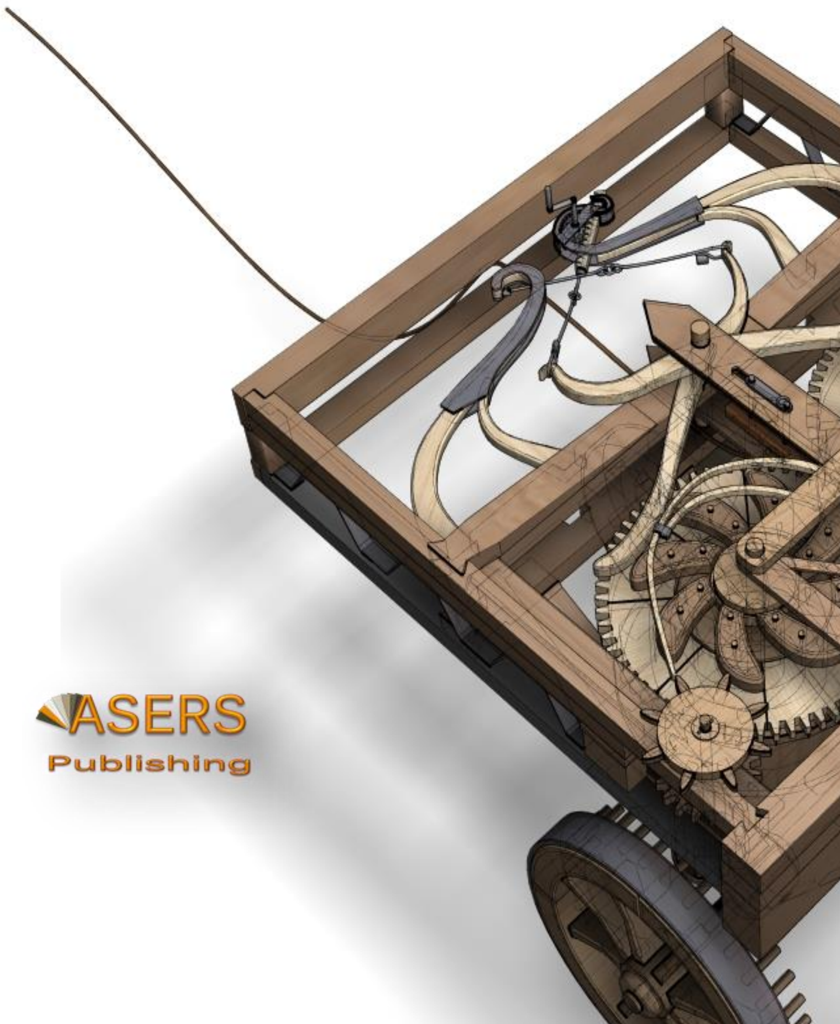
ASERS

Journal of Environmental Management and Tourism



Quarterly
Volume XIV
Issue 1(65)
Spring 2023
ISSN 2068 – 7729
Journal DOI
https://doi.org/10.14505/jemt

ASERS Publishing

Spring 2023
Volume XIV
Issue 1(65)

ASERS Publishing
http://www.asers.eu/asers-publishing
ISSN 2068 – 7729
Journal DOI: https://doi.org/10.14505/jemt

Table of Contents:

Spring 2023
Volume XIV
Issue 1(65)

ASERS Publishing
http://www.asers.eu/asers-publishing
ISSN 2068 – 7729
Journal DOI: https://doi.org/10.14505/jemt

Call for Papers
Summer 2023 Issues
Journal of Environmental Management and Tourism

Journal of Environmental Management and Tourism is an interdisciplinary research journal, aimed to publish articles and original research papers that should contribute to the development of both experimental and theoretical nature in the field of Environmental Management and Tourism Sciences.

Journal will publish original research and seeks to cover a wide range of topics regarding environmental management and engineering, environmental management and health, environmental chemistry, environmental protection technologies (water, air, soil), pollution reduction at source and waste minimization, energy and environment, modeling, simulation and optimization for environmental protection; environmental biotechnology, environmental education and sustainable development, environmental strategies and policies, etc. This topic may include the fields indicated above, but are not limited to these.

Authors are encouraged to submit high quality, original works that discuss the latest developments in environmental management research and application with the certain scope to share experiences and research findings and to stimulate more ideas and useful insights regarding current best-practices and future directions in environmental management.

Journal of Environmental Management and Tourism is indexed in SCOPUS, RePEc, CEEOL, and ProQuest.

All the papers will be first considered by the Editors for general relevance, originality and significance. If accepted for review, papers will then be subject to double blind peer review.

Deadline for submission:	21st April 2023
Expected publication date:	June 2023
Website:	https://journals.aserspublishing.eu/jemt
E-mail:	jemt@aserspublishing.eu

To prepare your paper for submission, please see full author guidelines in the following file: JEMT_Full_Paper_Template.docx, then send it via email at jemt@aserspublishing.eu.

DOI: https://doi.org/10.14505/jemt.v14.1(65).10

Modeling Lasolo Watershed Sedimentation and Mangrove Root Growth at the Lasolo Coast in North Konawe, Indonesia

Nurul KHAKHIM
Department of Geographical Information Science, Faculty of Geography
Universitas Gadjah Mada, Indonesia
nurulk@ugm.ac.id

Farid YASIDI
Doctoral Program in Faculty of Geography
Universitas Gadjah Mada, Indonesia
faridyasidi@yahoo.com

Djati MARDIATNO
Department of Environmental Geography
Universitas Gadjah Mada, Indonesia
djati.mardiatno@ugm.ac.id

Agung KURNIAWAN
Department of Geographical Information Science
Faculty of Geography, Universitas Gadjah Mada, Indonesia
agungk213@gmail.com

Suggested Citation:

Khakhim, N., Yasidi, F., Mardiatno, D., Kurniawan, A. (2023). Modeling Lasolo Watershed Sedimentation and Mangrove Root Growth at the Lasolo Coast in North Konawe, Indonesia. *Journal of Environmental Management and Tourism,* (Volume XIV, Spring), 1(65): 98 - 112. DOI:10.14505/jemt.v14.1(65).10

Article's History:

Received 9th of December 2022; Received in revised form 20th of December 2022; Accepted 27th of January 2023; Published 10th of March 2023.

Abstract

This research sought to simultaneously measure sedimentation and mangrove root growth rates at the Lasolo River estuary and construct a predictive sedimentation model from the measured rates. The applied methods were descriptive quantitative analyses using cloud-based computation to obtain sea surface temperatures, Landsat 8 and 9 OLI images to identify land cover change, field-derived data, and rain data. The neural network toolbox in MATLAB was used to perform the modeling. Results showed that sediments accumulated at the highest rate of 6.10 cm, and mangrove roots grew at an average of less than 1 cm per two weeks, meaning that the former always surpasses the latter. The forecasting model's training and validation each produced a regression value (R) of 0.92 and 0.69 for sedimentation rates and R=0.83 and R=0.88 for root growth rates. Sedimentation rates continued to vary until the end of the observation, with a maximum of 3.91 cm. Although the root growth rates had a similar pattern (fluctuating), an upward trend with signs of acceleration to 0.62 cm was observed. This study also detected a conversion of vegetated land into open mining areas, which expanded, tentatively, from 645.8 ha in 2013 to 2,112.6 ha in 2022.

Keywords: mangrove growth; sedimentation; sediment accumulation; Lasolo watershed; neural network.

JEL Classification: Q57; C60; R11.

1. Research Background

Indonesia is an area that is the habitat of 20% of the world's mangrove areas, and based on an inventory, it is the country with the highest variety of mangrove species with 3.2 million hectares of mangrove land successfully mapped (Ilman *et al.* 2016). However, mangrove conditions, *i.e.*, area and quality, in tropical countries persistently deteriorate from year to year (Friess & Webb 2014; Richards & Friess, 2016; Passos *et al.* 2022). Mangrove ecosystems refer to habitats of unique, diverse, and productive intertidal trees or shrubs that grow in saline-water environments (Rianta *et al.* 2018; Sukuryadi *et al.* 2021; Kamaludin *et al.* 2022). Mangroves occur worldwide along tropical coastlines (Tetelepta *et al.* 2020) and play an essential part in the life cycle on Earth, especially in coastal areas (James *et al.* 2007; Lukman *et al.* 2019) as they offer varied ecosystem services, including nutrient cycling, prevention of soil erosion, wood production, ecotourism, habitat provision for fish (Murdiyarso *et al.* 2015), and sequestration of carbon (C) (Nehren & Wicaksono 2018; Chen *et al.* 2018) in waterlogged anaerobic soil (Arifanti *et al.* 2022). Sustainable exploration and conservation are therefore indispensable to preventing extinction (Viennois *et al.* 2015; Eddy *et al.* 2016; Ditian *et al.* 2021).

Mangroves currently show a decline in species diversity. In Indonesia alone, hundreds of mangrove species are distributed across Java (166 species), Sumatra (157), Kalimantan (150), Papua (142), Sulawesi (135), Maluku (133), and Sunda Kecil Islands (120). However, coastal development, reclamation, pollution, mining, exploitation of mangrove forest products (Arifanti *et al.* 2022), and conversion into plantations and ponds (Viennois *et al.* 2016) eventually degraded about 637,000 ha or 10–33% of the total mangrove area. The 1987–1998 era marked the most extensive mangrove deforestation, resulting in a major decline in mangrove ecosystems (Arifanti *et al.* 2022). Mangroves, among other things, mainly serve as a sediment trap (Willemsen *et al.* 2016; Rizal and Anna 2020) through a particular mechanism that accelerates the accumulation of sediments from upstream at the estuary, especially during floods, and forms the barrier island system (Chaudhuri, Chaudhuri, and Ghosh 2020). As an ecosystem that is closely related to estuaries, mangroves also block pollutants from flowing further into the sea (Maghsodian *et al.* 2022; Jiao *et al.* 2022). Mangrove forests can entrap up to 80% of sediments carried by floods (Furukawa *et al.* 1997). The amount of sediments caught is 14 times larger on rainy than on non-rainy days (Terada *et al.* 2017). Mangroves also capture sediments during tidal events, although not as much as during floods. In high tide events, estuaries with mangroves can entrap sediments three times larger than those without (Willemsen *et al.* 2016). However, sediments are captured 25% larger by mangrove forests (Hoque *et al.* 2019) and 20 to 30% larger by the *Avicennia-Rhizophora* species combination during low rather than high tides (Kathiresan 2003). Therefore, sedimentation in this ecosystem is influenced by surface runoff more than tides (Schwarzer *et al.* 2016). Mangrove's ability to entrap sediments in estuaries protects other coastal ecosystems: seagrass and coral reefs. For instance, a stable mangrove forest structure will reduce the number of sediments flowing into the sea that would otherwise threaten the existence of the coral reef ecosystem (Soltani *et al.* 2017).

Trapped sediments create substrates for mangrove growth, which is optimal in coastal areas with large estuaries and deltas to which mud-rich rivers drain. Mangroves rarely grow in coastal areas without these conditions. Sedimentation promotes mangrove growth and development (Anthony 2004). However, some mangrove species might not survive if the high sedimentation rates they are adapted to are surpassed. This adaptation varies across species as manifested in changed or distinctive physiological, morphological, phenological, physiognomic characteristics, vegetation structure, and composition (Kartawinata *et al.* 1979). According to Sidik *et al.* (2016), high sedimentation rates inhibit the growth of mangroves, especially those belonging to the genus *Avicennia*. Atmaja and Soerojo (1994) explained that river-flowed sediments that are further transported by tides can cause the death of several mangrove species like *Avicennia* and *Sonneratia*. Although the stilt roots of *Rhizophora, Avicennia*, and *Sonneratia* effectively retain muddy sediments, *Rhizophora* has the most commonly planted species for rehabilitation purposes.

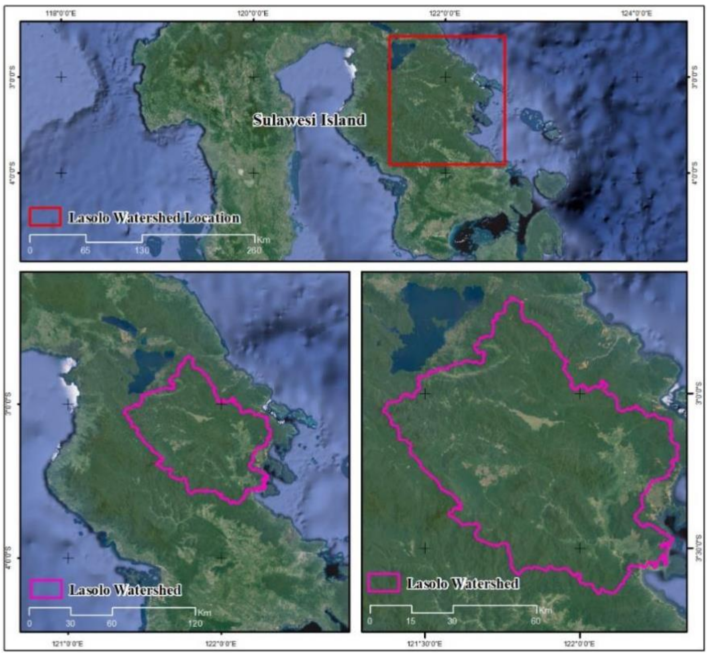
To grow optimally in littoral habitats, *Rhizophora* sp. adapts by forming unique roots that extend downward and attach themselves to the estuarine bed (Katherisan 2003). This root system penetrates the muddy bottom and has root tissues with two functions: tree stabilizer in the rise and fall of tides and pneumatophores that enable mangroves to breathe oxygen in waterlogged soil (Basyuni, Yuriswan and Bimantara 2020). *Rhizophora apiculata* roots grow more significantly in different inundation depths and sediment thicknesses. Pressures due to inundation and sediment thickness affect the root shape. Aboveground roots have more reddish-brown color in thicker sediments. Inundation or waterlogging influences root growth and structure; for instance, prop roots are denser in frequently inundated soil. Relative to *Avicennia* and *Sonneratia*, *Rhizophora* species have high adaptability to sediments because their roots have different abilities. However, this ability to adapt has certain limits. Similarly, the mangrove area at the Lasolo Coast (*i.e.*, the Lasolo River estuary or the Lasolo Watershed outlet) is the largest in North Konawe. Nickel mining sites are thought to produce massive supplies of sediments, which disrupt the growth of mangroves. This research aimed to model sedimentation using primary data collected continuously every two weeks to determine the pattern of sediment accumulation and increase in mangrove root length.

2. Methodology

2.1. Geographical Location of the Study Area

The study was conducted in North Konawe, Southeast Sulawesi, Indonesia (Figure 1). The landscape of the study area can be generally divided into three geomorphological units: sloping hills, steep hills, and plains. Steep hills occupy some areas characterized by steep slope gradients and sharp peaks at approximately 10-400 meters above sea level. The Lasolo-Sampara Watershed has 63 smaller watersheds covering an area of 14,979.6 km^2 with a total river length of 847.2 km (North Konawe Government, 2012). The part that traverses the North Konawe Regency drains water from three subwatersheds: Lasolo, Lalindu, and Tinobu. The length of the Lasolo River from the upper course to the estuary is about 170 km.

Figure 1. Lasolo Watershed



Source: Authors

2.2. Data

The empirical data used in this study were based on measurements in the field: (1) sedimentation rates and (2) mangrove root growth at the Lasolo River estuary. Additional secondary data to complement this field-derived information were rainfall data (2008–2020) and time-series data of sea surface temperature (SST) obtained from MODIS Aqua Level-3 SMI using Google Earth Engine (see Figure 2 for the programming code excerpt). Other supporting data were Landsat 8 and 9 OLI images to detect the land cover change from 2013 until 2022.

Figure 2 - JavaScript programming code for SST data acquisition from 2009 to 2022.

```
var startDate = ee.Date('2009-01-01'); // start date
var endDate = ee.Date('2022-06-30'); // end date

Map.centerObject(geometry);

// calculate the number of months to process
var nMonths = ee.Number(endDate.difference(startDate,'month')).round();

var point = geometry;
var sst = ee.ImageCollection('NASA/OCEANDATA/MODIS-Aqua/L3SMI').select('sst')
          .filterDate(startDate, endDate).map(function(dataset){return dataset.clip(geometry
```

Source: Authors

2.3. Method

The collected data were analyzed using a descriptive quantitative approach to explain the relationship between mangrove root growth rates and sediment transport rates at the estuary. The empirical data were processed by forecasting with neural-network approaches accommodated in the *nntoolbox*. Neural networking is a method of assembling simple, interconnected processing elements, units, or nodes, whose functions resemble a network of “neurons” in living organisms. Its ability to process data is stored in the connections between units, or weights, derived from adaptation or learning from a series of training patterns (Gurney 1997). As additional processing, unsupervised classification was applied to Landsat 8 and 9 OLI images. SST data were obtained through cloud-based computation in Google Earth Engine.

2.4. Sampling Location

Samples were collected at the Lasolo River estuary, an outlet of the larger Lasolo Watershed system. Generally, the Lasolo River is a carrier of various sediment loads produced by slow or rapid erosion from places at higher altitudes and dissolved or suspended by and through the river flowing downstream. Sediment transport rates were observed from at least five sampling points spread across the estuary. Table 1 shows the coordinates, or geographical positions, of these sampling points. In one set of observations, a data pair of sedimentation rate and mangrove root growth rate was collected at a relatively close distance (< 3 m) to avoid biases due to differences in the ability of water flows to transport sediments.

Table 1. Geographical distributions of observation and sampling locations at the Lasolo River

Observation sites	Geographical position	
	Latitudes	Longitudes
TK-1 and 2 (stake and mangrove)	-3°33’22.81”	122°14’40.82”
TK-3 and 4 (stake and mangrove)	-3°33’15.01”	122°14’42.58”
TK-5 and 6 (stake and mangrove)	-3°32’59.62”	122°14’34.89”
TK-7 and 8 (stake and mangrove)	-3°32’41.15”	122°15’0.46”
TK-9 and 10 (stake and mangrove)	-3°31’50.39”	122°16’6.714”

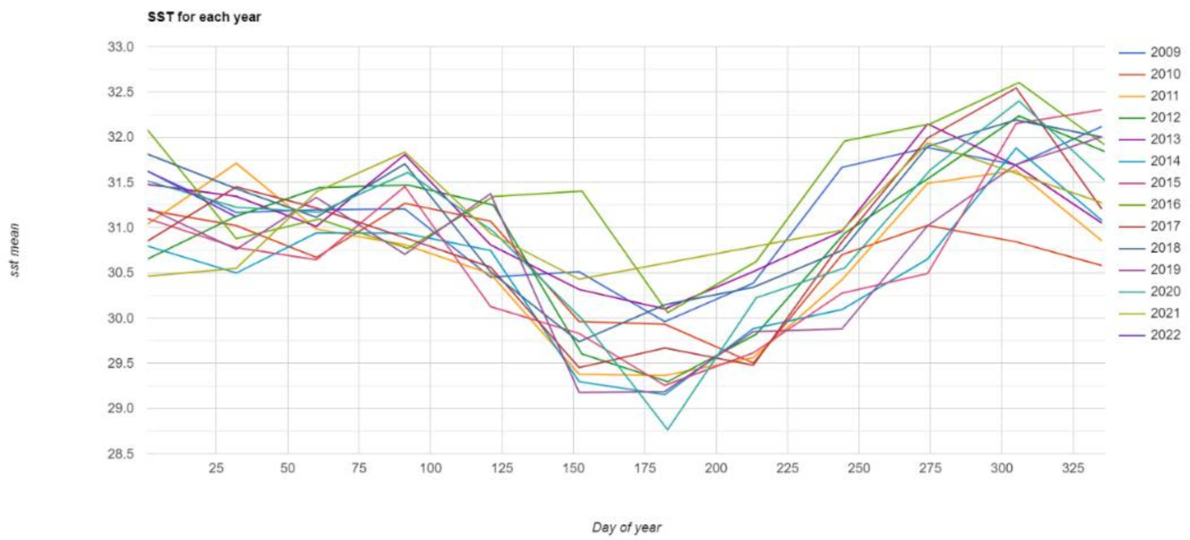
Source: Field measurement

3.Results

3.1. Climate Characteristics

North Konawe has two seasons (*i.e.*, dry and rainy) that are mostly influenced by the wind blowing above the area. From November until March, winds contain water vapor from the Asian continent and the Pacific Ocean that previously passed above several oceans. In these months, the rainy season occurs. Then, around April, winds are always erratic, sometimes with less or more rainfall, a season known by local sailors as the transition. Afterward, from May to August, easterly winds from the Australian continent carry less water vapor, causing less rainfall.

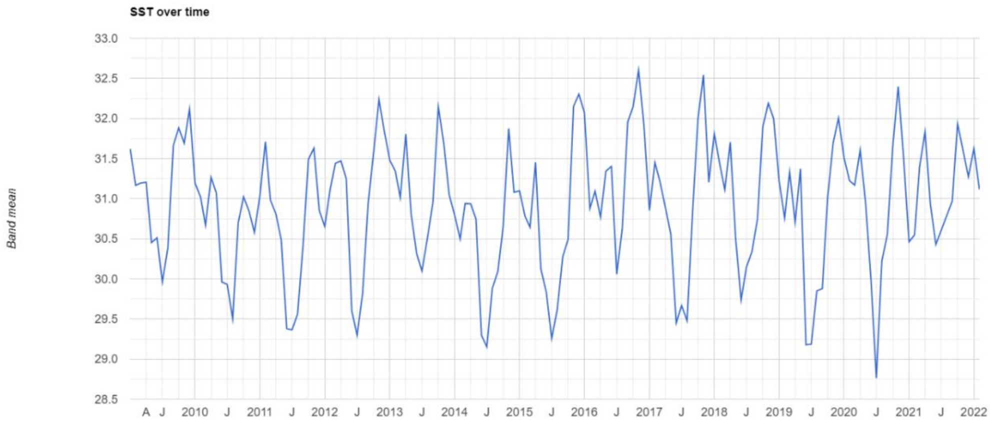
Figure 3. Identification of sea surface temperature (SST), 2009–2022.



Source: Authors processed in GEE

The dry seasons from August to October are often due to erratic changes in natural conditions, causing deviations from the average seasonal pattern. SST data analysis from 2009 to 2022 detected an upwelling at the end of transitional season I until the end of the east monsoon season (Figure 3). Observations of Modis-Aqua L3SMI images from 2009 until 2022 found the lowest temperature, 28.7°C, in July 2020 and the highest temperature, up to 32.6°C, in November 2016 (Figure 4).

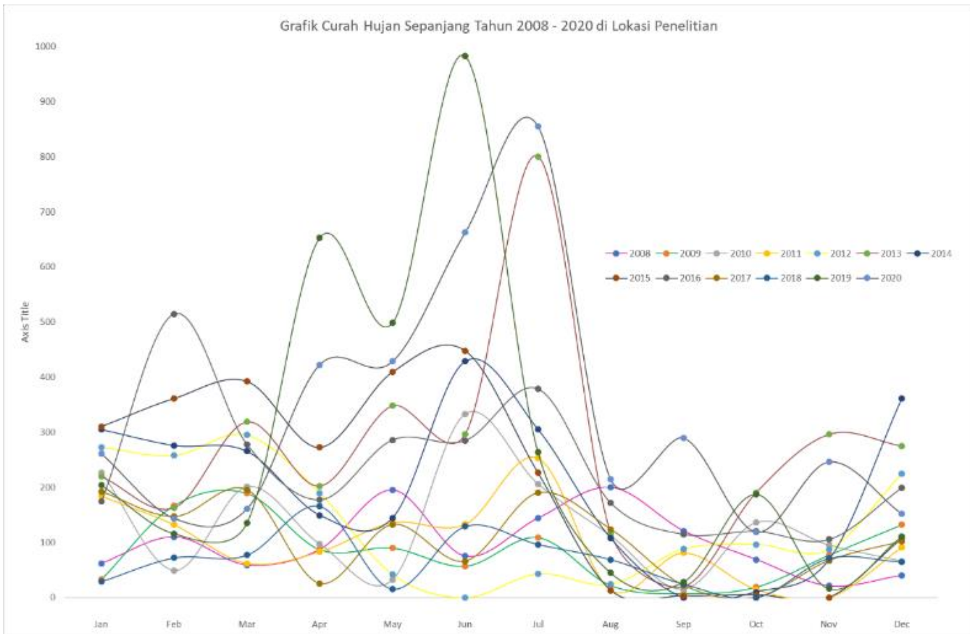
Figure 4. SST graph through the observation period, 2009–2022.



Source: Authors processed in GEE

Although the Lasolo River estuary has varied rainfall patterns from 2008 through 2020, one homogenous trend was identified. As seen in Figure 5, the highest average rainfall was detected in 2020, while 2018 saw the lowest average. The homogenous pattern was evident in relatively low rain from the east monsoon season until transitional season I (August to November) and higher and more frequent rainfall from the west monsoon season until transitional season I. Heavy rain started in March and ended in July. Mays and Junes in 2013, 2019, and 2020 saw the highest rainfall of up to 982.5 mm, meaning that these months contributed the largest water supply to the Lasolo Watershed.

Figure 5. Rainfall event data in the study area, 2008–2020 (in mm).



Source: Authors

4. Soil, Erosion, and Sedimentation

Table 2 shows the Soil Erodibility Index (K) analysis that combined soil properties responsible for the inherent sensitivity to erosion, namely texture, organic matter (OM), structure and stability, and infiltration or permeability. The soil in the study area was composed of several textures: silty clay (sampling points AS 1, AS 4, and AS 6), clay (AS 2), sandy clay (AS 3, AS 5, AS 7, and AS 9), and loamy sand (AS 8), and contained 1.82–4.62% organic matter (OM). The soil structures were mainly angular blocky with code 3 (AS 1 and AS 3) and subangular blocky with code 4 (AS 2, AS 4, AS 5, AS 6, AS 7, AS 8, and AS 9). Also, all samples had low permeability, meaning water moves very slowly through the soil (code 5). Based on these characteristics, the soil erodibility index values (K) ranged between 0.41 and 0.90.

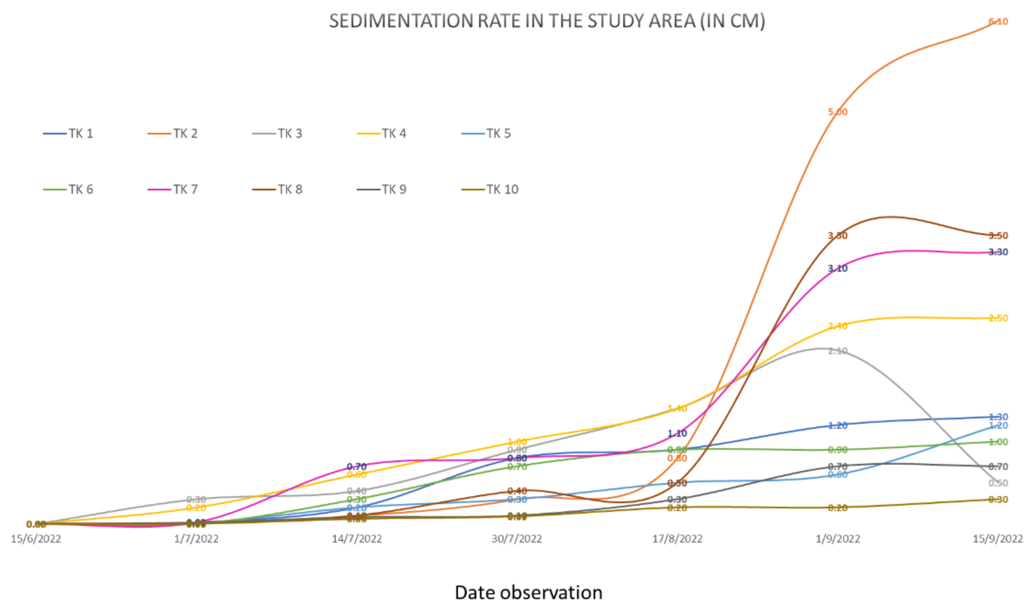
Table 2. Soil erodibility analysis

Samples	Soil texture	OM (%)	Soil structure		Permeability		K value
			Shape	Code	Qualitative	Code	
AS 1	Silty clay	3.28	Angular blocky	3	Slow	5	0.46
AS 2	Clay	2.24	Subangular blocky	4	Slow	5	0.50
AS 3	Sandy clay	3.56	Angular blocky	3	Slow	5	0.53
AS 4	Silty clay	4.62	Subangular blocky	4	Slow	5	0.41
AS 5	Sandy clay	2.52	Subangular blocky	4	Slow	5	0.67
AS 6	Silty clay	3.42	Subangular blocky	4	Slow	5	0.51
AS 7	Sandy clay	4.62	Subangular blocky	4	Slow	5	0.49
AS 8	Loamy sand	1.82	Subangular blocky	4	Slow	5	0.90
AS 9	Sandy clay	2.92	Subangular blocky	4	Slow	5	0.68

Source: Field-derived data and laboratory analysis.
Notes: OM = Organic matter; K = Soil erodibility factor.

Previous research on the Lasolo Watershed in North Konawe revealed that soil erosion and sedimentation started to occur at an alarming rate even before the mining activities. Observations at nine points in 2007 identified an actual erosion of 0.01–259.78 tons/ha/year, which were very low to very high categories in the Erosion Hazard Index (EHI), with the latter being dominant (Yasidi *et al.* 2007). From nine observation points in the Lasolo Watershed and its surroundings, these rates changed to 4.10–32.40 tons/ha/year (low to very high erosion hazard), and moderate EHI was dominant in 2010 Then, using the same observation points, another study in 2013 detected changes in the actual erosion rate. Soils were eroded at 72.82 tons/ha/year, categorized as low to very high hazard according to EHI, with the latter having the largest areal proportion (Yasidi *et al.* 2010). The 2007 study also observed sedimentation at four sites in the Lasolo Watershed and found sediment concentrations of 200–7,800 mg/liter, indicating poor conditions (Yasidi *et al.* 2007).

Figure 6. Rainfall event data in the study area, 2008–2020 (in mm)



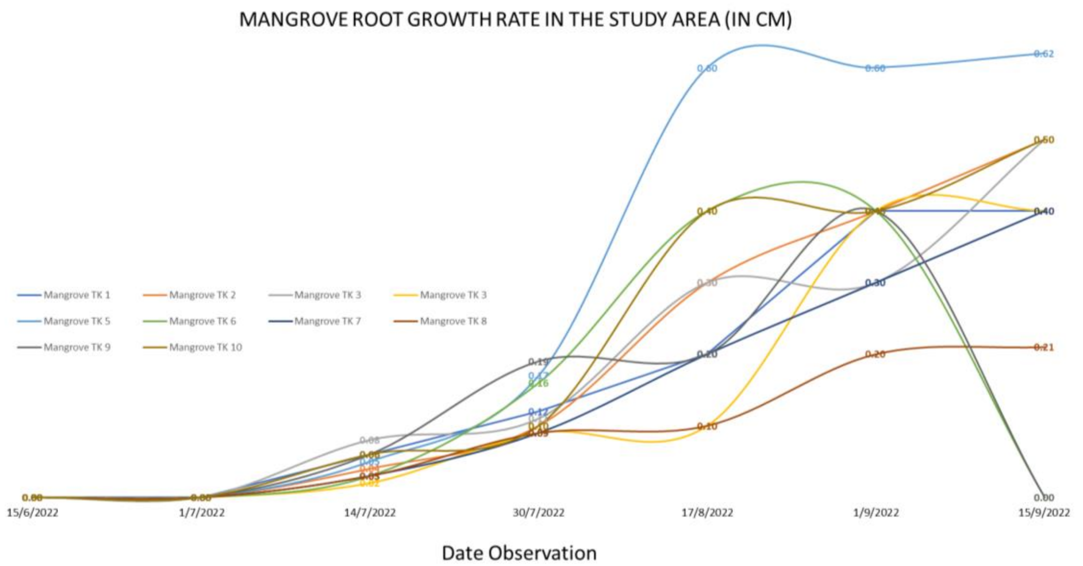
Source: Authors

Erosion and sedimentation data in the Lasolo Watershed and its surroundings confirmed that the soil is naturally susceptible to being eroded. Mining activities are believed to substantially speed up the rates at which erosion and sedimentation occur. The sedimentation and erosion rates measured at ten stakes placed around the estuary indicated a progressive accumulation of sediments (Figure 6). Stakes 2, 4, 5, 7, and 8 recorded substantially accelerating sedimentation rates, while stakes 1, 6, 8, and 10 saw a slower acceleration. Relative to other measurement points, stake 2 exhibited the most significant rate increase. On the contrary, only stake 3 showed a significant decelerating trend in the third week of the observation when the sedimentation rate decreased from about 2.10 to 0.50 cm. Therefore, based on the biweekly measurement at ten stakes in the last three months (June 15–September 15, 2022), the average sedimentation rate in the mangrove forest was 1.672 cm.

5. Mangrove and Land Cover Change

The mangrove study at 19 observation stations around the estuary identified 15 mangrove species: *Acrostichum speciosum, Aegiceras corniculatum, Bruguiera cylindrica, Bruguiera gymnorhiza, Bruguiera parviflora, Lumnitzera littorea, Morinda citrifolia, Nypa fruticans, Pandanus tectorius, Pongamia pinnata, Rhizophora mucronata, Rhizophora stylosa, Scyphiphora hydrophyllacea, Sonneratia alba,* and *Acrostichum speciosum*. *Nypa fruticans* and *Rhizophora mucronata* were the area's two most common true vegetation (Yasidi *et al.* 2006). Based on the biweekly observation at ten stakes in the last three months (June 15–September 15, 2022), the roots of *Rhizophora* sp. grew at the rate of 0.448 cm. From the trend in Figure 7, it can be inferred that the mangroves sampled at the Lasolo River estuary experienced a progressive root growth of less than 1 cm per two weeks. On average, the root length grew 0.81 cm every two weeks. Figure 7 also shows that the mangrove roots continued to grow at all measurement points, forming a positive trend, except for stake 9, where no root growth was observed.

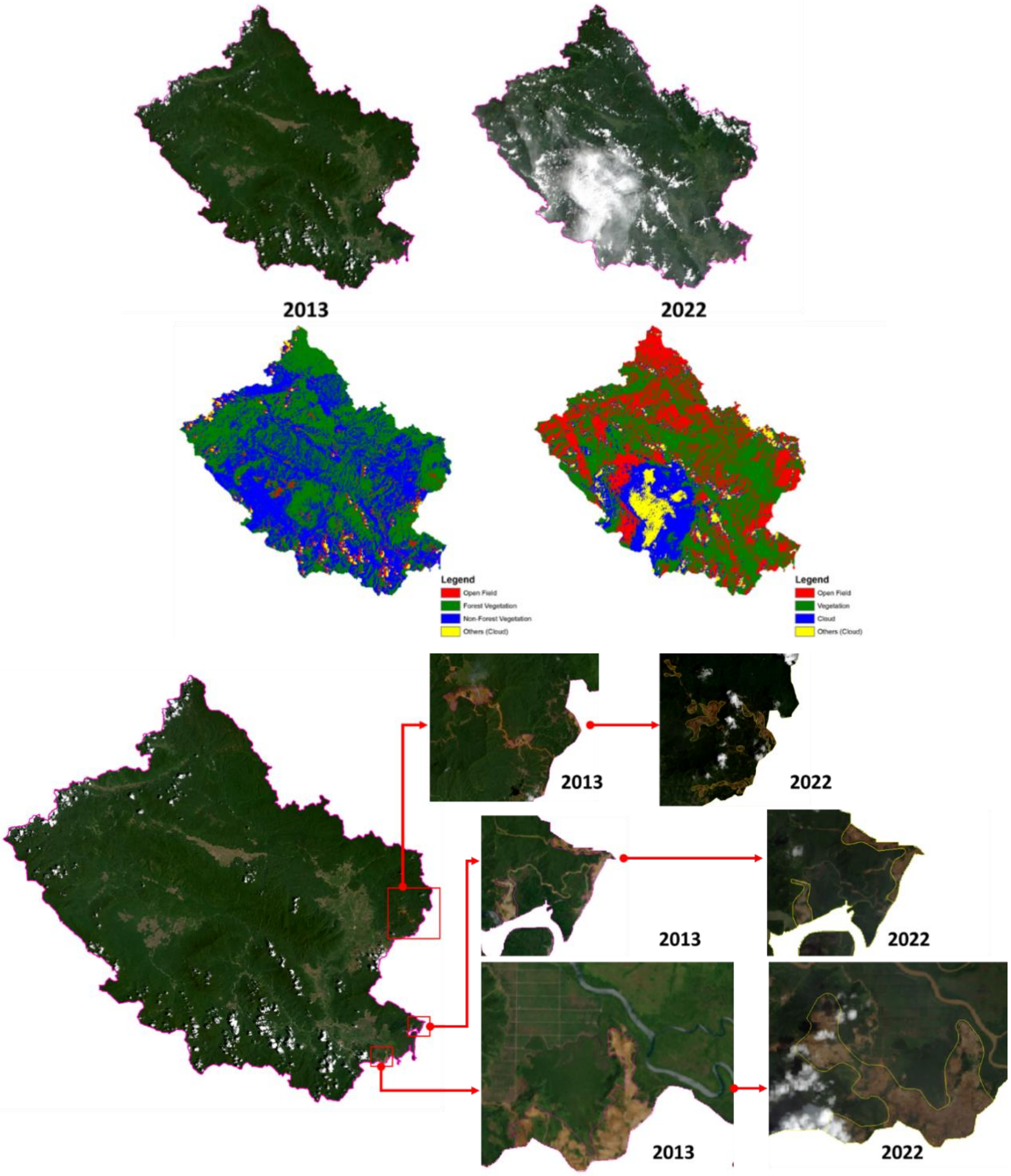
Figure 7. Mangrove root growth rates at ten observation stakes at the Lasolo River estuary.



Source: Authors

In addition, land cover change is an important factor to consider in analyzing sediment accumulation at the estuary. To detect any changes, Landsat 8 and 9 OLI images in 2013 and 2022 were compared. With unsupervised classification, the extracted land cover types within the topographic boundaries of the Lasolo Watershed were purely differentiated or classified based on pixels. In this case, the land cover was divided into four: vegetation, open land, sparsely vegetated land, and others (cloud cover). However, because the classification results were suboptimal due to limited data quality, changes in land cover were detected with visual observations. Results showed that the areas near the estuary experienced the most extensive land cover change (Figure 8). Also, more vegetation-covered areas were turned to open fields identified as mining sites from 2013 until 2022. The open land was 645.8 ha in 2013 and increased to 2,112.6 ha in 2022. The extent of this land cover shift was assumed to result from the increasing number of mining business permits issued for the area. It is believed that land clearing for mining sites and their operations is partly responsible for the high sedimentation rate at the estuary.

Figure 8. Mangrove root growth rates at ten observation stakes at the Lasolo River estuary

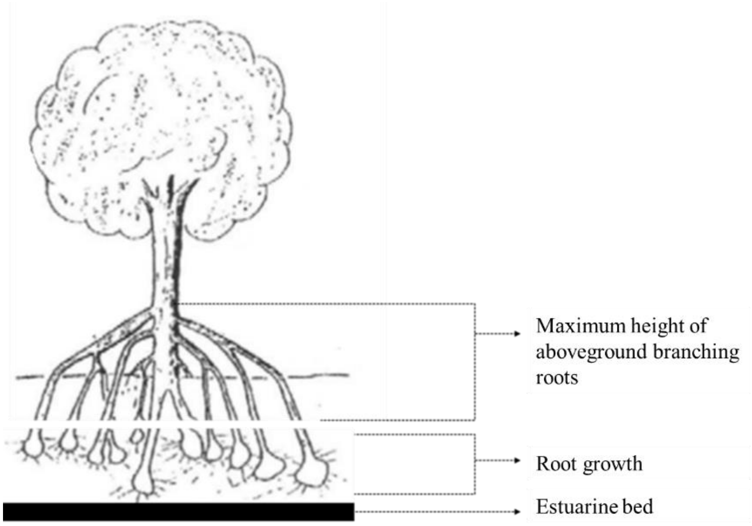


Source: Authors

6. Discussion

This study compared the rates at which sediments accumulated and mangrove roots grew at the Lasolo River estuary. To represent the study area, ten samples were collected at randomly determined sites. Root growth was measured in detail because a constantly growing root system enables a mangrove tree to grow taller and thus continue to survive in a sediment-rich environment (Figure 9). Biweekly observations at ten stakes showed a positive trend, and especially at stake 5, the root length increased by up to 0.62 cm in the last three months. On average, the roots grew very slowly, only 0.17 cm per two weeks. Mangrove growth is potentially inhibited or, in worse scenarios, ceased because the anthropogenic activities upstream affect the amounts of produced sediments and their accumulation rates at the estuary. Based on the observation results, it can be surmised that sedimentation rates increase the amount of material deposited at the estuary every two weeks of measurement. Stake 2 saw the highest sedimentation rate, which first increased slowly from 0 cm in July to 0.80 cm in August before soaring to 6.10 cm in September 2022. This last figure is twice as large as the average sedimentation rates at the other nine stakes. This observation was made from July to September 2022 or during the east monsoon season. As seen in the SST distribution pattern in Figure 4, the SST was also at its lowest in this season. Similarly, July–September 2022 experienced a fairly low average relative to other months in 2008–2022 (see Figure 5). These findings correspond to Schwarzer *et al.* (2016), which found that rainfall controls the entry of sedimentation into the river, particularly when rainwater and the induced runoff trigger faster currents than the ones generated by tides.

Figure 9. Mangrove root growth process measured at each observation stake.

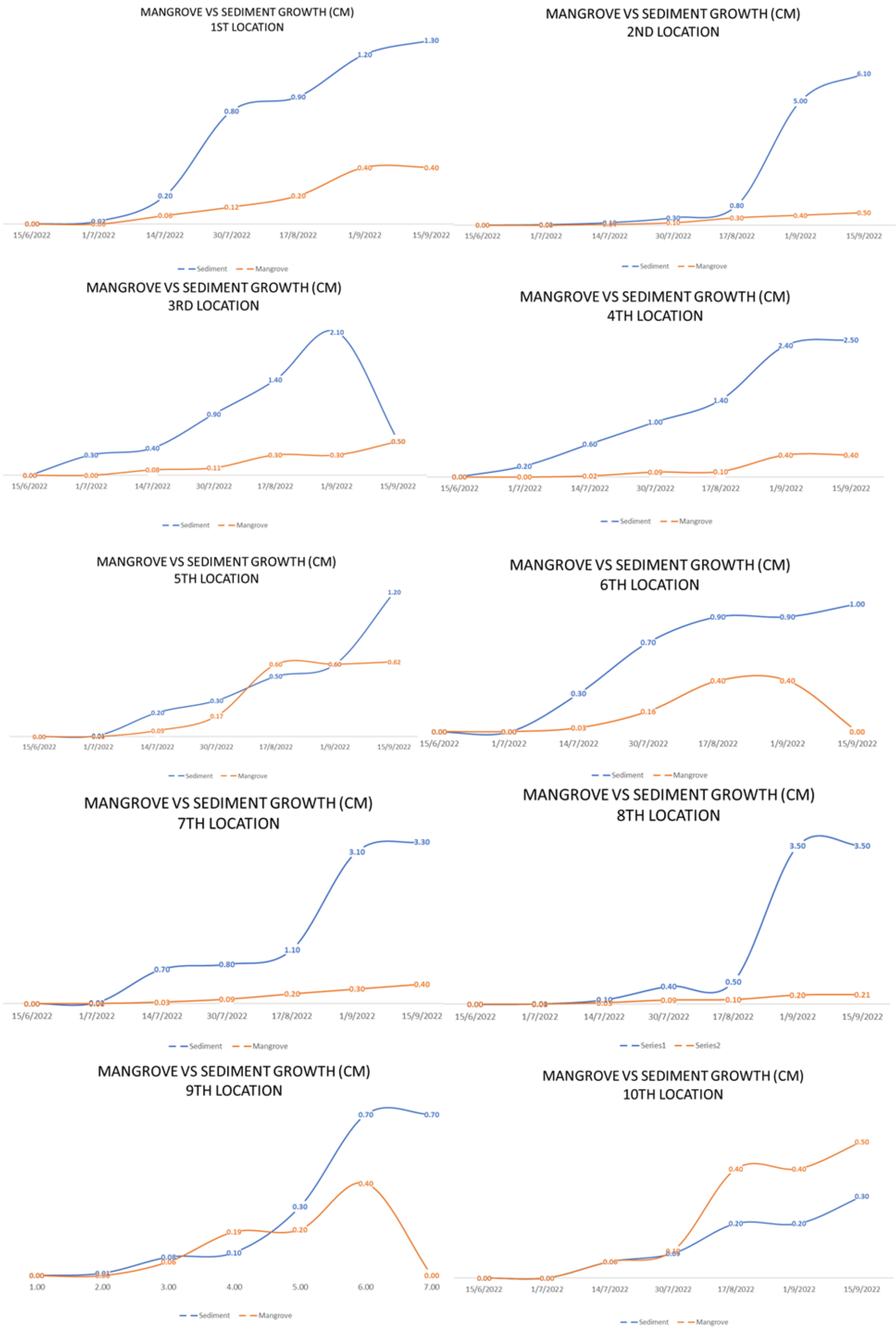


Source: modified from Janssen-Stelder *et al.* 200.

The speed at which mangrove roots grow is much slower than the sedimentation rate at the Lasolo River estuary. Based on the empirical data, nine observation stakes showed the same results in the last week of the observation, where the thickness of sediment accumulation (cm) was more than the increase in root length (Figure 10). Nardin *et al.* (2021) stated that *Soneratia* spp. used to characterize the outermost (seaward) segment of the mangrove forest in the Mekong River delta, Vietnam, but high sedimentation rates buried their roots and pneumatophores, leading to the death of this mangrove ecosystem. On the contrary, stake 9 showed a different result: the mangrove growth rate was faster than the sedimentation rate. This finding can be explained by mangrove density. Using a statistical approach, Rahman Halim *et al.* (2018) found a negative correlation between mangrove density and sediment accumulation: forests with sparser (denser) mangrove trees allow for higher (lower) sedimentation rates.

Data on mangrove root growth and sedimentation rates in the last three months of the observation were then used to create a predictive regression. Neural network approaches were employed in the experiment to forecast sediment accumulation and root growth. The model's training was performed repeatedly and consecutively until reliable predictive data was obtained. Regression of the sedimentation rate was less favorable in the first training (Figure 11a), but repeated trials of training resulted in a better regression equation (Figure 11b). Figure 11a shows the regression result obtained from the first run of forecasting using neural networks, while Figure 11b is from the last run. Forecasting with the *nntoolbox* produced a final regression value (R) of 0.91806 for training and 0.69236 for validation. It showed that the sedimentation rate would continue to vary before gradually increasing at the end of 2022. Based on the predicted data (Figure 12), most sedimentation rates would decrease in the first two weeks and then fluctuate before increasing in the last week of the year. The highest predicted rate was 3.91 cm. Afterward, the sedimentation rate would peak (3.85 cm) six weeks into the prediction period (November) before decreasing again in the following two weeks. The rainfall in the study area (see Figure 5) starts to increase in November. Thus, it can be said that rains and the predicted sedimentation rates have a positive relationship.

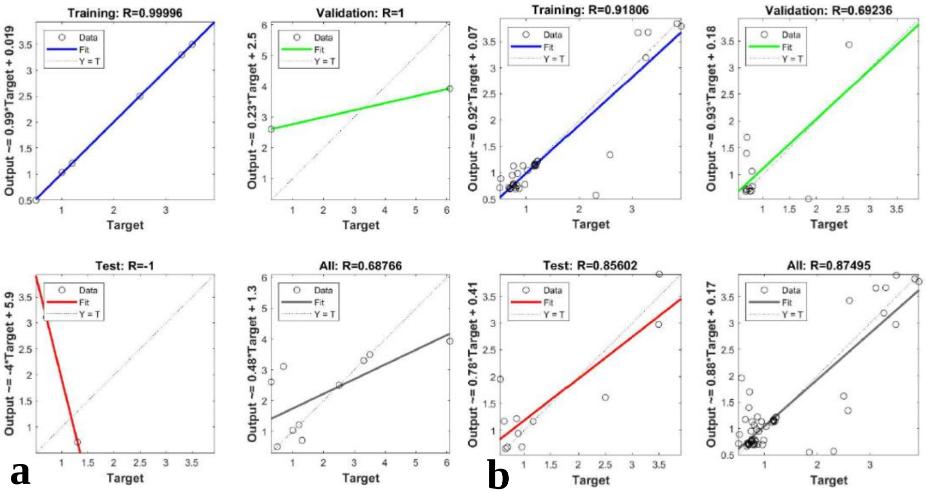
Figure 10. Graphs comparing sedimentation and mangrove root growth rates at ten observation stakes



Source: Authors

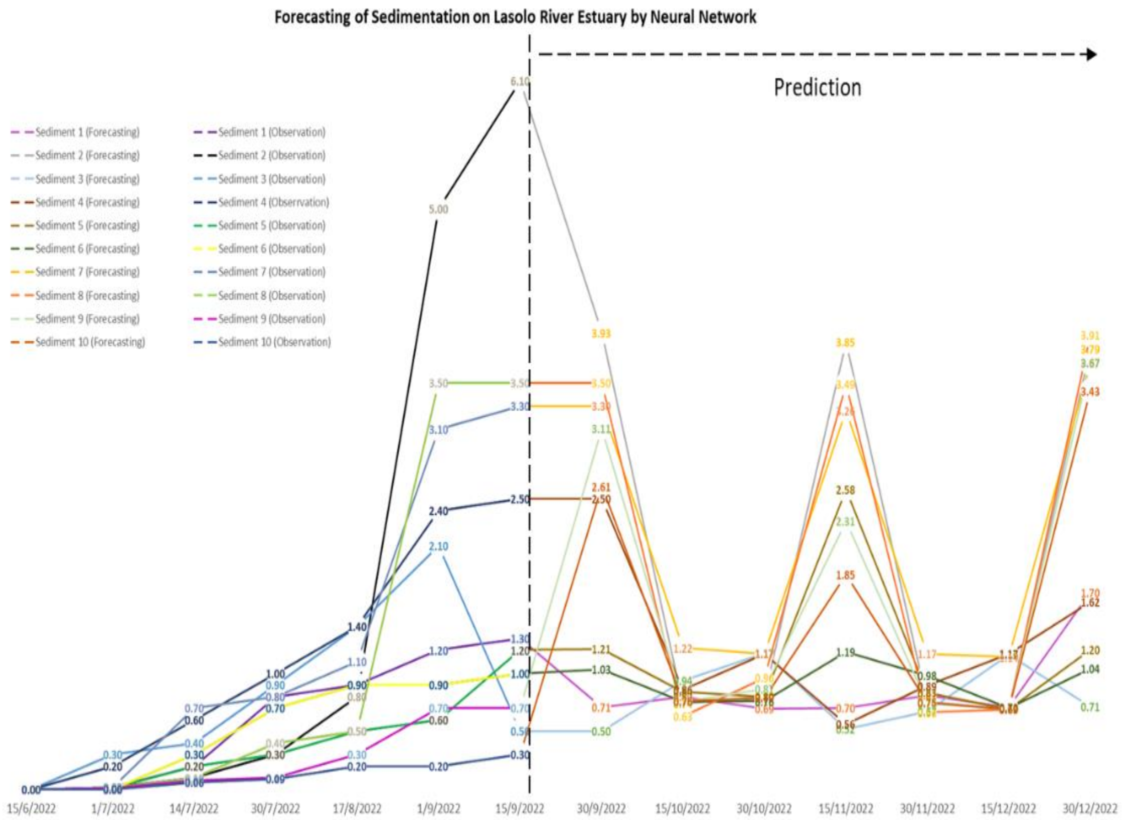
In the first run, the root growth forecasting produced a significant regression value (Figure 13a), which was closed with a "sufficient" value in the last run (Figure 13b). The forecasting experiment found a positive and accelerating trend in root growth rates, although fluctuations in each derived pattern were observed. Regression analyses produced R=0.82603 for the forecasting model's training and R=0.88519 for the validation. A striking difference was detected at stake 5, where the predicted rate would increase to and hover around the highest point (0.62) without any significant decreases. Meanwhile, other stakes would see an upward trend, with some fluctuations in places, until the end of 2022, with the highest predicted rate of 0.62 cm (Figure 14).

Figure 11. Regression analyses based on the forecasting model's training and validation for sedimentation rates. Results showed a significant increase in accuracies



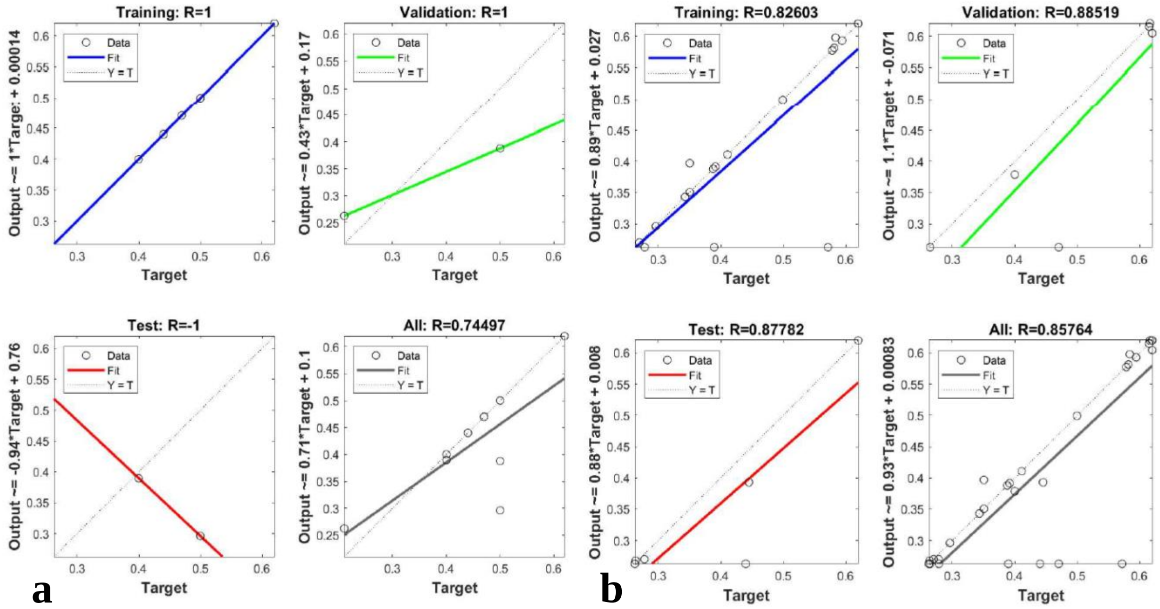
Source: Authors

Figure 12. Measured and predicted sedimentation rates at the Lasolo River estuary. The forecasting experiment is based on empirical data.



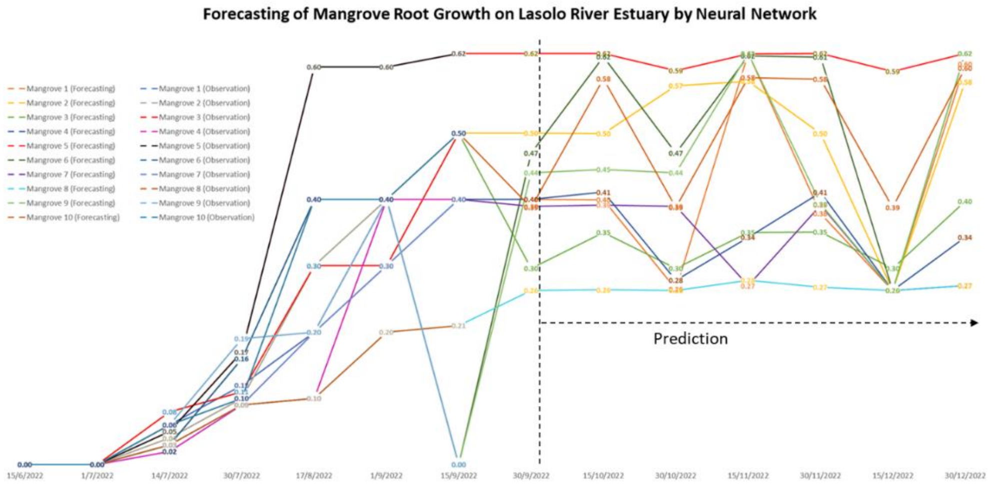
Source: Authors

Figure 13. Regression analyses based on the forecasting model's training and validation for mangrove root growth rates. Results showed a reliable accuracy in the first and last runs



Source: Authors

Figure 14. Measured and predicted rates of root length growth at the Lasolo River estuary. The forecasting experiment is based on empirical data.



Source: Authors

This study also highlights the significance of land cover shifts in modifying sedimentation and mangrove root growth rates. Comparing Landsat 8 and 9 OLI satellite images in 2013 and 2022, it discovered the conversion of vegetated land (forest and non-forest) into open areas with similar characteristics to those of mining sites. Mining areas, where the soil is exposed directly to weathering and erosion factors, are thought to be the main source of the many sediments trapped by mangroves at the estuary. This assumption is supported by the tentative expansion of open areas visible on Landsat 8 and 9 OLI satellite images from 645.8 ha in 2013 to 2112.6 ha in 2022. On the ground, rainwater partitions into, among other things, runoff. With clay dominating the watershed's soil texture, runoff can easily remove soil particles from open areas (mining) and carry them downstream to be entrapped and deposited in mangrove forests, resulting in sediment accumulation at the estuary.

Conclusion

Empirical data obtained from measurements at the Lasolo Coast (*i.e.*, the Lasolo River estuary or the Lasolo Watershed outlet) indicate that sediments accumulate much faster than the growth of mangrove roots. The highest recorded sedimentation rate is 6.10 cm per two weeks, and mangrove roots generally grew at less than 1 cm per two weeks. Forecasting has been performed using neural network approaches (*nntoolbox*) to determine the pattern and predict both sedimentation and root growth rates. The forecasting model's training and validation have a regression value (R) of 0.91806 and 0.69236 for sedimentation rates and 0.82603 and 0.88519 for mangrove root growth rates. Modeled predictions showed that the sedimentation rates will fluctuate before peaking at 3.91 cm at the end of 2022 and that the root growth rates will progressively increase to 0.62 cm. Excessive sediment accumulation is thought to result from the extensive conversion of vegetated areas into open land for mining in the watershed. Landsat 8 and 9 OLI image analysis found an open land of 645.8 ha in 2013, which later increased to 2112.6 ha in 2022. In deforested areas, surface runoff can easily remove soil particles and carry them into the river. Water carrying these sediments drains into the mangrove area at the estuary, causing a progressive sediment buildup.

Acknowledgements

This research was funded by Gadjah Mada University through the Final Project Recognition grant scheme for the fiscal year 2022.

References

[1] Anthony, E.J., 2004. Sediment Dynamics and Morphological Stability of Estuarine Mangrove Swamps in Sherbro Bay, West Africa. *Marine Geology*, 208(2-4): 207-224.

[2] Arifanti, V. B., *et al.* 2022. Challenges and Strategies for Sustainable Mangrove Management in Indonesia: A Review. *Forests*, 13(5): 1–18. DOI: https://doi.org/10.3390/f13050695

[3] Atmaja W. S., and Soerojo, 1994 Mangrove status of Indonesia. In: *Proceedings of the Third ASEAN-Australia Symposium on Living Coastal Resources*. Wilkinson C., Sudara S., Ming C. L. (eds), pp. 201-207, Volume 1: Status Reviews, Australian Institute of Marine Science, Townsville.

[4] Basyuni, M., Yuriswan, W., and Bimantara, Y. 2020. Root development in mangrove plant Rhizophora mucronata under different shade intensities. *IOP Conference Series: Earth and Environmental Science*, *452*(1). DOI: https://doi.org/10.1088/1755-1315/452/1/012090

[5] Chaudhuri, P., Chaudhuri, S., and Ghosh, R. 2020. The Role of Mangroves in Coastal and Estuarine Sedimentary Accretion in Southeast Asia. In *Sedimentary Processes - Examples from Asia, Turkey and Nigeria* (pp. 1–24). DOI: 10.5772/intechopen.85591

[6] Chen, S., *et al.* 2018. Ecosystem carbon stock of a tropical mangrove forest in North Sulawesi, Indonesia. *Acta Oceanologica Sinica*, *37*(12): 85–91. DOI: https://doi.org/10.1007/s13131-018-1290-5

[7] Ditian, Melinda Meganatha, R. D., Prasetyo, W. E., Hartanto, S., and Hartono, R. 2021. Mangrove Extent and Change Mapping of Muaragembong from 1990 to 2020 using Google Earth Engine (GEE). *Proceeding - 2021 IEEE Ocean Engineering Technology and Innovation Conference: Ocean Observation, Technology and Innovation in Support of Ocean Decade of Science, OETIC 2021*, 35–38. DOI:https://doi.org/10.1109/OETIC53770.2021.9733736

[8] Eddy, S., Rasyid Ridho, M., Iskandar, I., and Mulyana, A. 2016. Community-Based Mangrove Forests Conservation for Sustainable Fisheries. *Jurnal Silvikultur Tropika*, *07*(3): 42–47.

[9] Friess, D. A., and Webb, E. L. 2014. Variability in mangrove change estimates and implications for the assessment of ecosystem service provision. *Global Ecology and Biogeography*, 23(7): 715–725. DOI:https://doi.org/10.1111/geb.12140

[10] Furukawa, K., Wolanski, E., and Mueller H., 1997. Current and Sediment Transport in Mangrove Forest. *Esstuarine*, *Coast al and Shelf Science*, 44(3): 301-310.

[11] Gurney, K. 1997. An introduction to neural networks. In *The Lancet* (Vol. 346, Issue 8982). UCL Press Limited. DOI: https://doi.org/10.1016/S0140-6736(95)91746-2

[12] Hoque, A., Kumar, D., Paul, A.K. and Rahman, M. 2019. Sedimentation in dune forest, mangrove forests and cc block system and associated topographic changes. *Bangladesh Acad. Sci*., 43(1): 67-78.

[13] Ilman, M., Dargusch, P., Dart, P., and Onrizal 2016. A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. *Land Use Policy*, 54: 448–459. DOI:https://doi.org/10.1016/j.landusepol.2016.03.010

[14] James, G. K., *et al.* 2007. Satellite-based assessment of the extent and changes in the mangrove ecosystem of the Niger Delta. *Marine Geodesy*, 30(3): 249–267. DOI: https://doi.org/10.1080/01490410701438224

[15] Janssen-Stelder, B. M., Augustinus, P. G. E. F., and van Santen, W. A. C. 2002. Sedimentation in a coastal mangrove system, Red River Delta, Vietnam. *Proceedings in Marine Science*, 455–467.

[16] Jiao, M., *et al.* 2022. Mangrove forest: An important coastal ecosystem to intercept river microplastics. *Environmental Research*, *210*(January), 112939. DOI: https://doi.org/10.1016/j.envres.2022.112939

[17] Kamaludin, M., *et al.* 2022. Effectiveness of a conservation education program among school students on the importance of mangrove ecosystems in Setiu Wetlands, Malaysia. *Applied Environmental Education and Communication*, *21*(1), 23–41. DOI: https://doi.org/10.1080/1533015X.2021.1936298

[18] Kartawinata, K., Adisoemarto, S., Soemodihardjo, S. and Tantra, I.G.M. 1979. Knowledge Status of Mangrove Forests in Indonesia. *Pro. Sem. eco. Mangrove Forest*, 21-39.

[19] Kathiresan 2003. How do mangrove forests induce sedimentation?. *Rev. biol. trop* vol.51 n.2 San José Jun. 2003.

[20] Lukman, K. M., *et al.* 2019. Indonesia Provincial Spatial Plans on mangroves in era of decentralization: Application of content analysis to 27 provinces and "blue carbon" as overlooked components. *Journal of Forest Research*, *24*(6): 341–348. DOI: https://doi.org/10.1080/13416979.2019.1679328

[21] Maghsodian, Z., *et al.* 2022. Study of microplastics pollution in sediments and organisms in mangrove forests: A review. *Environmental Research*. DOI:https://doi.org/10.1016/j.envres.2022.112725

[22] Murdiyarso, D., *et al.* 2015. The potential of Indonesian mangrove forests for global climate change mitigation. *Nature Climate Change*, *5*(12): 1089–1092. DOI: https://doi.org/10.1038/nclimate2734

[23] Nardin, W., Vona, I., and Fagherazzi, S. 2021. Sediment deposition affects mangrove forests in the Mekong delta, Vietnam. *Continental Shelf Research*. DOI:https://doi.org/10.1016/j.csr.2020.104319

[24] Nehren, U., and Wicaksono, P. 2018. Mapping soil carbon stocks in an oceanic mangrove ecosystem in Karimunjawa Islands, Indonesia. *Estuarine, Coastal and Shelf Science*, *214*(September): 185–193. DOI:https://doi.org/10.1016/j.ecss.2018.09.022

[25] North Konawe Government, 2012. *Spatial Plan Document for North Konawe Regency*, 2012–2016. North Konawe. North Konawe Government

[26] Passos, T., Sanders, C. J., Barcellos, R., and Penny, D. 2022. Assessment of the temporal retention of mercury and nutrient records within the mangrove sediments of a highly impacted estuary. *Environmental Research.* DOI: https://doi.org/10.1016/j.envres.2021.112569

[27] Rahman Halim, M. A., Ihrami Rahmila, Y., Muhammad, F., and Safitri, Y. 2018. The Effect on Mangrove Density with Sediment Rate in Coastal Pasar Banggi of Rembang Regency. *E3S Web of Conferences*, *73:* 1–5. DOI: https://doi.org/10.1051/e3sconf/20187304020

[28] Rianta, P., Ernawati, W., Chen, G., and Chen, S. 2018. Diversity and abundance of mangrove fiddle crabs, genus Uca (Decapoda, Ocypodidae) at a mangrove in Kema, North Sulawesi, Indonesia. *Acta Oceanologica Sinica*, *37*(12): 92–96. DOI: https://doi.org/10.1007/s13131-018-1336-8

[29] Richards, D. R., and Friess, D. A. 2016. Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. *Proceedings of the National Academy of Sciences of the United States of America*, 113(2): 344–349. DOI: https://doi.org/10.1073/pnas.1510272113

[30] Rizal, A., and Anna, Z. 2020. The Effect on Mangrove Density with Sediment Transport Rate in Sikakap Coastal Area of Mentawai Island District, West Sumatera Province, Indonesia. *World Scientific News*, *146*(June): 202–214. Available at: http://psjd.icm.edu.pl/psjd/element/bwmeta1.element.psjd-f6c96356-2aea-4335-866e-031c1c0a4ced

[31] Schwarzer, K., Thanh, N. C., and Ricklefs, K. 2016. Sediment re-deposition in the mangrove environment of Can Gio, Saigon River estuary (Vietnam). *Journal of Coastal Research*, 1(75): 138–142. DOI:https://doi.org/10.2112/SI75-028.1

[32] Sidik, F., Neil, D., and Lovelock, C. E. 2016. Effect of high sedimentation rates on surface sediment dynamics and mangrove growth in the Porong River, Indonesia. *Marine Pollution Bulletin*, 107(1): 355–363. DOI: https://doi.org/10.1016/j.marpolbul.2016.02.048

[33] Soltani, P., Askar, M.B, Bahrami, H, and Pour, S.H, 2017 Evaluation of Sediment Transport in the Naiband Gulf Area Using Mike21. *Open Journal of Geology*, 7: 182-192.

[34] Sukuryadi, Harahab, N., Primyastanto, M., and Semedi, B. 2021. Collaborative-based mangrove ecosystem management model for the development of marine ecotourism in Lembar Bay, Lombok, Indonesia. *Environment, Development and Sustainability*, *23*(5): 6838–6868. DOI: https://doi.org/10.1007/s10668-020-00895-8

[35] Terada, K., Koibuchi, Y., and Isobe, M. 2017 Rainfall effect on sediment and nutrient fluxes in a small mangrove river, Okinawa, *Japan Journal of Marine Research*, 75: 1–17.

[36] Tetelepta, J. M. S., Loupatty, S., and Wawo, M. 2020. Sustainable Management Strategy for Mangrove Forest of Pelita Jaya Bay and Kotania Bay, Western Seram, Indonesia. *TRITON: Jurnal Manajemen Sumberdaya Perairan*, *16*(2): 53–67. DOI: https://doi.org/10.30598/tritonvol16issue2page53-67

[37] Viennois, Gaëlle, *et al.* 2016. Multitemporal Analysis of High-Spatial-Resolution Optical Satellite Imagery for Mangrove Species Mapping in Bali, Indonesia. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *9*(8): 3680–3686. DOI: https://doi.org/10.1109/JSTARS.2016.2553170

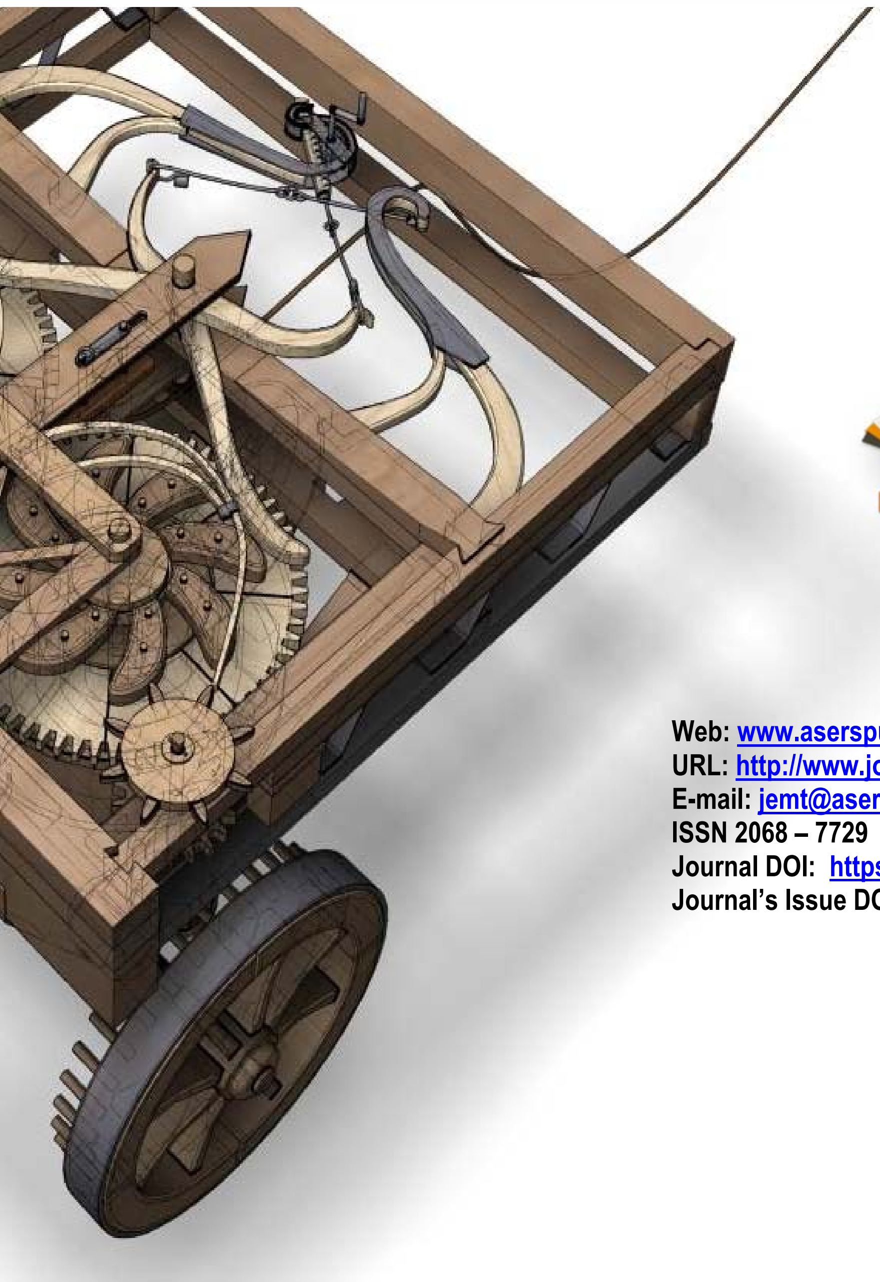
[38] Viennois, G., *et al.* 2015. Temporal stability of mangrove multispectral signatures at fine scales: Stability of mangrove multispectral signatures. *2015 8th International Workshop on the Analysis of Multitemporal Remote Sensing Images, Multi-Temp 2015*, *Fig 1*, 2–5. DOI: https://doi.org/10.1109/Multi-Temp.2015.7245803

[39] Willemsen, P. W. J. M., *et al.* 2016. Sensitivity of the sediment trapping capacity of an estuarine mangrove forest. *Geomorphology*, *273*: 189–201. DOI: https://doi.org/10.1016/j.geomorph.2016.07.038

[40] Yasidi F. and Zulkarnain, 2010. Erosion in the Lasolo River. *Preparation of Amdal Documents for Nickel Ore Processing PT. Abuki Jaya steinless Indonesia at Mandiodo*. North Konawe Regency, Southeast Sulawesi.

[41] Yasidi, F. and Pangerang, U.K. 2007. Mangrove Conditions in the Lasolo Mandiodo River Estuary. *ANDAL. Compilation of Amdal Documents for Nickel Ore Processing and Operation of Special Ports* in Mandiodo, North Konawe Regency, Southeast Sulawesi

ASERS



ASERS Publishing

Web: www.aserspublishing.eu
URL: http://www.journals.aserspublishing.eu/jemt
E-mail: jemt@aserspublishing.eu
ISSN 2068 – 7729
Journal DOI: https://doi.org/10.14505/jemt
Journal's Issue DOI: https://doi.org/10.14505/jemt.v14.1(65).00