Original Paper

Spectral angle mapper algorithm for mangrove biodiversity mapping in Semarang, Indonesia

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Received: 15 November 2021 | **Accepted:** 7 May 2022 | **Published:** 2 June 2022

Keywords: Mangrove biodiversity mapping; Remote sensing; Spectral angle mapper.

Abstract. *Monitoring biodiversity is a key component of sustainability research related to safeguarding ecosystems. Although there still exist limits to its application, remote sensing has been used to map mangrove biodiversity and its distribution using spectral reflectance. This study considers the mangrove ecosystem in the Semarang coastal area using the Spectral Angle Mapper (SAM) method for biodiversity identification at species level. The* *remote sensing data is SPOT 7 imagery, acquired on 24 December 2019. In situ spectral reflection measurements were performed using a USB4000 spectrometer. The result from in situ measurement is referred to as the spectral library used for mangrove classification. Eight mangrove species were identified by the SAM method in this study, with a preponderance of the species* Avicennia marina *in the northern part of the study area, an open area that directly faces the sea, corresponding to the original habitat of* Avicennia marina. *The study shows that while the SAM method can be considered accurate for species with larger concentrations, the classification results demonstrate an overall moderate-low accuracy of 52% because some species classes have small patches that are intermingled with areas of different land-use. Further developments in remote sensing analysis techniques and more research will be necessary to endeavor to overcome these limits.*

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1. Introduction

Indonesia is an archipelago country with the second longest coastline, after Canada (Dahuri, 2007). The coast has diverse ecosystems, ranging from the marine ecosystem to the mangrove ecosystem. It is estimated that 18-23 percent of the world's mangrove ecosystem is in Indonesia, and 80 percent of the world's mangrove species (Fawzi, 2016; Rusila Noor, Y., M. Khazali, 1999). However, Indonesia's mangrove ecosystem has faced gradual loss due to aquaculture development, urbanization, and agriculture (Ilman et al., 2016). Indonesia's annual mangrove loss is only six percent of total forest loss, but the impact rises to 31% of carbon emissions in the land-use sector (Murdiyarso et al., 2015). There is a real risk that mangroves will become extinct and relatively soon become a part of history (Julkipli et al., 2018).

The conservation of the mangrove ecosystem's high carbon stock is vital to help mitigate climate change in the land-use sector (Alongi, 2020). Mangroves constitute a vitally important ecosystem because they affect the wellbeing of many other ecosystems. Studying mangrove sustainability on the coast of Semarang, involves taking into consideration social and environmental issues, together with the roles of economic agents and policy makers (Dayan, 2020). Direct observation in the field allows us to observe several aspects of mangrove sustainability at the research site. Mangroves are growing well where community participation can maintain and continue to expand the mangrove ecosystem.

At the same time, many people depend on mangroves to meet their daily needs, but their long-term survival is in jeopardy because of tidal flooding, garbage, confusion over the ownership of mangrove land and various other coastal problems (Kesemat, 2021). The results of interviews with the community in Mangkang Kulon show that the problem of ownership of mangrove land is one of the crucial problems. An activist group reports that its endeavors to protect and promote mangrove ecosystems have been hampered by landowners' desire to designate the land for other uses. Where the land currently used is not 100% owned by the community, there is always a risk of such groups being forced to move their mangrove land to another location. Certainly, the rehabilitation of mangrove land takes a very long time and increasing the area of mangrove land on the coast of Semarang City poses many challenges. Much more research is required into the sustainability of mangroves on the Semarang Coast and their relationship with other ecosystems.

Supporting their conservation needs reliable mangrove condition data, including its species and distribution. The main problem is the data that had been provided by the government is not up to date and it is hard to identify mangrove change. Rahadian et al. (2019) have stated that mangrove biodiversity information is a national problem, given the importance of having accurate and consistent historical data. Such data is essential for developing policies in mangrove management. In recent years, remote sensing data has begun to successfully provide mangrove ecosystem information (Pham et al., 2019). In the past, available mangrove data has usually not given information concerning specific species, but this is fundamental for mangrove management (Atkinson et al., 2016; Chow, 2018). Moreover, indiscriminate land use change, not in accordance with a specific designation, has led to increasing degradation of the mangrove area and consequent loss of mangrove species.

Accurate mangrove species mapping relies on the spectral characteristics of mangrove species in remote sensing images (Kamal et al., 2017, 2018). Every mangrove species has its signature of spectral reflection on a different wavelength. Hence, using the spectral library for mangrove species data in mangrove ecosystem mapping is efficient and cost-saving. In Indonesia, this method has not been widely used because it requires *in situ* measurement. A Spectral Angle Mapping (SAM) algorithm aims to become a reliable method for mangrove ecosystem mapping using spectral library data. In its application, the SAM algorithm has already proved successful as the most promising approach for mangrove species mapping (Salghuna & Pillutla, 2017; Su et al., 2019). This research aims to map the mangrove ecosystem in Semarang coastal area using the SAM method for biodiversity identification.

2. Materials and Methods

2.1 Study Area

The research was conducted in Semarang coastal region (6°59'35" S 110°25'14" E). Semarang city has an area of 373.8 km² with 1.5 million inhabitants. The rainfall 2,800 mm per year. This research was conducted in two-site, Mangkang Kulon and Mangunharjo Village and Tugurejo and Tambakharjo Village. The research was conducted in these four villages because they have different mangrove characteristics. Mangkang kulon and mangunharjo have mangrove conditions that are still well preserved, while the other two villages are starting to be degraded by other developed land and fishponds. The difference in these characteristics can be used as a comparison material in the classification process later.

The data obtained covers an area of around 172.79 ha, most of which is located on the coastline of Mangunharjo Village with 69.47 ha and on the coastline of Tugurejo Village with 62.69 ha. Most of the mangroves in this location have a longitudinal distribution pattern on pond embankments and river borders. There are also some mangroves that have cluster patterns, such as in Mangunharjo Village and Tugurejo Village (Dukuh Tapak).

Mangroves that are currently growing are the result of planting carried out by the community with edutourism programs, government agency programs (DLH and DKP Semarang City), universities through community service activities and companies through Corporate Social Responsibility (CSR) programs. Only a small part of the Semarang City area has mangroves that grow naturally, and the vast majority is the result of the rehabilitation process carried out by residents and related parties. The tables and figures present information related to mangroves on the west coast of Semarang City, both spatially and in terms of their appearance in the field.

Figure 1. The study location in the coastal area of Semarang City, Central Java.

2.2 Data and Analysis

The remote sensing data in this research is the SPOT 7 image acquired on December 24, 2019. SPOT 7 has four multispectral bands and one panchromatic with 6 meter and 1.5-meter spatial resolution respectively (Astrium Services, 2013). The image was corrected geometrically and converted to top-of-atmosphere value (W/cm2.sr.nm). The radiometric correction used the Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) method.

Fieldwork was conducted on August 14-15, 2020, between 09:00 and 11:00 a.m., to collect eight mangrove species' spectral data. The purposive random sampling method employed provided as many as 30 samples. The samples were taken according to the number of species contained in the study area. In this area there were 8 species of mangroves to be covered and data was collected for each species 3 to 4 times in different locations. The sampling location was based on the ease of accessibility to permit measurement using a spectrometer. In addition, samples were taken only on vegetation that gets optimal sunlight. Each measurement at the sample point recorded coordinates to facilitate identification at the time of processing using SPOT imagery where there was sufficient space for cables connected to the spectrometer.

The eight mangrove species were Avicennia marina, Rhizophora apiculata, R. mucronata, R. stylosa, Bruguiera Gymnorhiza, Ceriops Tagal, Sonneratia alba and Xylocarpus granatum. The measurement used a USB4000 spectrometer with sensor wavelength at 200 to 1100 nm. The wavelength of spectrometer calibrated with the wavelength on SPOT 7 image, with a range within 400 – 900 nm. Before using the spectrometer, it was calibrated with white and dark reference spectra to obtain reference spectrally. Spectral data from the spectrometer was calculated following this equation to obtain the spectral characteristic of each mangrove species (Optic, 2009).

$$R\lambda = \frac{S\lambda - D\lambda}{Ref\lambda - D\lambda} \times 100\%$$

The thirty samples were measured during two days of fieldwork. The data was converted into a spreadsheet for spectral library database input in mangrove classification using the SAM method. SAM is an algorithm based on the assumption that a pixel in the remote sensing imagery reflects an object on the earth's surface (Rashmi et al., 2014). This algorithm uses a deterministic similarity measure to compare with an unknown pixel based on the spectral library (Bertels et al., 2002). A pixel's spectral reflection can be described as a vector in a n-dimensional space or feature space, n being the number of wavelengths. Each vector must have a certain length and direction (Kruse et al., 1993). Classification using the SAM algorithm is done by calculating the spectral angle between the spectral reflection of a pixel and the spectral library. Each pixel is grouped into a class based on the lowest value on its spectral angle. The smaller the angle formed, the more suitably it reflects the spectral library. The spectral reflection pattern that is furthest away from the maximum threshold of the specified angle is categorized as unclassified (Cho et al., 2012). The SAM method is a supervised classification because it uses the spectral library from *in situ* measurement for the training area. The following equation was used (Jensen J. R, 2005):

$$\alpha = cos^{-1}\left[\frac{\sum_{i=1}^{nb} t_i r_i}{\left(\sum_{i=1}^{nb} ti^2\right)^{1/2} \left(\sum_{i=1}^{nb} ri^2\right)^{1/2}}\right]$$

Where α is a spectral angle, nb is the satellite image band (four in SPOT 7), t is the spectral pixel, and r is the spectral library. The fieldwork data was also checked for accuracy measurement using the confusion matrix method, a specific table layout that allows visualization of the performance of an algorithm.

3. Results and Discussion

3.1 Mangrove Spectral Reflectance

The results obtained show that spectral reflectance from field measurement has two peaks at the green and near-infrared wavelength. The vegetation has a sharp change in leaf reflectance from red to near-infrared, also known as a red-edge (Horler et al., 1983). In mangrove species, the red-edge information can improve species classification (Schuster et al., 2012).

In Figure 2, the spectral reflection of each mangrove species shows the pattern of healthy vegetation. Healthy vegetation has absorbed the wavelength in blue (400-500 nm) and red (600-700 nm) and increase in green because of chlorophyll and red edge in near infrared (Kamal et al., 2018).

The *Bruguiera gymnorhiza* species has the highest spectral reflectance among the mangrove species. *A. marina* has the lowest reflectance value in the visible wavelength and *Sonneratia alba* in the near-infrared wavelength. Even where mangrove species have the same pattern of reflectance, every species has a different signature wavelength. So, despite having the same pattern, each species will have a different spectral reflectance (Arfan et al., 2015; Indarto, 2012). The difference is caused by age, health condition, and tree physiology, such as canopy and leaf geometry (Blasco et al., 1998).

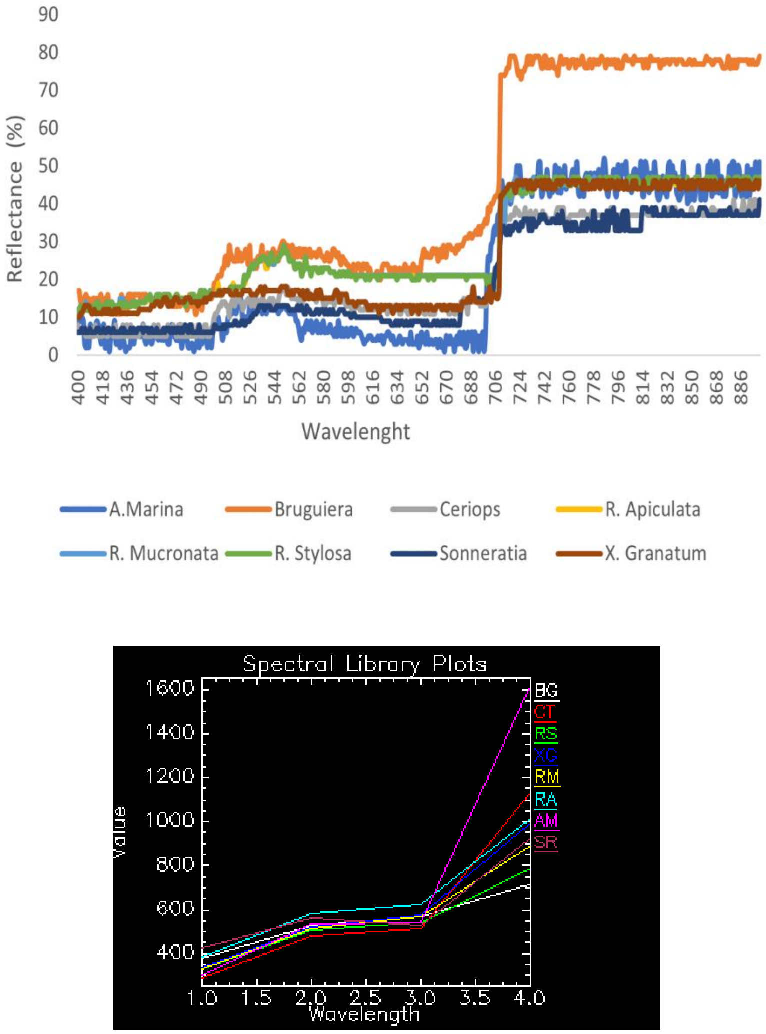

Figure 2. (a) the spectral reflectance of mangrove species from *in situ* measurement, and (b) spectral plot for classification in SPOT 7 image from *in situ* measurement.

 http://dx.doi.org/10.13135/2384-8677/6238

3.2 Mangrove Mapping

The spectral library from *in situ* measurement became a reference for mangrove species mapping in SPOT 7. The results (Figure 3) show how A. marina dominated in the northern area of up to 30 hectares directly adjacent to the sea (Table 1). Avicennia has adaptation in high salinity with several adaptations, such as excluding the excess salt from metabolic mechanisms (Hogarth, 2017). The distribution followed by Rhizophora with a total from three species is over 29 hectares. The Xylocarpus granatum and Ceriop tagal dominated mangrove distribution on the mainland due to their adaptation to lower salinity. The study also detected a one-hectare presence of Sonneratia.

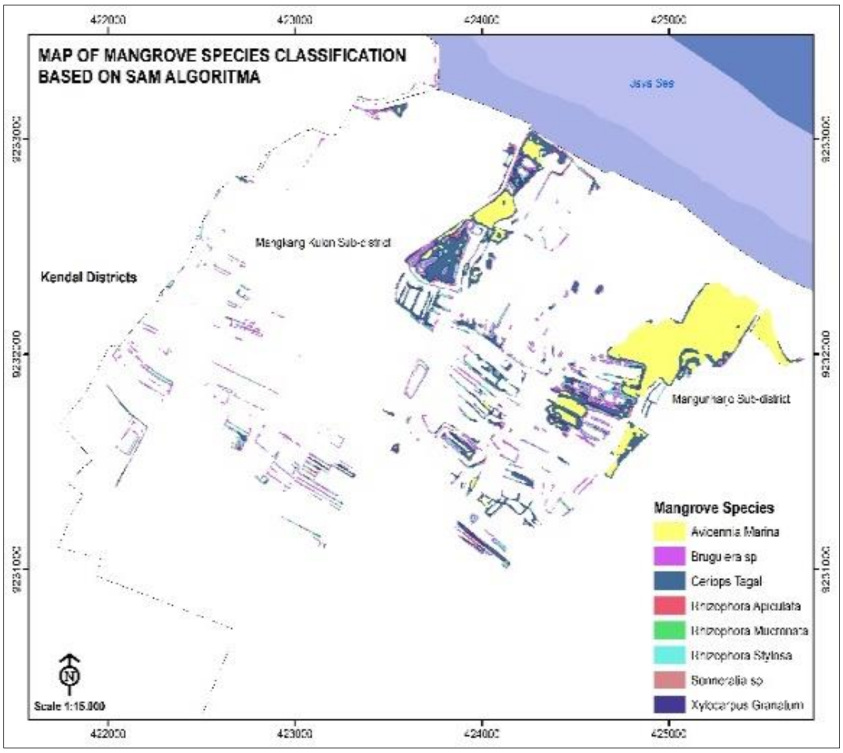

Figure 3a. the mangrove species map using SAM algorithm in Mangkang Kulon and Mangunharjo Village.

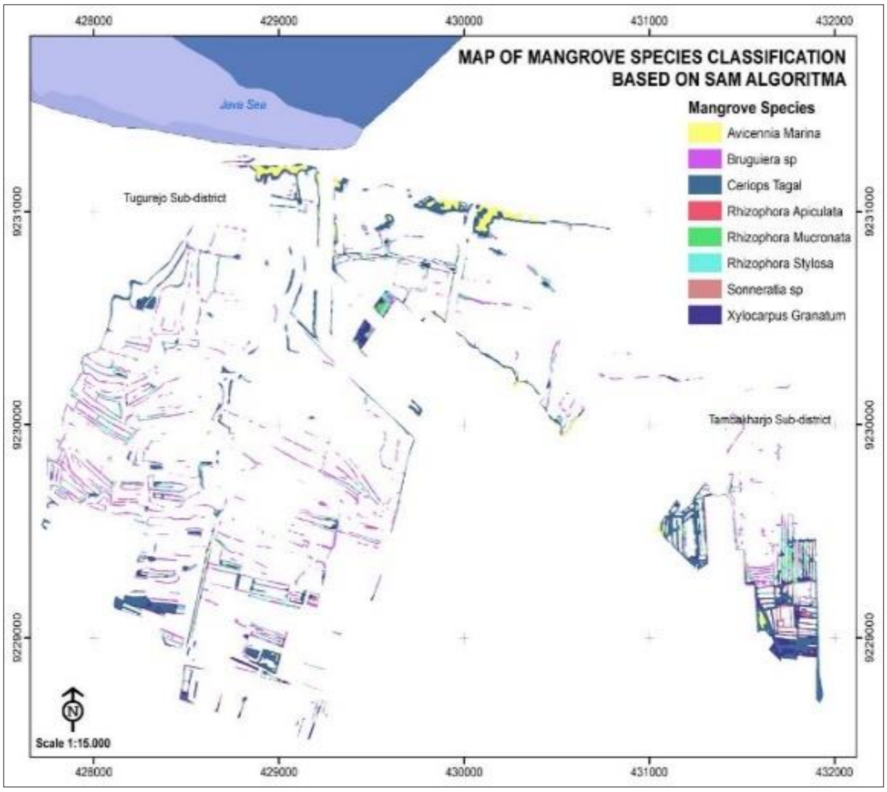

Figure 3b. The mangrove species map using SAM algorithm in Tugurejo and Tambakharjo Village.

Previous research (Tri Martuti, 2014; Tri Martuti et al., 2019) on the composition of vegetation in Tapak village, Tugu district, showed that Tapak has 16 vegetation species, consist of 12 families with dominance of A. marina and R. mucronata. This coincides with the result of our study and the reason is that Tapak village was designated as an artificial ecosystem for mangroves. A. marina and R. mucronata are the most widely grown crops in these kinds of ecosystems.

No	Mangrove species	Area(Ha)
1	Sonneratia alba	0.86
2	Rhizophora apiculata	5.05
3	R. mucronata	7.20
4	R. stylosa	15.56
5	Xylocarpus granatum	20.02
6	Ceriops tagal	27.42
7	Avicennia marina	29.63
8	Bruguiera gymnorhiza	29.87

Table 1. The total area of mangrove species from SAM classification

The classification results using the Sam method were tested for accuracy by comparing them with conditions in the field. The accuracy test was carried out using the confusion matrix or error matrix method. An error matrix is an arrangement of numbers arranged in rows and columns that is a representation of the number of sample units (such as pixels, pixel groups, or polygons), filled in according to categories, relative to actual categories (Congalton & Green, 2005). Matrix errors contain classes of image classification results in their rows, and field checking classes in columns, while matrix contents show the number of objects. The more objects there are that show the similarity of classes in rows and columns, the higher the accuracy of classification results. Matrix errors produce a reading of overall accuracy. Overall accuracy is the percentage of the number of pixels resulting from the correct SAM classification based on field data. In addition, matrix errors also produce producer and user accuracy. Producer's and user's accuracies are ways of representing individual category accuracies. Producer's accuracy is the number of errors of attribution. A commission error is defined as including an area in a category (one of the species) when it does not belong to that category (species). User accuracy is the number of errors of omission. An omission error is defined as excluding an area from the category (species) to which it belongs. Every error is an omission from correct category (species) and an attribution to a wrong category (species) (Congalton & Green, 2005).

The confusion matrix method to found overall accuracy is only 52%. This means that only half of the classified mangrove area has the correct species based on the conditions in the field. The reason for lower accuracy is from the scatter of non-dominant species distribution. Scatter distribution leads to increased background noise from land-use around Bruguiera such as ponds and road. The decrease in the accuracy value can be seen in the following matrix containing information about producer accuracy and user accuracy for each species. Producer accuracy shows how well each species in the field has been classified. If producer accuracy produces a value of 100%, no pixels from that class are entered into other classes. Meanwhile, if user accuracy produces a value of 100%, the class does not misclassify by not taking pixels from other classes (Story & Congalton, 1986). In the matrix below, the highest user accuracy is in the classes R. mucronata, R. apiculata and A. marina. Conditions in the field also show that these three species dominate the mangrove area at the study site. Thus, the potential for misclassification can also be avoided.

However, the R. stylosa, X. granatum and Sonneratia species have low user accuracy, even as much as 0%. This is because these three species do not dominate in the research location, their distribution is sporadic and therefore does not meet SPOT pixels with a size of 6x6 meters. The image used is SPOT with a spatial resolution of 6x6 meters. If an object has an area of less than 36 m2, it will produce mixed pixels meaning that the reflectance value of the pixel is not the value of a single object. In the field, the three non-dominant objects at the time of measurement have an area of less than 36m2, and the pixel value at the location is heavily influenced by the reflectance of other objects such as roads, ponds, and pond embankments. Conditions like this can lead to a considerable risk of misclassification (Choodarathnakara et al., 2012).

The highest measure of user accuracy values was for the three species: R. mucronata, R. apiculata and A. marina. In contrast, other species did not measure a large accuracy value and even reached 0%. This causes the overall accuracy value to be low, and the resulting value is 52%. However, research on classification using the spectral library with the SAM method often produces an accuracy value that is not very high. Similar studies such as by (Kamal et al., 2018) regarding the classification of mangrove species on Karimun Java Island resulted in an accuracy value of 62%. Research on the classification of seagrass habitats using the SAM method on Tunda Island resulted in an accuracy value as low as 35.6% (Aziizah et al., 2016). Factors that cause low accuracy include mixed pixels and ambiguous classification results as occurred for some of the data in our study.

Classified Value

Thematic	B. gymnorhiza	C. tagal	R. stylosa	X. granatum	R. mucronata	R. apiculata	A. marina	Sonneratia	User accuracy (%)
B. gymnorhiza	1	0	0	0	1	0	0	0	50
C. tagal	0	1	0	0	1	0	0	0	50
R. stylosa	0	0	0	0	0	0	2	0	0
X. granatum	0	0	0	0	1	0	1	0	0
R. mucronata	0	0	0	2	0	0	0	0	100
R. apiculata	0	0	0	0	2	0	0	0	100
A. marina	0	0	0	0	0	2	0	0	100
Sonneratia	0	0	0	0	2	0	0	0	0
Producer Accuracy (%)	100	100	0	0	28.6	100	40	0	52

Table 2. SAM classification results

4. Conclusions

Mangrove biodiversity mapping using the SAM method has been proven to show better results in Semarang coastal. Eight species dominated the study area. Fieldwork measurement using spectrometer found mangrove species also have a red-edge effect in near-infrared wavelength. Despite the opportunity to map mangrove distribution, our research only has 52% accuracy. Moreover, our remote sensing analysis was carried out only once. Subsequent research will need to repeat this at least three times to assess data reproducibility and the consequent reliability of the analysis.

In the future, there is a need for improvement in image processing to increase map accuracy. Methods of species identification using remote sensing still require considerable further development. This will necessarily require an improvement in the number of samples with different location variations so that the spectral library is richer, together with improvements to the algorithms used to better identify species. In terms of overall monitoring of biodiversity, SAM clearly has some current limits. Remote sensing analysis can only show how a certain distribution of vegetation changes with time. Further development is necessary to separate different mangrove species. Such an improvement in remote sensing analysis techniques will enable it to play an increasingly important role in building monitoring systems that are able to provide the consistent, reliable biodiversity data necessary for safeguarding ecosystems.

Acknowledgements

The author would like to thank Dr. Suwito Eko Pramono, M.Pd as the Head of the Semarang State University of Research and Community Service Institute, who has provided funds to achieve this research. We would like to Mr. Sururi for giving permission and providing instructions during field measurements. Also, for National Aeronautics and Space Agency for give this opportunity and providing SPOT 7 data.

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Authors' contributions

This research was carried out by a team, consisting of Tjaturahono Budi Sanjoto, Vina Nurul Husna and Wahid Akhsin Budi Nur Sidiq. Conceptualization for the research was done by Tjaturahono BS, and developing the methodology, finding the appropriate software, validation, formal analysis, data curation, writing original draft preparation and editing was done by Vina NH. Supervising this project and project administration was done by Wahid Akhsin. Funding acquisition was done by Tjaturahono.

Funds

This research was funded by Research and Community Service Institute of Semarang State University, with grant number SP DIPA-023.17.2.677507/2020.

Competing Interests

The authors have declared no conflict of interest and the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Citation

Sanjoto, T.B., Husna, V.N., and Sidiq, W.A.B.N. (2022) Spectral Angle Mapper Algorithm for Mangrove Biodiversity Mapping in Semarang Indonesia. *Visions for Sustainability*, 18, 6238, 173-190. http://dx.doi.org/10.13135/2384-8677/6238