НАУКИ О ЗЕМЛЕ

УДК 528.88
DOI: 10.7868/S25000640210302

# DETECTING COASTLINE CHANGE IN THE SURABAYA COASTAL AREAS (INDONESIA) USING REMOTE SENSING METHOD

**© 2021 D.A. Safitri[1, 2], L.A. Bespalova[2], F. Bioresita[3], R.T. Nugroho[3]**

**Abstract.** Coastline change in the Surabaya coastal areas (Indonesia) is caused by erosion, accretion, and anthropogenic activities, which are caused by human activities in the coastal areas. All human activities in the Surabaya coastal areas have an impact on the coastline. The purpose of this study was to detect the coastline change in the Surabaya coastal areas from 1994 to 2018. The researchers used remote sensing method to detect the coastline change. The data were obtained from the satellites of Landsat 5 (1994), Landsat 7 (2003), and Landsat OLI 8 (2018). The researchers used the Digital Shoreline Analysis System software and the statistical calculation of End Point Rate. The results showed that from 1994 to 2018 the highest of the average accretion rate in Kalisari sub-district was 75.75 m/year, and the highest of the average erosion rate in Wonorejo sub-district was measured as of −3.4 m/year. Accretion and erosion occur due to the land use change. In Wonorejo, some mangrove areas were reduced due to illegal logging. In addition, land use change due to new ponds and residential areas occurred in East Surabaya. Meanwhile, anthropogenic activities had an impact on several areas due to Tanjung Perak and Teluk Lamong ports. To improve the environmental situation, continuous monitoring of the coastal areas of Surabaya and cooperation between the Government and the population are necessary.

**Keywords:** coastline, remote sensing, erosion, accumulation, coastline change rate, Surabaya, Indonesia.

## ОПРЕДЕЛЕНИЕ ИЗМЕНЕНИЯ БЕРЕГОВОЙ ЛИНИИ В РАЙОНЕ СУРАБАИ (ИНДОНЕЗИЯ) С ПОМОЩЬЮ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ

**Д.А. Сафитри[1, 2], Л.А. Беспалова[2], Ф. Биоресита[3], Р. Нугрохо[3]**

**Аннотация.** Изменение береговой линии в прибрежных районах Сурабаи (Индонезия) вызвано абразией, аккумуляцией и антропогенной деятельностью. Вся деятельность человека в прибрежных районах Сурабаи оказывает влияние на береговую линию. Цель этого исследования состояла в том, чтобы выявить изменение береговой линии в прибрежных районах Сурабаи за период с 1994 по 2018 г. Для обнаружения изменения береговой линии был использован метод дистанционного зондирования. Данные были получены со спутников Landsat 5 (1994), Landsat 7 (2003) и Landsat OLI 8 (2018). Использовалось программное обеспечение Цифровой системы анализа береговой линии (DSAS) и статистический расчет скорости конечных точек (EPR). С 1994 по 2018 г. самая высокая средняя скорость аккумуляции зафиксирована в подокруге Калисари и составила 75,75 м/год, а самая высокая средняя скорость размыва берегов – в подокруге Вонорехо, −3,4 м/год. Аккумуляция и абразия происходят из-за изменений в землепользовании. В Вонорехо из-за незаконной вырубки леса произошло сокращение мангровых зарослей. Кроме того, в Восточной Сурабае произошли изменения в землепользовании, связанные с созданием прудов и новых жилых районов. Антропогенная деятельность оказала воздействие

[1] Universitas of 17 Agustus 1945 (UNTAG) Surabaya (Университет 17 Августа 1945 (УНИТАГ) Сурабая, Индонезия), Indonesia, 60118, East Java, Surabaya, Sukolilo Sub-disctrict, Menur Pumpungan Urban Village, Jalan Semolowaru No 45, e-mail: dikadede@gmail.com
[2] Institute for Earth Sciences of the Southern Federal University (Институт наук о Земле Южного федерального университета), Российская Федерация, 344006, г. Ростов-на-Дону, ул. Большая Садовая, 105/42, e-mail: bespalowaliudmila@yandex.ru
[3] Department of Geomatics Engineering, Sepuluh Nopember Institute of Technology (ITS) Surabaya (Отделение геоматической инженерии, Технологический институт Сепулу Нопембер (ИТС), Сурабая, Индонезия), Indonesia, East Java, 60111, Surabaya, Sukolilo Sub-district, Keputih Urban Village, Geomatics Engineering Building ITS, e-mails: filsa.bioresita@gmail.com, rheza.trin.9@gmail.com

и на несколько районов из-за строительства портов Танджунг-Перака и Телук-Ламонг. Для улучшения экологической ситуации необходимы постоянный мониторинг состояния прибрежных районов Сурабаи и сотрудничество между правительством и населением.

**Ключевые слова:** береговая линия, дистанционное зондирование, абразия, аккумуляция, скорость изменения береговой линии, Сурабая, Индонезия.

## INTRODUCTION

The coastline is a line that forms the boundary between the land and the ocean and is influenced by tides. The coastline consists of the lowest tide, the highest tide, and the mean sea level. Seeing the varying position of the coastline, the coastline tends to have a dynamic character and its position can change [1].

The coastline is subjected to continuous change due to natural causes and human interventions in coastal zone. Identifying the areas vulnerable for erosion and quantifying its extent is essential for coastal zone management. Coastal erosion is a severe problem, particularly for a country facing explosive population growth along the coastal areas. The coastline is always subjected to change due to coastal processes, which are controlled by wave characteristics, sediment characteristics, beach form, etc. [2].

The coastal area is an area that is very intensively used for human activities, such as a central government area, settlement, industry, port, aquaculture, agriculture, fisheries, tourism, etc. The existence of these various activities can lead to an increase in the need for land, infrastructure, etc., which in turn will result in the emergence of new problems such as coastal erosion which damages residential areas and urban infrastructure in the form of retreating coastline or advancing coastline. The advancement of the coastline on the one hand can be said to be beneficial because of the emergence of new land, while on the other hand it can cause urban drainage problems in coastal areas [3].

Some of the activities of coastal communities in Surabaya, for example pond fishery activities, agriculture, changes in land use such as from mangrove areas to fish ponds, ponds to residential areas, cause some problems. The coastline change in the Surabaya coastal areas is caused by natural and anthropogenic activities. For this reason, periodic monitoring of the coastal areas is required.

In general, monitoring of coastal areas is carried out by using remote sensing satellites and the Geographic Information System (GIS). The Digital Shoreline Analysis System (DSAS) is software that is usually used to calculate coastline change and generate the change metrics of End Point Rate (EPR), Net Shoreline Movement, Linear Regression Rate, etc. Analyzing the coastline change with the DSAS, remote sensing technology can be an important and efficient tool. The use of remote sensing data is very useful for determining coastline change. Coastline change can be calculated using medium resolution satellite imagery. This calculation produces information in the form of a coastline change value of a specified period. Through remote sensing method, it was possible to study a very large area of land. The use of satellite imagery with a medium spatial resolution, such as the Landsat, is appropriate for dynamics monitoring of coastline [4].

Several studies were conducted with the Landsat satellite imagery to monitor coastline change. Dewidar and Frihy [5] found that the Landsat satellite data can be used to examine rapidly changed coastline along the northwestern part of the Nile delta from the Abu Qir Bay to Gamasa embayment. El Banna and Hereher [6] detected temporal coastline changes and erosion/accretion rates with remote sensing method and their associated sediment characteristics along the coast of North Sinai.

Coastal engineers and managers need a comprehensive understanding of the coastline physical change, key elements of the coast as a system, and an ability to identify historical coastline change and to predict future coastline change over times in order to achieve sustainable coastal management. This study was conducted to monitor the coastline change in the Surabaya coastal area over 25 years (1994–2018) by using the Landsat satellite imagery and DSAS.

## MATERIAL AND METHODS

Remote sensing is one of the most commonly used methods for monitoring coastal areas, such as to monitor coastline change. In this study, the researchers used remote sensing method to detect coastline change. The data were obtained from the satellites of Landsat 5 (1994), Landsat 7 (2003), and Landsat OLI 8 (2018). The other data were wind data in 2016, 2017, and 2018 (recorded every 1 hour for 24 hours). Wind data processing was intended to find out the most dominant

**Table 1.** The wind direction in Surabaya in 2016–2018
**Таблица 1.** Направление ветра в Сурабае в 2016–2018 гг.

| Angle and wind direction / Направление ветра | The percentage of frequency of wind direction / Процент частоты направления ветра: Wind speed (knot) / Скорость ветра (узел) | | | | | | | | Total percentage / Сумма |
|---|---|---|---|---|---|---|---|---|---|
| | 0~2 | 2~4 | 4~6 | 6~8 | 8~10 | 10~12 | 12~14 | 14~16 | |
| N | 0.79 | 1.12 | 0.41 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 2.36 |
| NE | 1.16 | 1.70 | 0.98 | 0.09 | 0.01 | 0.00 | 0.00 | 0.00 | 3.94 |
| E | 1.13 | 4.08 | 8.43 | 8.62 | 3.88 | 0.62 | 0.05 | 0.00 | 26.81 |
| SE | 0.98 | 6.99 | 13.95 | 6.10 | 1.47 | 0.28 | 0.00 | 0.00 | 29.79 |
| S | 0.88 | 1.46 | 0.53 | 0.29 | 0.11 | 0.03 | 0.00 | 0.00 | 3.30 |
| SW | 1.10 | 1.89 | 1.26 | 1.45 | 0.09 | 0.00 | 0.00 | 0.00 | 5.79 |
| W | 1.11 | 3.67 | 5.29 | 4.26 | 2.95 | 2.62 | 1.09 | 0.38 | 21.37 |
| NW | 0.90 | 2.09 | 1.71 | 0.93 | 0.33 | 0.36 | 0.21 | 0.11 | 6.65 |
| Total / Всего | 8.06 | 23.00 | 32.57 | 21.79 | 8.83 | 3.91 | 1.35 | 0.49 | 100.00 |

wind direction. This direction was used to find out the trend in the direction of sediment movement. The wind recording data were data from the Tanjung Perak Surabaya waters station with the coordinates of Longitude 112.663646°E and Latitude 7.107339°S (Table 1).

The researchers used the Digital Shoreline Analysis System (DSAS) software and the statistical calculation of End Point Rate.

DSAS is extension software from ArcGIS that allows users to calculate coastline change statistically over times [7]. DSAS enables users to do transect creation perpendicular to the baseline of the initial coastline change. In general, the functions of DSAS are (1) to determine the baseline reference for measurement; (2) to create transects and metadata based on predetermined parameters; and (3) to provide statistical information on coastline change. DSAS can do some statistical calculations that are End Point Rate, Linear Regression Rate, and Weighted Linear Regression Rate. This study with DSAS used the statitical calculation of EPR. According to Thieler [7], the equation of the Endpoint Rate Calculation (ECI) is as below:

$$ECI = \pm \frac{\sqrt{E_{tA}^2 + E_{tB}^2}}{Date(A) - Date(B)}.$$

$E_{tA}$ is the uncertainty of the position of the coastline *A*; $E_{tB}$ is the uncertainty of the position of the coastline *B*; *Date* (*A*) and *Date* (*B*) are the time or date of the coastline *A* and *B*, respectively.

This study used a baseline that was placed onshore. The transect was made towards the sea. The distance between the transects was 50 m and the transect length was 3,000 m. The researchers made the distance of 50 m because the data were mostly satellite imagery based on pixels and were considered sufficiently detailed to be applied to the Surabaya coastline which had a length of ±47 km and had an irregular shape. It was necessary to modify the transect so that the researcher found out the coastline change rate in Surabaya over 24 years.

The researchers used the Landsat satellite imagery of the coastline in 1994, 2003, and 2018 as the research data. The researchers drew the baseline and the coastline on screen digitizing. DSAS was performed on ArcGIS 10.1 software to automatically calculate the coastline change. The working principle of coastline change analysis applying DSAS was to use the new line obtained from the intersection of the transect line and the coastline in certain time [8]. The analysis was carried out by analyzing the results of the calculation of the coastline change and by selecting the data that had the highest and lowest change in each coastal urban village in Surabaya. The research flowchart is presented in Figure 1.

## RESULTS AND DISCUSSION

**The wind direction in Surabaya.** The researchers made a wind rose from wind data (Table 1) and it is presented in Figure 2. The results show that the dominant wind direction for 3 years was to the Southeast (29.79 %) and to the East (26.81 %) with the greatest wind speed of 4–6 knots. The direction of the sediment was from the southeast towards the east coast of Surabaya.

**The coastline change in Surabaya.** Changes in the Surabaya coastline indicated that there were

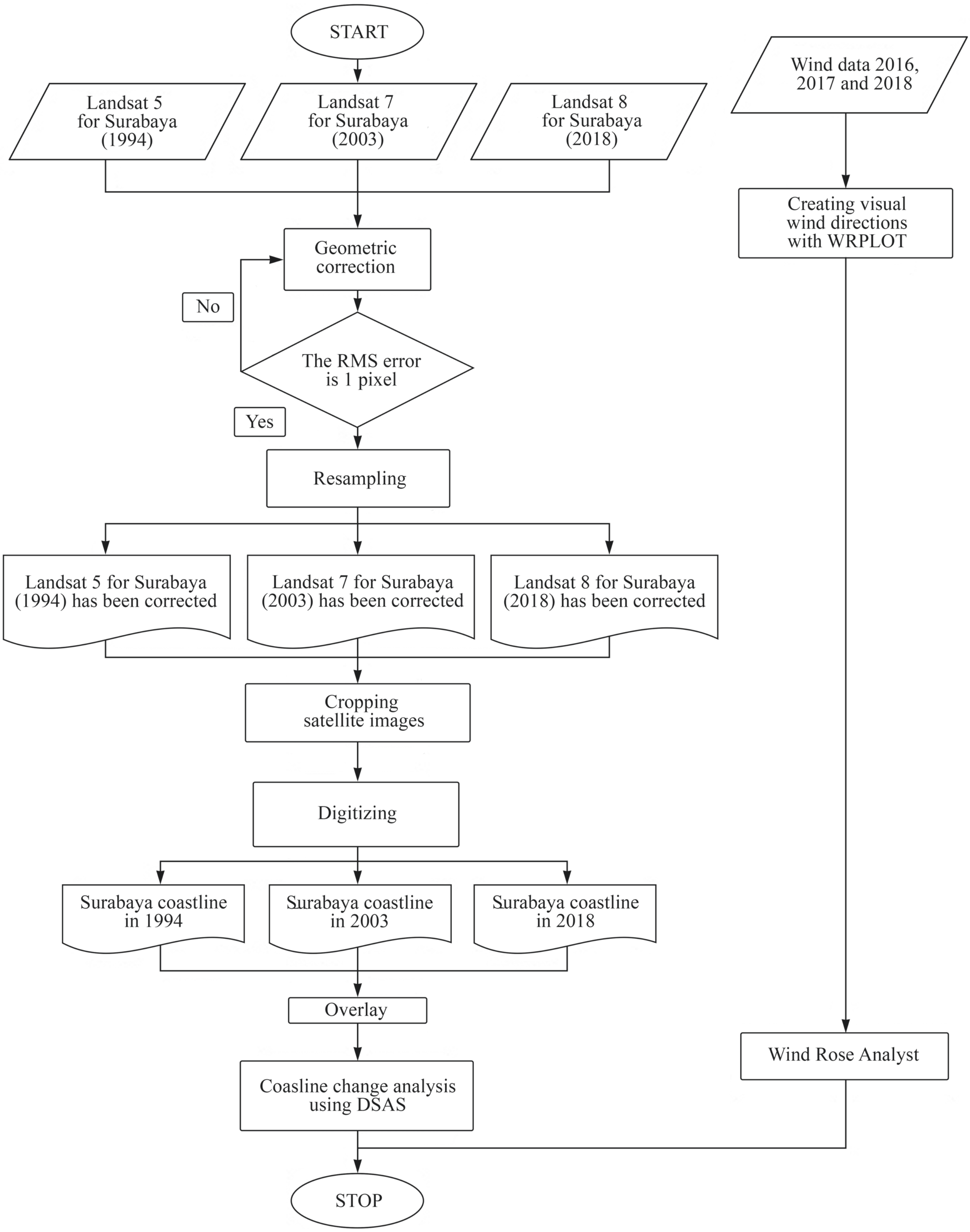


**Fig. 1.** The research flowchart.
**Рис. 1.** Блок-схема исследования.

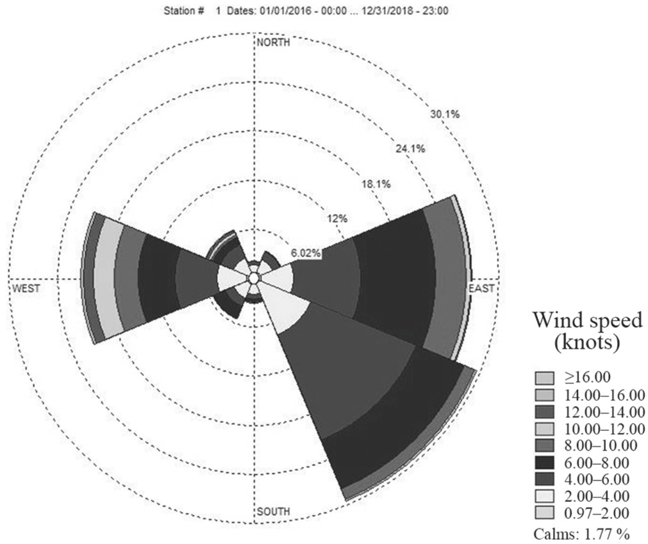


**Fig. 2.** The wind direction in Surabaya in 2016–2018.
**Рис. 2.** Направление ветра в Сурабае в 2016–2018 гг.

erosion, accretion and anthropogenic activities in the Surabaya coastal areas. The location identification to know where the coastal abrasion and accretion occurred was carried out by using overlaying method (the longest coastline with the current coastline). The results are presented in Figure 3. Based on the results of digitization, the researchers indicated areas where the coastline changed because of erosion, accretion, and anthropogenic activities. Safitri with co-authors [9] states that during the last 24 years erosion occurred in several sub-districts in the Surabaya coastal areas such as Wonorejo urban village, Rungkut sub-district measuring 141637.1 m$^2$. While the accretion almost occurred in all coastal areas in Surabaya. Accretion in Sukolilo sub-district was the largest accretion measuring 4401201.3 m$^2$. Most of the anthropogenic activities were because the construction of the Teluk Lamong Port in 2013 measuring 916068.3 m$^2$.

After the researchers had identified the locations where the erosion, accretion, and anthropogenic activities occurred, the researchers carried out data analysis to find out the coastline change rate by using DSAS. This was also to find out the rate of erosion, accretion, and anthropogenic activities in more detail. The statistical calculation was End Point Rate in DSAS.

The data showed that erosion occurred in the West North and East Surabaya coastal areas. The erosion occurred for 24 years in six sub-districts (10 urban villages) that were Benowo and Asemrowo sub-districts in the West, Krembangan and Kenjeran sub-districts in the North, and Sukolilo and Rungkut sub-districts in the East.

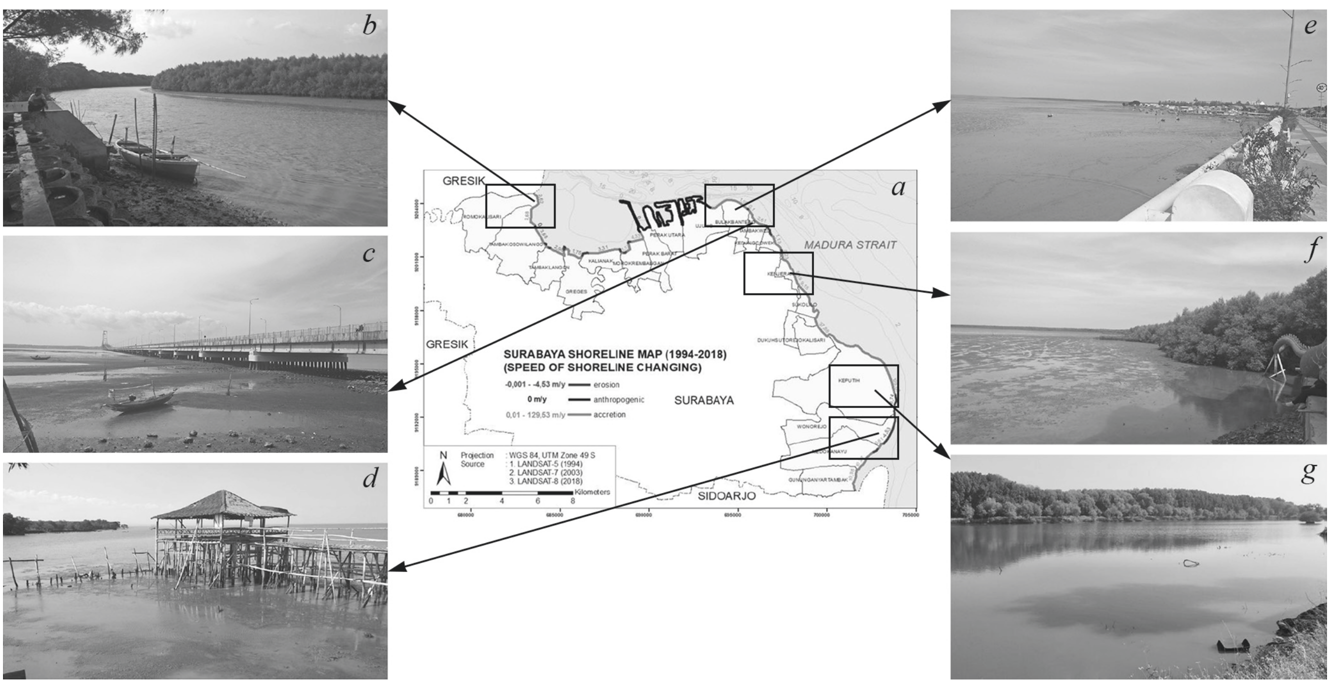


**Fig. 3.** The Surabaya coastline change speed map (*a*), and condition of coastline: *b* – in Romo Kalisari sub-district; *c* – in Wonorejo sub-district; *d* – under the bridge of Suramadu, Tambak Wedi sub-district; *e* – in a fishing urban village in Bulak sub-district; *f* – in "Dewi Kwan Im" temple in Kenjeran sub-district; *g* – in Keputih sub-district covered by mangroves.
**Рис. 3.** Карта скорости изменения береговой линии Сурабаи (*a*) и состояние береговой линии: *b* – подокруг Ромо Калисари; *b* – подокруг Воноремо; *c* – под мостом Сурамаду Веди, подокруг Тамбааку; *d* – в рыбацком поселке городского типа, подокруг Булак; *e* – в районе храма Деви Кван Им, подокруг Кенджеране; *f* – побережье, покрытое мангровыми лесами, подокруг Кеппутих.

**Table 2.** The average speed rate of erosion in the coastal areas of Surabaya (1994–2018)
**Таблица 2.** Средняя скорость размыва в прибрежных районах Сурабаи (1994–2018)

| | Sub-district<br>Подокруг | Urban village<br>Поселок городского типа | Speed rate over 24 years (m/year)<br>Скорость в среднем за 24 года (м/год) |
|---|---|---|---|
| West Surabaya<br>Западная Сурабая | Benowo | Tambak Osowilangun | −0.67208 |
| | Asemrowo | Greges<br>Kalianak | −3.355<br>−1.52444 |
| North Surabaya<br>Северная Сурабая | Krembangan | Moro Krembangan | −1.21 |
| | Kenjeran | Bulak Banteng<br>Tambak Wedi<br>Kedung Cowek | −0.03 min<br>−0.7<br>−0.62111 |
| East Surabaya<br>Восточная Сурабая | Sukolilo | Keputih | −1.82321 |
| | Rungkut | Wonorejo<br>Medokan Ayu | −3.4 max<br>−1.0975 |

During 24 years (1994–2018), the results indicated that the lowest of the average erosion speed rate was −0.03 m/year in Bulak Banteng urban village, Kenjeran sub-district, and the highest of the average erosion speed rate was −3.4 m/year in Wonorejo urban village, Rungkut sub-district (Table 2).

The coastal areas of East Surabaya were a mangrove area spread across Keputih, Wonorejo, and Medokan Ayu urban villages. Illegal logging of mangroves, especially in Wonorejo urban village, caused most of the erosion. Apart from erosion, the accretion occurred in 18 urban villages in 8 sub-districts that were Benowo and Asemrowo sub-districts in the West, Krembangan, Semampir, and Kenjeran sub-districts in the North, and Mulyorejo, Sukolilo, Rungkut, and Gunung Anyar in the East.

The data showed that the lowest of the average accretion speed rate was 0.81 m/year in Ujung urban village, Semampir sub-district, and the highest of the average accretion speed rate was 75.75 m/year in Kalisari urban village, Sukolilo sub-district (Table 3).

The researchers were local people in Sukolilo sub-district. Based on personal experience and interviews with local residents, there was coastal reclamation in Keputih and Kalisari urban villages. The new land is used as a new residential area. In addition, the illegal logging of mangroves that aimed to change a mangrove area to be a pond area caused coastal accretion, which then caused coastline change. The East Surabaya coastal areas were the territory that needed the greatest concern because the erosion and accretion occurred mostly in these particular areas (Fig. 3).

**The field observation.** During the last 24 years, the Surabaya coastal areas had undergone several changes, one of which was the change of coastline. In this study, the researchers also conducted a field observation to determine the current conditions of the coastline. With the Landsat satellite imagery, the researchers identified the areas where erosion, accretion and anthropogenic activities took place.

In West Surabaya, anthropogenic activities occurred in 2013 due to the construction of a new port that was Teluk Lamong Port in Tambak Osowilangun sub-district. Most of the West Surabaya was industrial areas and there were many loading and unloading activities. This condition also occurred in North Surabaya. Meanwhile, East Surabaya experienced very significant changes, especially in Kalisari sub-district, Keputih sub-district, and Wonorejo sub-district. In these districts, the accretion and erosion were quite severe. The accretion in Kalisari and Keputih sub-districts occurred due to land use change as initially there were mangroves and then they were changed to be ponds or vice versa. The erosion occurred due to illegal logging of mangroves. These community activities affected the condition of the Surabaya coastline. The researchers conducted a field observation to several locations in the Surabaya coastal areas and conducted brief interviews with local residents. The residents agreed that there was a need for cooperation with the government to protect the Surabaya coastal areas from erosion in particular by replanting mangroves. In addition, the government needed to conduct evaluation to protect areas vulnerable to accretion and anthropogenic activities so as not to damage the coastal environment (Fig. 3).

The researchers conducted a field observation in June-August period, which was a dry season in Indonesia – so the beaches were at low tide. Most of the coastal areas in East Surabaya are mangrove forests area. Nowadays, this area is an educational recreation area. There are many studies on mangrove ecosystems in East Surabaya. Good management attracts people

**Table 3.** The average speed rate of accretion in the coastal areas of Surabaya (1994–2018)
**Таблица 3.** Средняя скорость аккумуляции в прибрежных районах Сурабаи (1994–2018)

| | Sub-district<br>Подокург | Urban village<br>Поселок городского типа | Average speed rate over 24 years (m/year)<br>Средняя скорость в среднем за 24 года (м/год) |
|---|---|---|---|
| West Surabaya<br>Западная Сурабая | Benowo | Romo Kalisari<br>Tambak Osowilangun | 4.8407692<br>1.3232083 |
| | Asemrowo | Tambak Langon<br>Greges<br>Kalianak | 4.7653333<br>2.44<br>2.3997059 |
| North Surabaya<br>Северная Сурабая | Krembangan | Moro Krembangan | 5.2584 |
| | Semampir | Ujung | 0.8125 min |
| | Kenjeran | Bulak Banteng<br>Tambak Wedi<br>Kedung Cowek<br>Kenjeran<br>Sukolilo | 1.0581481<br>2.8504545<br>1.1086667<br>3.7715152<br>5.9335135 |
| East Surabaya<br>Восточная Сурабая | Mulyorejo | Dukuh Sutorejo<br>Kalisari | 64.175<br>75.758333 max |
| | Sukolilo | Keputih | 33.808804 |
| | Rungkut | Wonorejo<br>Medokan Ayu | 2.944<br>8.6010345 |
| | Gunung Anyar | Gunung Anyar Tambak | 11.45913 |

to visit these tourist attractions. Apart from providing economic income for the local community, mangrove forests prevent erosion and tsunamis. This makes the people around the mangrove forests be aware of the importance of conserving this ecosystem.

## CONCLUSION

Monitoring coastal areas using DSAS can determine the speed rate of coastline change. The topography of the Surabaya coastal areas, which are relatively sloping, and the community activities are two of the factors that cause coastline change in the Surabaya coastal area. Based on the Landsat satellite imagery in 1994, 2003, and 2018, it may be indicated that the coastline change was due to erosion, accretion, and anthropogenic activities. This study monitored the coastline change in all coastal areas of Surabaya over 24 years. Anthropogenic processes were caused by the activities at the Tanjung Perak Port and the Teluk Lamong Port. East Surabaya had the biggest problem of the other coastal areas in Surabaya. The data showed that the most severe erosion and accretion occurred in East Surabaya, especially in Wonorejo sub-district and Kalisari sub-district, respectively. In addition, the data showed that of all coastal areas in Surabaya the most severe erosion and accretion will be in East Surabaya. It is necessary to have supervision over the coastal areas, especially in East Surabaya, monitoring changes in land use, like in Wonorejo urban village by monitoring mangrove forests not to be logged illegally. In addition, it is necessary to have regulations regarding land use related to residential areas. With the cooperation of the government and the community, the erosion can be mitigated or even prevented so that not to occur in the future.

The research was implemented using methods and approaches developed within the frameworks of the RFBR Scientific Project No. 18-05-80082 entitled “Patterns of formation of dangerous coastal processes in the Sea of Azov and the socio-economic consequences of their manifestations”.

## REFERENCES

1. Cui B.-L., Li X.-Y. 2011. Coastline change of the Yellow River estuary and its response to the sediment and runoff (1976–2005). *Geomorphology.* 127(1–2): 32–40. doi: 10.1016/j.geomorph.2010.12.001

2. Kumar A., Narayana A.C., Jayappa K.S. 2010. Shoreline changes and morphology of spits along southern Karnataka, west coast of India: A remote sensing and statistics-based approach. *Geomorphology.* 120(3–4): 133–152. doi: 10.1016/j.geomorph.2010.02.023

3. Triatmodjo B. 1999. *Teknik Pantai.* Yogyakarta, Beta Offset: 397 p.

4. Ruiz L.A., Pardo J.E., Almonacid J., Rodríguez B. 2007. Coastline automated detection and multi resolution evaluation

using satellite images. In: *Proceedings of Coastal Zone 07 (Portland, Oregon, USA, 22–26 July 2007)*: 1–5.

5. Dewidar K., Frihy O. 2007. Pre- and post-beach response to engineering hard structures using the Landsat time-series at the northwestern part of the Nile delta, Egypt. *Journal of Coastal Conservation*. 11(2): 133–142. doi: 10.1007/s11852-008-0013-z
6. El Banna M.M.E., Hereher M.E. 2009. Detecting temporal shoreline changes and erosion/accretion rates, using remote sensing, and their associated sediment characteristics along the coast of North Sinai, Egypt. *Environmental Geology*. 58(7): 1419–1427. doi: 10.1007/s00254-008-1644-y
7. Thieler E.R., Himmelstoss E.A., Zichichi J.L., Ergul A. The Digital Shoreline Analysis System (DSAS) version 4.0 - An ArcGIS extension for calculating shoreline change (ver. 4.4, July 2017): U.S. Geological Survey Open-File Report 2008-1278. doi: 10.3133/ofr20081278
8. Istiqomah F., Sasmito B., Amarrohman F.J. 2016. Pemantauan Perubahan Garis Pantai Menggunakan Aplikasi Digital Shoreline Analysis System (DSAS) Studi Kasus: Pesisir Kabupaten Demak. *Geoid Undip*. 5(1): 78–89.
9. Safitri D.A., Bespalova L.A., Bespalova E.V. 2020. Study of geomorphological changes in the coastline of Surabaya, Indonesia using remote sensing data. *Nauka Yuga Rossii*. 16(4): 19–25. (In Russian). doi: 10.7868/S25000640200403

*Поступила 11.06.2021*