggara.

Then, Figure 11 shows that the majority class in Flores is unsuitable class (73%) while the percentage of the suitable class is 26%. Another example from the other type of conversion that has a match with the unsuitable class is the North Sulawesi, the unsuitable class has 60% of the total suitable site for mangrove map in Sulawesi, whereas suitable and perfectly suitable class has 38% and 2% respectively. Therefore, we indicate that one of the seasons which make mangrove deforestation is the unsuitable sites for mangrove grow.
4. Acknowledgement
The study was fully funded by PMDSU Scholarship from the Ministry of Research, Technology and Higher Education Indonesia. The study was conducted with Center of Remote Sensing (CRS) and Remote Sensing and GIS group Bandung Institute of Technology (ITB).

5. References
[1] Baran E 1999 A review of quantified relationships between mangroves and coastal resources Phuket Marine Biological Center Research Bulletin 62 pp 57-64
[2] Nagelkerken L, Blaber S J M, Bouillon S, Green P, Haywood M, Kirton LG, Meynecke, J-O, Pawlik, J, Penrose, H M 2008 The habitat function of mangroves for terrestrial and marine fauna: A review. Aquatic Botany 89 pp 155-185
[3] Cannicci S, Burrows D, Fratini S, Smith III T J, Offenberg J, Dahdouh-Guebas F 2008 Faunal impact on vegetation structure and ecosystem function in mangrove forests: A review Aquatic Botany 89 pp 186-200
[4] Giri C, Ochieng E, Tieszen L L, Zhu Z, Singh A, Loveland T, Masek J, Duke N 2011 Status and distribution of mangrove forests of the world using earth observation satellite data Global Ecology and Biogeography 20 pp 154-159
[5] Barbier E B, Hacker S D, Kebbedy C, Loch EW, Stier A C, Silliman B R 2011 The value of estuarine and coastal ecosystem services The Ecological Society of America pp 169-193
[6] Kathiresan K, Rajendran N 2005 Coastal mangrove forests mitigated tsunami Estuarine Coastal and Shelf Science 65 pp 601-606
[7] Dahdouh-Guebas F, Jayatissa L P, Nitto D D, Bosire J O, Seen D L, Koedam N 2005 How effective were mangroves as a defence against the recent tsunami? Current Biology 15 (12)
[8] Food and Agriculture Organization (FAO) of the United Nations 2007 The world’s mangroves 1980-2005 FAO Forestry Paper vol 153 pp 1-77
[9] de Neve T A 1918 Looistof-fabriek in Nederlandsch-Indie Tectona 11 pp 543-549
[10] Wind R 1924 Her looistof vraagstuk in Nederlandsch-indie Metzger & Wittig Leipzig
[11] Primavera J H 2005 Mangrove, fishponds, and the quest for sustainability Global Voices of Science vol 310
[12] Walters B 2005 Patterns of local wood use and cutting of Philippine mangrove forest Economic Botany 59 pp 67-76
[13] Naylor R L, Goldburg R J, Mooney H, Beveridge M, Clay J, Folke C, Kautsky N, Lubchenco J, Primavera J, Williams M 1998 Nature’s subsidies to shrimp and salmon farming Science of Aging 282 (5390): 883 pp 1-5
[14] Dahdouh-Guebas F, Koedam N 2002 Asynthesis of existent and potential mangrove vegetation structure dynamics from Kenya, Sri Lankan and Mauritanian case-studies Bulletin Seances Acadamie Royale Des Sciences D’outre-mer 48 pp 487-511
[15] Kathiresan K, Rajendran N 2005 Coastal mangrove forests mitigated tsunami Estuarine Coastal and Shelf Science 65 pp 601-606
[16] Primavera J H, Esteban J M A 2008 A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects Wetlands Ecol. Manage 18 pp 345-358
[17] Hamilton S E, Casey D 2016 Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21) Global Ecol. Biogeogr. 25 pp 729-738
[18] Teas H J 1983 Biology and Ecology of Mangroves Springer Science+Business Media Dordrecht 1st ed
[19] Leong R C, Friess D A, Crase B, Lee W K, Webb E L 2017 High-resolution pattern of mangrove species distribution is controlled by surface elevation Estuarine, Coastal and Shelf Science 202 pp 185-192
[20] Clarke L D, Hannon N J 1969 The mangrove swamp and salt marsh communities of the Sydney District: II the holocoenotic complex with particular reference to physiography Journal of Ecology 57 pp 213-234
[21] Yamadazaki I, Ikeshima D, Tawatari R, Yamaguchi T, O’Loughlin F, Nael C J, Sampson C C, Kanae S, Bates P D 2017 A high-accuracy map of global terrain elevations Geophys. Res. Lett. 44 pp 5844-5853
[22] Bhat N R, Suleiman M K 2004 Classification of soils supporting mangrove plantation in Kuwait Archives of Agronomy and Soil Science 50 (6) pp 535-551
[23] Simard M, Fatoyinbo L, Smetanka C, Rivera-Monroy V H, Castaneda-Moya E, Thomas N, der Stocken T V 2019 Nature Geoscience 12 pp 40-45

[24] Osland M J, Feher L C, Griffith K T, Cavanaugh K C, Enwright N M, Day R H, Stagg C L, Krauss K W, Howard R J, Grace J B, Rogers K 2016 Climatic controls on the global distribution, abundance, and species richness of mangrove forests Ecological Monographs 87

[25] Rajagukguk Y S, Sakti A D, Yayusman L F, Harto A B, Prasetyo L B, Irawan B, Wikantika K 2018 Evaluation of Southeast Asia mangrove forest deforestation using longterm remote sensing index datasets Proceedings Asian Conference on Remote Sensing 2018 2 pp 931-937

[26] Fauzi A I, Sakti A D, Yayusman L F, Harto A B, Prasetyo L B, Irawan B, Wikantika K 2018 Evaluating mangrove forest deforestation causes in Southeast Asia by analyzing recent environment and socio-economic data products. Proceedings Asian Conference on Remote Sensing 2018 2 pp 880-889