Geospatial Modeling of the Nitrate Distribution as an Indicator of Aquatic Fertility in the Lagoon Waters of the Mangrove Information Center (PIM), Pekalongan

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Abstract

In the lagoon area of the Mangrove Information Center (PIM), Pekalongan, annual flooding leads to inundation in some land areas, particularly pond areas, lagoons, and residential areas. The area of submergence due to tidal floods in 2020 reached 783.99 hectares. The construction of embankments to the south of the lagoon as protection against flooding has transformed the northern area into a lagoon. Our research, crucial for understanding and managing these environmental changes, aims to determine and analyze the content and distribution of nitrate in the Lagoon Area of Mangrove Information Center Waters, Pekalongan. This was achieved through a thorough process of in situ observations based on purposive sampling at six sampling sites on June 22, 2023. The nitrate distribution data was then interpolated with a 2D current hydrodynamic model, ensuring the most accurate representation of the data. The value of nitrate content in the Mangrove Information Center lagoon ranges between 0.0065-0.1072 mg/L. This distribution pattern, influenced by deposits of mangrove litter, the depth of the lagoon, and water circulation, reflects the accumulation of physical and chemical influences in the waters.

Keywords: Nitrate, Mangrove Information Center (PIM), Lagoon, Pekalongan

INTRODUCTION

Pekalongan waters were flooding yearly, resulting in inundation in some land areas around the coast, especially pond areas, lagoons, and some residential areas. An analysis of the area of submergence due to tidal floods was carried out by Zainuri *et al*. (2022), which showed that in 2020 it reached 783.99 hectares. These results also predict possible areas in 2025, 2030and 2035 of 3388.98, 6523.19, and 7578.94 hectares. This causes the local government to build embankments in flood areas, thus forming an inundation area, becoming a lagoon. The development process is in stages, resulting in different inundation patterns and periods (Mentari *et al*., 2022). Efforts to overcome flooding and inundation are also carried out by rehabilitating coastal mangrove areas. In the lagoon area, a mangrove area was created, known as the Mangrove Information Center (PIM), which plays a role in efforts to reduce inundation areas by forming a mangrove green belt, especially in the front shoreline area which is used for aquaculture areas (Pratiwi *et al*., 2022). This is related to the ecological role of mangrove plants as trapping sediment and preventing abrasion and erosion. However, the mangrove area makes the lagoon an area rich in nutrients and impacts the fertility of the waters. This condition causes interactions between mangrove plants and water fertility through biogeochemical processes. Mangrove plants will provide litter from mangrove leaves that increase nutrients after being degraded by bacteria. Meanwhile, sediments and waters will be resuspended by tidal floods, causing the distribution of nutrients. One of the components that increases is the

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Diterima/Received: 02-08-2024, Disetujui/Accepted: 01-09-2024
DOI: https://doi.org/10.14710/jkt.v27i3.24081

presence of nitrate elements. Nitrate originating from upstream water areas will enter the estuary and lagoon areas in Pekalongan waters through the return mass of the tidal flood (tidal) process. This condition will cause distribution in the lagoon area, which will ultimately be related to the photosynthesis process and the fertility of the waters in the lagoon. The process of nutrient enrichment as a result of mangrove leaf litter and organic waste from upstream areas and rivers will have an impact on the nitrate content in the lagoon area, as well as its distribution as a result of the influence of tides, coastal currents and waves (Maslukah *et al*., 2019; 2022, Zainuri *et al*., 2022 and Ridarto *et al*., 2023). Mapping efforts are carried out by applying remote sensing technology. This application is intended to determine the distribution of nitrate in line with observations based on time, place, and season. This is because a geospatial approach using remote sensing will provide opportunities for sustainable data processing and can be used for more accurate forecasting (Topouzelis *et al*., 2021). In this study, a remote sensing approach was carried out using multispectral imagery from Sentinel-2, the level of accuracy of which can provide differences between the area of land, water, plants, and coastal areas (Caballero *et al*. 2018). This research was carried out using in situ observations, which were integrated with the use of imagery from Sentinel-2.

MATERIAL AND METHODS

The research was conducted in situ by taking samples from 6 stations on June 22, 2023. The sampling points were carried out from the mouth of the Pencongan River, in the wast side until the west side of the lagoon in Pekalongan waters. The observation side located at 6° 51' 9,312'' S - 6° 50' 48,142'' S and 109° 41' 50,279'' E- 109° 39' 17.612'' E. At the research location, water mass circulation is influenced by currents moving up the coast and tides related to the seasons. The tides in these waters are predominantly mixed prevailing diurnal tides (Pratama, 2018; Maharlika *et al*., 2020).). Tidal data obtained from the Geospatial Information Agency (BIG), 2022 iPASOET | Sea Level Monitoring (big.go.id) then processed using the admiralty method. The samples were collected at an elevation of 1.796 meters with LWL 1.249 meters, MSL 1.709 meters, and HWL 2.198 meters.

Water sampling and nitrate quantification

Water samples were taken using a Nansen bottle sampler at the sea surface on 0.2d. The nitrate concentration was measured using a UV-visible spectrophotometer with a cadmium reduction method (SNI 6989.79:2011).

Satellite Data Pre-Processing

The image data uses satellite acquisition data for June 2023 to describe the location according to the conditions during *in-situ* data collection. Sentinel-2 level 1C image taken from EarthExplorer (usgs.gov) then examines the accuracy of the surface reflectance product resulting from the atmospheric correction on the image using Sen2Cor software to become sentinel-2 level 2A (Padró *et al*., 2018). This approach attempts to create a surface reflectance or Bottom of Atmospheric (BOA) value by subtracting the Top of Atmosphere (TOA) reflectance value from the multi-temporal image used (Bioresita *et al*., 2018; Caballero *et al*., 2018). The sentinel-2 level 2A bottom of the atmospheric (BOA) satellite imagery was obtained, and the shoreline extraction was performed using ArcGIS 10.8 software. Shoreline extraction is processed by separating the land boundary from the sea boundary using the band ratio and RGB composite method. The band ratio technique produces land-water boundaries not covered by vegetation, classifying into the sea area. The results of this limitation are later exported as vector data in the form of coastline data in .shp format and corrected using the on-screen digitize method on images that have been given a composite RGB color display on the three-image data. The coastline extraction uses the Normalized Difference Water Index algorithm to distinguish between water and land boundaries using Near-Infrared (NIR) (band 8) and green band (band 3) (McFeeters, 1996; Du *et al*., 2016; Kamaruddin *et al*., 2022; Ridarto *et al*., 2023).

Interpolation Model

A spline-based interpolation technique displayed nitrate concentrations as a distribution pattern. The Spline method was used because it assumes that the interpolation value would fluctuate linearly as a function of distance from the closest sample value and will not be influenced by the location of the sample data. (Ahmad and Deeba, 2020; Kamaruddin *et al*., 2022). This distribution pattern graphically and informatively describes each parameter. (Ahmad and Deeba, 2020). The interpolation method used is spline with barriers, where this method separates the interpolation area from the boundary area, namely the land area. The land vector is used as input barrier features, which, in this case, uses the lagoon land around the Mangrove Information Center area, Pekalongan. Then, in the environment setting, the extent used is the area of interest in the study area. In addition, the mask on the raster analysis is also set according to the area of interest so that the resulting interpolation follows the study area (Ridarto *et al*., 2023).

Wind Data Processing

The wind data were obtained from the European Center for Medium-Range Weather Forecast (ECMWF). The data used the u and v components, which will be processed into speed and wind direction data. The data extraction results were presented in the wind rose using WRPLOT. Downloaded wind data at speeds u and v, then calculated the resultant wind speed and direction in vectors x and y. The wind data used is at one-hour intervals for an entire month, in June 2023, representing the east season each year. Wind data determines the dominant characteristics of the wind's direction and speed that passes over the lagoon around the Mangrove Information Center area, Pekalongan (Ridarto *et al*., 2023).

2D Hydrodynamics Characteristics of Ocean Currents

Ocean currents are generated by inputting wind, tidal, and bathymetry data in the lagoon waters around the Mangrove Information Center area, Pekalongan. MIKE 21 software was used with the FM flow model module to obtain sea surface current data. Current processing has several stages, such as pre-processing the model, in the form of preparation of bathymetric and unstructured triangular mesh data; processing the model in the form of set up model parameter coefficient values in the control model section; and post-processing models in the form of numerical simulation results (Ridarto *et al*., 2023; Suhana *et al*., 2023).

RESULTS AND DISCUSSION

The research results on nitrate content in the Mangrove Information Center's lagoon waters show the lowest content at station 4, the station closest to the open sea, with a nitrate content value of 0.0065 mg/L. This is related to the position of station 4, which borders the sea, so it is heavily influenced by the mass of sea water that enters the lagoon. This mass of water will dilute the organic matter in the water, including the nitrate content, which will become lower. This condition is also supported by the sampling time, which is carried out at high tide (Zainuri *et al.,* 2022, Ridarto *et al.,* 2023). Meanwhile, the highest nitrate content was shown at station 1, with a value of 0.1072 mg/L, where station 1 was on the lagoon's edge. In this area, much sediment settles and produces organic material, so the nitrate content at station 1 is high. This causes the nitrate content to come more from bottom sediments and freshwater organic waste in the Pencongan river, which is not mixed much with water masses originating from the sea. The nitrate contents in the lagoon waters tend to be stagnant and are not much influenced by the mixing of seawater. The nitrate content mostly comes from washing from sediment, which tidal currents carry toward high tide (Maslukah *et al*., 2019; Maslukah *et al*., 2022; Mentari *et al*., 2022).

Stations 2, 3, and 6 have a medium nitrate content value because each station is in stagnant areas at river mouths, inner lagoons, and water areas close to mangrove forests. This condition occurs because, during the time of sampling, it was during the high to low tide period. This makes it easier for the location to be stagnant and to get more fresh water sources from land. It was explained by Zammi *et al*. (2018) and Pratiwi *et al*. (2022) that coastal areas, which are not much influenced by physical oceanographic processes, will tend to have low material content. Overall, it can be concluded that the nitrate content obtained from the station impacts the physical and chemical oceanographic interaction processes, with the carrying capacity and capacity of the water body.

Spatial distribution of Nitrate

The distribution of nitrate in the Mangrove Information Center, Pekalongan City's lagoon has a convergent pattern. Based on the results, the highest nitrate concentration values were in areas near land. In this area, a nitrate value of 0.1072 mg/L was found. Meanwhile, Nitrate with the lowest values was found at stations 4 and 5 with values of 0.0065 mg/L and 0.0099 mg/L. Stations 4 and 5 are located in the border between the lagoon and the open sea. High nitrate levels in estuary areas occur because there is a process of trapping nutrients from rivers and the sea.

Maslukah *et al*. (2022) and Zainuri *et al*. (2022) stated that the closer the location is to the sea, the lower the nitrate concentration will be so that the highest concentration values will be in areas far from the open sea, namely estuary areas such as lagoons. This is because estuary areas are one of the sources of marine nutrients. In mangrove waters, nitrate content was quite high, with a value of 0.023 mg/L. The high nitrate value in mangrove waters is due to mangroves being one of the sources of nutrient production in estuary areas. Nitrates are formed from plants' decomposition process and dead organisms' remains. Nitrates are also formed due to the presence of mangrove litter decomposed by decomposing bacteria into detritus. Then, it will dissolve in water and precipitate as nutrients. The density of mangrove stands also influences the presence of nitrates in the area. The higher the mangrove density, the higher the nitrate value (Latifah *et al*., 2018; Ridarto *et al*., 2023). The high value of nitrate in estuary areas is influenced by sedimentation. High nitrate concentrations will be found in estuary areas with low depth. This can be seen in station 1 (Figure 1), which is the area closest to land and has a shallow depth. The nitrate content at this station reached 0.1072 mg/L. This value indicates that the estuary waters or lagoons of the Mangrove Information Center are classified as polluted waters. Apart from sediment, the presence of nitrates in estuary or lagoon areas is influenced by tides. At low tide, the nitrate content will increase; at high tide, the nitrate content tends to decrease. High nitrate levels at low tide are caused by waste discharge (Maslukah *et al*., 2022). In Pekalongan Waters, pond waste is the main source of waste in the estuary or lagoon area.

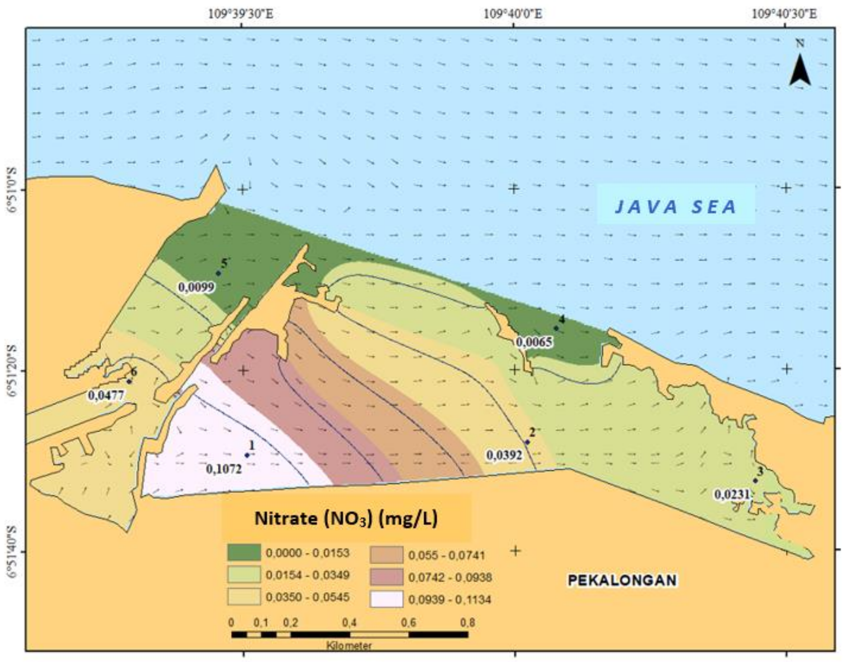

Figure 1. Spatial distribution pattern of the nitrate content in the lagoon around Mangrove Information Center area, Pekalongan.

Factors that affect the distribution are hydro-oceanographic parameters such as currents moving from northeast to southwest and tides that carry dissolved particles in the waters. The pattern of distribution of nitrate content in the Mangrove Information Center follows the circulation pattern and the contour shape of the lagoons in the area. Deposits from mangrove litter influence the content and distribution of nitrate in the Mangrove Information Center, the depth of the lagoon, and water circulation as an accumulation of physical and chemical effects of the waters (Zainuri *et al.,* 2022).

Tidal Characteristic

Tidal data in this study was related to the seawater sampling for nitrate processing and was taken on June 22, 2023, or during the transition season 1 and at 08.00 – 11.30 WIB when the tide is as seen in Figure 2. The tidal elevation is obtained from the Indonesian Geospatial Reference System (SRGI) website provided by the Geospatial Information Agency (SRGI). The downloaded elevation data is then filtered to get the hourly tidal elevation. Furthermore, the tidal chart below is obtained by processing the elevation value using the admiralty method. The formzhal number obtained is 0.793771982, so the tidal type is a mixture inclined to double daily.

Wind Characteristic

Wind data is represented by a windrose, as shown in Figure 3. The image contains information on wind speed as well as the direction of the wind that occurred in Pekalongan waters in June 2023. The research was carried out in the month of the East season, namely June. The most dominant wind direction comes from the southeast to the northwest. The dominant wind speed is 0.5–2.1 m/s. Sometimes, the wind also blows faster, reaching 2.1–3.6 m/s. The greatest wind speed comes from the northeast to the southwest, 3.6–5.7 m/s.

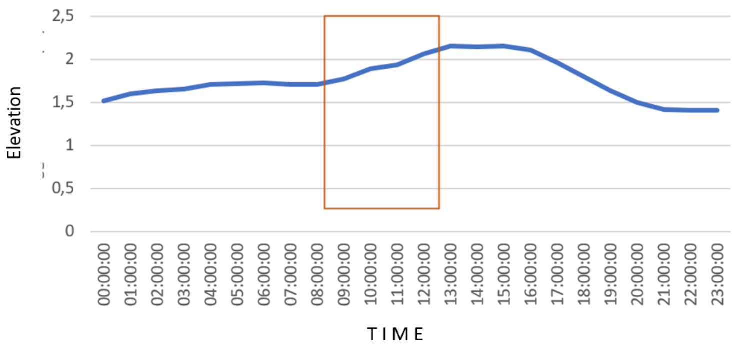

Figure 2. Tidal Chart of lagoon around Mangrove Information Center area, Pekalongan on June 22, 2023

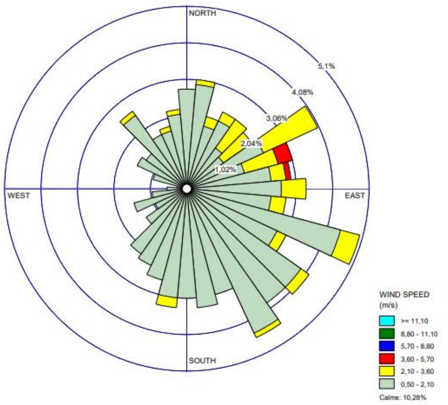

Figure 3. Wind Rose in of lagoon around Mangrove Information Center area, Pekalongan (June 2023)

CONCLUSION

The value of nitrate content in the Mangrove Information Center lagoon ranges between 0.0065-0.1072 mg/L. This distribution pattern shows a convergent model due to the influence of deposits of mangrove litter, the depth of the lagoon, and water circulation as an accumulation of physical and chemical influences in the waters.

ACKNOWLEDGMENTS

This research project was funded by a Research Grant from the Faculty of Fisheries and Marine Sciences, Diponegoro University in addition to the State Budget No. 39/UN7.F10/PP/III/2023, 3 Maret 2023.

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