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MAPPING AND MONITORING OF MANGROVE AREA IN SURABAYA (INDONESIA) IN THE PERIOD OF 1994–2018 USING LANDSAT SATELLITE DATA AND GOOGLE EARTH ENGINE

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Abstract. Mangroves have an important role in supporting the sustainability of coastal and small island environments. Mangroves act as fish habitat and are an indicator of a healthy coastal environment through the presence of various types of fish. Mangroves are also able to become economic centers for coastal communities through cultivation and tourism activities. Therefore, the monitoring of mangrove areas becomes very important. Utilization of remote sensing technology can be used to monitor the condition of mangroves. The City of Surabaya has a natural potential for the growth of various types of mangroves. The purpose of this study was to monitor the mangrove species and mangrove area and to determine the biomass and carbon stock value produced by mangroves in the City of Surabaya. The monitoring covered Landsat imagery data of 1994, 2003 and 2018 and exercised the Google Earth Engine (GEE) platform with Random Forest (RF) algorithms. The results showed that in general there were three genera of mangroves growing in East Java, especially Surabaya: *Rhizophora*, *Sonneratia*, and *Avicennia*. Compared to 1994, the mangrove area in Surabaya increased by 429.954 ha in 2018. According to the findings, as the number of mangroves in Surabaya increases, there is a corresponding increase in the production of biomass and carbon stock value. This periodic monitoring of mangroves is expected to be able to support the sustainability of a healthier coastal ecosystem.

Keywords: mangrove, remote sensing, Google Earth Engine, biomass, carbon stock.

КАРТОГРАФИРОВАНИЕ И МОНИТОРИНГ МАНГРОВЫХ ЗАРОСЛЕЙ В СУРАБАЕ (ИНДОНЕЗИЯ) В ПЕРИОД 1994–2018 гг. С ИСПОЛЬЗОВАНИЕМ СПУТНИКОВЫХ ДАННЫХ LANDSAT И GOOGLE EARTH ENGINE

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Аннотация. Мангровые заросли играют важную роль в поддержании устойчивости прибрежной и окружающей сред малых островов. Они служат местом обитания различных видов рыб и являются показателем здоровья прибрежной экосистемы. В дальнейшем мангровые заросли также могут стать экономическими центрами для прибрежных сообществ благодаря сельскому хозяйству и туристической деятельности. Поэтому значение мониторинга мангровых зарослей с каждым годом становится все более важным. Одним из решений данной проблемы может стать использование дистанционного зондирования Земли для мониторинга состояния мангровых зарослей. Город Сурабая (Индонезия) является потенциально благоприятной территорией для произрастания различных видов мангровых зарослей. Целью этого исследования был мониторинг трех типов мангровых зарослей и площади их

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произрастания, а также определение величины биомассы и углерода, производимых ими в городе Сурабае. Были использованы данные снимков Landsat за 1994, 2003 и 2018 гг. и платформа Google Earth Engine с использованием алгоритма Random Forest. В индонезийской провинции Восточная Ява, как и в ее административном центре Сурабае, произрастают мангровые деревья, принадлежащие к трем родам: *Rhizophora*, *Sonneratia* и *Avicennia*. По сравнению с 1994 г. площадь мангровых зарослей в Сурабае в 2018 г. увеличилась на 429,954 га. Результаты показали, что чем больше мангровых зарослей в Сурабае, тем больше биомасса и углеродные запасы. Периодический мониторинг мангровых зарослей сможет поддержать устойчивость прибрежной экосистемы этого региона.

Ключевые слова: мангровые заросли, дистанционное зондирование, Google Earth Engine, биомасса, углерод.

INTRODUCTION

The City of Surabaya is the capital of East Java Province, Indonesia and located in coastal area. Surabaya has mangrove forest ecosystems in the Pamurbaya (east coast of Surabaya) and the Panturbaya (north coast of Surabaya). The Pamurbaya is predicted to be 916.743 hectares or about 82.68% of mangrove forest ecosystems total predicted area in the City of Surabaya [1]. The Pamurbaya area is included in the indicated damaged mangrove area in Indonesia. Based on the City of Surabaya Spatial and Regional Plan Number 12 of 2014 [2], Pamurbaya has been designated as a protected area. However, the shrinkage of mangrove ecosystem as a result of land use changes continues to occur in the Pamurbaya area [3]. One of the land use change causes is the construction of housing and apartments by developers [3].

Pamurbaya has a mangrove tourism programm called Wisata Anyar Mangrove (WAM). This place has benefits as an ecotourism site and has an economic diversificationsignificance as mangroves can provide raw materials for syrup and other food ingredients and medicines. In addition, the community forms Mangrove Ecotourism policy which includes boat ecotourism, fishing place, and monitoring post [4]. WAM tourism has natural potential in the form of beautiful and natural scenery, various types of fauna and flora such as birds and mangrove forests. The formulated policy directions indicate that the concept of developing tourism potential of WAM is to increase tourism attractiveness and use tourism revenue to improve the condition of mangroves. In addition to tourism, WAM is intended to be a place of education and research. The potential of the mangrove ecosystem can be developed for various tourism activities such as fishing, boating, birdwatching, observing plant species, wildlife attractions, photography, education, picnics, and as the means of mangrove education and interpretation [5].

In monitoring mangroves, besides their type and extent, the biomass and carbon stock value are also important to observe. Related to mangroves type, there are four types of mangrove vegetation. The first is open mangroves, which is mangroves that are on the sea waterfront, for example *Avicennia marina*. The second is middle mangroves, which is mangroves behind the open mangroves. Middle mangroves are mostly *Rhizophora*. The third is brackish mangroves, which is mangroves located along rivers with brackish water to fresh water. Mangroves that are usually found in this location are *Nypa* or *Sonneratia*. The fourth is mainland mangroves, which is mangroves located in the brackish water zone or almost fresh water zone behind the actual mangrove green belt. Mangroves that are usually found in this location are *Ficus microcarpus* (*F. retusa*), *Intsia bijuga*, *Nypa fruticans*, *Lumnitzera racemosa*, *Pandanus* sp., and *Xylocarpus moluccensis* [6].

Biomass is the total amount of living organic matter expressed in dry weight in tons per unit area [7]. Biomass can be divided into two types, which is above ground biomass and below ground biomass. An estimation of forest biomass is needed to determine a change in carbon stock. The estimated value of above ground biomass is very important for assessing carbon stock and the effects of deforestation and carbon storage in the context of global carbon balance [8]. The higher is biomass value, the less carbon dioxide is in the atmosphere.

In monitoring and mapping mangrove ecosystems, remote sensing can provide a wide area analysis without having to go directly to the area [9]. In other words, the data collection is done by using images, one of which is satellite imagery. Landsat is a remote sensing satellite imagery which was launched for the first time in 1927 [10]. There are many researches using Landsat for mangroves monitoring [11–13]. The study presented used the satellite imagery from Landsat 5 (1994), Landsat 7 (2003), and Landsat 8 (2018) [14].

Identification of vegetation density using remote sensing technology can be done by means of digital image interpretation using a vegetation index. A vegetation index is one of the parameters used to analyze a vegetation condition by measuring the vegetation canopy greenness, the leaf chlorophyll composite properties, the leaf area, the structure and canopy cover of vegetation in the study area [15]. As for biomass and carbon stock of mangroves vegetation can also be observed using remote sensing [7; 16–18]. Technological advances support remote sensing data processing with cloud-based processing platforms, one of which is Google Earth Engine (GEE). In addition, the presence of freely accessible satellite image data and new non-parametric machine learning algorithms for land use classification can be used for easy monitoring [19–21].

Based on this background data and information, the research aims to identify and monitor mangrove areas using Landsat imagery and the GEE platform with the Random Forest (RF) classification algorithms. The observation includes mangroves areas and types, the biomass, and carbon stock.

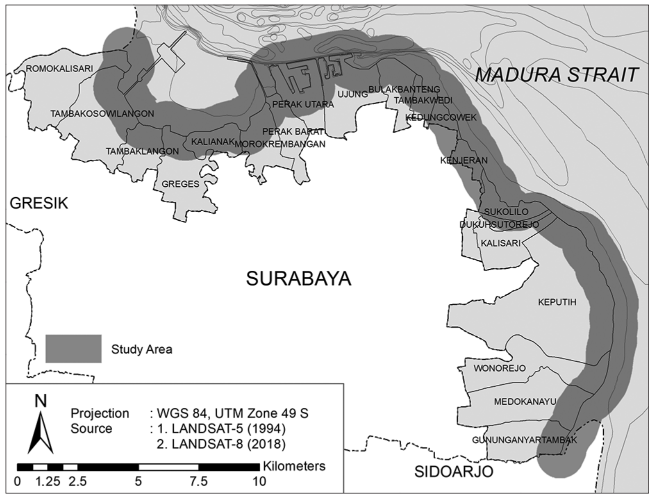

Fig. 1. Study area.
Рис. 1. Район исследований.

DATA AND METHODS

Study area. Monitoring the mangrove quality through mangrove survey activities is carried out by the City of Surabaya Environmental Service for Supervision and Control in previous research (Fig. 1). The activities are performed in order to mitigate mangrove damage. In addition, the city development of Surabaya is increasing, including the development around the mangrove areas. The increasing development activities may damage the mangroves. The survey results are useful for the Surabaya government in formulating environmental management policies for coastal areas, especially the mangrove areas as well as for environmental management practitioners and environmentalists [22].

The monitoring was carried out in the mangrove ecosystem area in Surabaya (North Coast and East Coast areas of the City of Surabaya). The study area for this research was around these two locations of mangrove ecosystems. The research was conducted in the administrative area of the City of Surabaya with a buffer of 1 km off the coastal area. The buffer was done in order to create coastal area boundary. We also did some field observations in those areas.

Data. Remote sensing data are the data most often used to monitor mangrove forests because the data collection process is easy and fast and it enables the researchers to perform analysis of data collected in the past. The following are the remote sensing satellite imagery data used in this study:

– 1994: USGS Landsat 5 Surface Reflectance & Top of Atmosphere;

– 2003: USGS Landsat 7 Surface Reflectance & Top of Atmosphere;

– 2018: USGS Landsat 8 Surface Reflectance & Top of Atmosphere.

Some additional data used in the study are:

– Shuttle Radar Topography Mission (SRTM) data on the height above the sea level to filter mangrove locations based on the height. The height that was the focus of the study was 2 meters above the sea level.

– Mangrove sample data from the field.

– The City of Surabaya Administration vector data.

Methods. The workflow in the study is shown at Figure 2. Landsat level 2 Surface Reflectance was used to identify mangrove areas and classify mangrove species while Landsat level 2 Top of Atmosphere (ToA) was used to obtain the biomass and carbon stock value. Regarding the mangrove area identification, the researchers selected the sample randomly in Surabaya based on the identification and the results of the researchers' field observation. After that, the classification was carried out using Machine Learning Random Forest on Google Earth Engine platform to get mangrove areas and non-mangrove areas (first classification).

Machine learning algorithms from supervised classification consist of Support Vector Machine (SVM), Random Forest (RF), decision tree algorithms, and Extreme Gradient Boosting (XGboost) [4]. The use

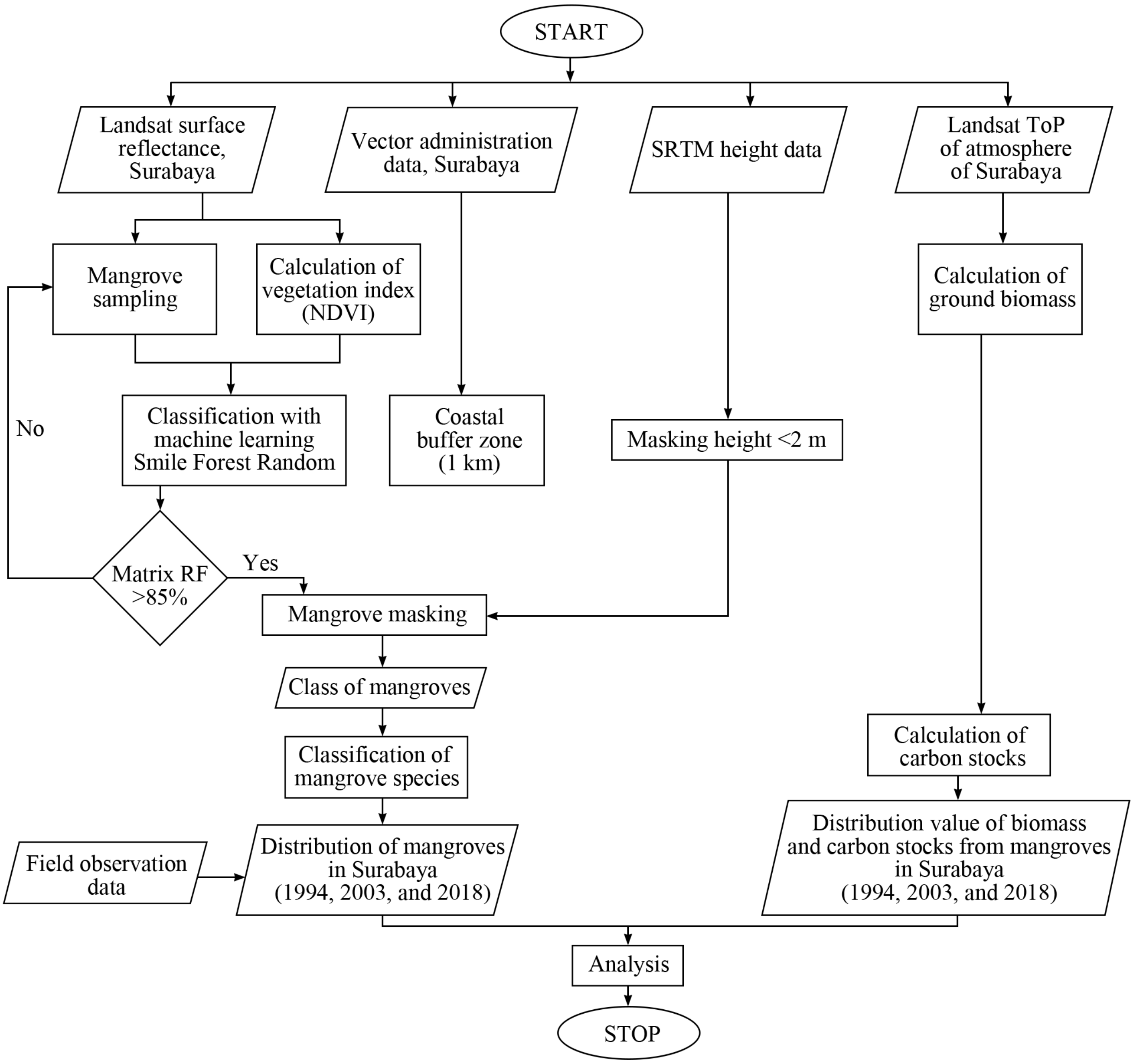

Fig. 2. The researchers' workflow.
Рис. 2. Схема исследования.

of Random Forest is popularly used in remote sensing for land cover mapping [23; 24]. The advantages of Random Forest are using non-parametric algorithms, having high classification accuracy, and having an ability to determine important variables and to predict missing values. Random Forest is a machine learning assembler that is efficient in handling big data and complies with requirements and commands. Random Forest is a combination of non-parametric classification and decision trees/CART (Classificarion and Regression Trees). To get an optimum parameter value, random forest parameters were tested in the form of maximum depth, minimum number of samples per tree, and maximum number of trees [11].

Breiman [24] presented the Random Forest (RF) algorithms, which is a classifier that uses several independent decision trees to predict categories of randomly selected sample data. A bootstrap sampling approach was applied to extract data from the training sample set, and each decision tree consisted of several binary trees that were split recursively from the root node to bisect the training sample set according to the notion of minimum node purity [18]. Each decision tree is a classifier. Several independent decision trees combine the RF algorithm model and random forest noise on each decision tree classification result to get the final classification result. The RF method has the advantage of not being sensitive to parameters and not too complex.

In the study, the researchers carried out a masking process to ensure that the expected results of the first classification were in accordance with reference data. The first parameter that had to be filtered was the cloud using the band information obtained from the pixel_qa band on Landsat. Pixel_qa band is a pixel quality attribute generated from the CMASK algorithm. Vegetation index parameters and other indices were also used to identify mangrove characteristics such as MSAVI (Landsat Modified Soil Adjusted Vegetation Index), NDWI (Normalized Difference Water Index), and NDVI (Normalized Difference Vegetation Index). In the research we used NDVI identification.

Classification accuracy was assessed using a confusion matrix based on the sample points taken in conducting the classification. Sample points were randomly assigned for training and validation. 80% of the sampling points were used to 'train' the model while 20% were used for validation. This was done to eliminate systematic errors as a result of using the same pixels to train and validate classifiers [25; 26]. Independent accuracy assessments were carried out via Google Earth Engine. The classification was carried out to obtain the types of mangroves based on the value of NDVI. NDVI formula has been discovered by Rouse et al. [26] using NIR and Red band to calculate the vegetation index:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}.$$

From the mangrove class data, it was then classified according to the criteria developed by the Department of Forestry [27] with modification.

Regarding the biomass and carbon stock calculation, the researchers used Landsat level 1 Top of Atmosphere data. First, the reseachers calculated the Ground Biomass from the data and worked out equation 4 and equation 5 [17]. The biomass value was estimated using the Steininger formula as follows [18]. This formula was used due to the same application for tropical area:

$$AGB = 50.77 - 287.62 \times X.$$

AGB is above ground biomass (kg/m^2). *X* = Landsat TM atmospherically corrected reflectance. After that, the researchers calculated the carbon stock value using the following formula [7; 16; 17]:

$$Carbon\ storage = 0.5 \times biomass.$$

RESULTS AND DISCUSSION

Mangrove area, distribution, and type. There are 77 mangrove species around the world [28]. The processing of Landsat satellite imagery data of 1994, 2003, and 2018 showed that in general there were 3 mangrove genus that grow on the coast of Surabaya: *Avicennia*, *Rhizophora*, and *Sonneratia*. Each genus has different characteristics or values so that in this study the researchers divided NDVI range values into 3 groups: 0–0.32 for the *Sonneratia* mangrove genus, 0.32–0.42 for the *Avicennia* mangrove genus, and 0.42–1 for the *Rhizophora* mangrove genus. The results of each mangrove genus are described in Table 1.

The classification results showed that in 1994 most mangroves were composed of *Sonneratia* (391.286 ha). The *Avicennia* mangrove genus has the least number compared to the other two mangrove genera. The total width of mangroves in Surabaya in 1994 was 743.843 ha. In 2003, the total width of mangroves increased by 1253.287 ha. Nearly 10 years since 1994, the population of *Rhizophora* has almost doubled. The *Rhizophora* mangroves grew in a 614.586 ha area in 2003 and 911.786 ha in 2018. In 2018, the population of *Sonneratia* mangrove declined sharply, which grew only on a 82.258 ha area while the total mangrove area in Surabaya was 1173.797 ha. Only *Sonneratia* mangroves experienced population drop, while generally from 1994 to 2018 the width of mangrove area in Surabaya increased by 429.954 ha.

Based on the data analysis, the *Avicennia* and *Rhizophora* mangroves increased in abundance in 1994, 2003, and 2018. During the last 24 years, the *Avicennia* mangrove area has increased by 164.852 ha, and the *Rhizophora* mangrove area has increased by 574.13 ha. On the other hand, the *Sonneratia* mangrove area decreased by 309.028 ha. The *Sonneratia* area experienced an up and down phenomenon when the area expanded from 1994 to 2003 but narrowed in 2018.

Table 1. The mangrove genus classification results in Surabaya (ha)
Таблица 1. Площадь мангровых зарослей в Сурабае в исследуемый период по результатам определения их родовой принадлежности (га)

Mangrove genus / Род мангровых деревьев	Year / Год		
	1994	2003	2018
Sonneratia	391.286	508.980	82.258
Avicennia	14.901	129.720	179.753
Rhizophora	337.656	614.586	911.786
Total / Всего	743.843	1253.287	1173.797

Table 2. Estimation of biomassa and carbon stock in Surabaya in mangroves during the study period
Таблица 2. Определение биомассы и запаса углерода в Сурабае в мангровых зарослях в исследуемый период

Mangrove genus Род мангровых деревьев	Biomass results estimation (kg/m²) Результат определения биомассы (кг/м²)			Carbon stock results estimation (kg/m²) Результат определения углерода (кг/м²)		
	1994	2003	2018	1994	2003	2018
Sonneratia	10.239	37.315	33.408	5.120	18.658	16.704
Avicennia	11.830	36.944	33.882	5.915	18.472	16.941
Rhizophora	20.828	21.786	18.868	10.414	10.893	9.434
Total / Всего	42.897	96.045	86.158	21.449	48.023	43.079

In 2012, the Surabaya government assigned the mangrove area in Surabaya a conservation area status. In addition, the Surabaya government begun to focus on managing mangrove areas into educational and tourism areas in Wonorejo and Gunung Anyar sub-districts. One of the reasons for the ups and downs in the mangrove area width in Surabaya is due to changes in land function. The City of Surabaya is an economic center in Indonesia so the mangrove area that should be a conservation area turns into a residential area or a pond area and vice versa [29]. There is a need for strict regulations from the Surabaya government regarding the supervision and rehabilitation of mangrove forests in the future.

So far, mangrove forest rehabilitation activities have been carried out using *Rhizophora* mangroves [5] without paying attention to the condition of the ecosystem to be rehabilitated and the previous zoning of mangrove plants. This can change the natural zoning system that has taken place in the ecosystem. Therefore, it is necessary to structure mangrove vegetation monitoring in areas that have been rehabilitated [13]. The North and East Coasts of the City of Surabaya were the locations for monitoring the mangrove ecosystem quality. If the location experiences a decrease in the mangrove area width, it will be necessary to review the mangrove ecosystem management.

Estimated biomass and carbon stock value. Mangrove forests are wetland ecosystems, having carbon storage reaching 800–1 200 tons per hectare. The release of emissions to the air in mangrove forests is smaller than in forests on land because the decomposition of aquatic plant litter does not release carbon into the air. The amount of mangrove forest biomass plays an important role in the carbon cycle because about 50% of forest carbon is stored in its vegetation. Therefore, if forest damage occurs, the amount of CO_2 that can be absorbed will also decrease [30].

The data of biomass and carbon stock is shown in Table 2. The estimated biomass value in Surabaya has an up and down state. Over 24 years, the estimated change in biomass produced by mangroves in Surabaya has increased by 100%. In 1994, the estimated value of biomass was 42.897 kg/m^2 while in 2003 it increased to 96.045 kg/m^2, and in 2018 it decreased again by 86.158 kg/m^2. Calculation of the estimated carbon stock value is half of the estimated biomass value. As a result, the estimated carbon stock value in 1994 was 21.449 kg/m^2 while in 2003 it increased to 48.023 kg/m^2, and in 2018 it decreased by 43.079 kg/m^2. The data from the calculation of the estimated biomass value in this study had a correlation value with the 2018 environmental service report data, which is 0.8903 while the estimated carbon stock value was 0.8901.

Mangrove forests have an important role in the ecosystem balance in the Surabaya area. The point is that mangroves function to protect land from sea waves and reduce abrasion or erosion of land by sea water. Therefore, a biomass inventory of mangrove forests in Surabaya is very necessary to determine changes in carbon stocks and the ability of vegetation to absorb carbon, which is one of the most important environmental components in mitigating climatic changes. In addition, data on biomass and carbon stock in the Surabaya mangrove forest is important for mangrove forest conservation management.

CONCLUSION

The presented study used Landsat image data and the GEE platform to generate information about mangroves in the City of Surabaya. The study found that there were three genera of mangroves growing in Surabaya: *Rhizophora* (dominant), *Sonneratia*, and *Avicennia*. The increasing number of mangroves in Surabaya is due to the Surabaya government program that was replanting mangrove forests (generally using the *Rhizopora* genus) on the Surabaya coast so that the North and East coasts of Surabaya were the locations for monitoring the mangrove ecosystem quality. Other governmental activities were to increase the width of the mangrove forest by issuing several regulations regarding the management of the Surabaya coastal area, for example the regulations regarding developments in the coastal area. The more mangroves, the higher the value of biomass and carbon stock produced. The potential of the mangrove forests in Surabaya is expected to contribute to minimizing the occurrence of greenhouse gases or global climatic change by absorbing carbon released into the air. The form of monitoring is carried out such as research or field measurements regarding the value of coastal mangrove biomass. In the future, it is hoped that periodic monitoring of the Surabaya mangrove area can be continued and can utilize and develop remote sensing data with the method offered in the study.

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