ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol 54, No 1 (2022):
DOI: 10.22146/ijg.69840 website: https://jurnal.ugm.ac.id/ijg

INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

Spatial Analysis of Health and Physical Parameters of the Mangrove Forest at Taman Hutan Raya Ngurah Rai, Bali Using Sentinel-2A

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Received: 2021-12-22
Accepted: 2022-07-16

Keywords:
environmental quality; mangrove forest health; NDVI; ordinary kriging; Sentinel-2A

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Abstract. Mangrove forests are continuously degraded due to human activities, despite being a very valuable natural resource. Therefore, this study aimed to map the distribution and analyze mangrove forests' health based on the normalized difference vegetation index (NDVI) and environmental quality. The health distribution was determined through the processing of Sentinel-2A satellite imagery in 2020 and field measurements. The environmental quality was obtained by processing physical parameters including water temperature, salinity, pH, and substrate texture using the Ordinary Kriging method. Based on the results, Taman Hutan Raya (Tahura) Ngurah Rai mangrove forest is dominated by healthy trees which become worse once closer to the shore and riverbanks. Hence, mangrove vegetation with good conditions tends to have optimal environmental quality conditions and vice versa.

1. Introduction

Mangroves constitute the most dominant coastal forests in tidal and saltwater areas in tropical and subtropical climates (Davidson, 2009). Furthermore, they live by forming distinctive zones based on substrate type, tides, and salinity (Mughoffar et al., 2018). Mangrove forests have high adaptability to a very diverse environment such as being able to grow and develop in coastal environments with extreme salt levels, water saturation, unstable soil conditions, and even anaerobic conditions (Pramudji, 2001). Their benefits include the capability to protect the coast from abrasion, support coastal communities' livelihood, and play an important role in global climate regulation (UNEP, 2014). Mangroves are one of the forests with high economic productivity, an energy source for the organisms in their waters, and a habitat for many types of flora and fauna (Susiana, 2015).

Moreover, they are continuously depressed and degraded regardless of the ecological and economic values possessed (Noor et al., 2006). Damages to mangrove forests are caused by various factors, such as human activity which triggers conversions of the trees into residential areas, port construction, and aquaculture (Pawar, 2013). Water conditions, specifically salinity, also affect mangroves' quality (Noor et al., 2006). Although these trees have high adaptability to changes in salinity, they are susceptible to changes in the quality of other environmental parameters (Schaduw, 2018). Once there is damage or disturbance to the coastal environmental quality, mangroves' health decline, and death will occur.

Mangroves in the Taman Hutan Raya (Tahura) Ngurah Rai are also not immune from damage risks. According to the Bali Provincial Government in 2012, a permit was issued for reclamation activities in Tanjung Benoa by the Governor's Decree No. 2138/02-C/HK/2012 which threatens coastal forests including those comprised of mangroves. Ngurah Rai airport expansion, Benoa Harbor construction, and organic and inorganic pollution caused by resident waste disposal in the river that empties into Benoa Bay are other threats encountered (BPKH Region VIII Denpasar, 2016). The Bali Mandara Toll Road construction tends to also affect several physical parameters (Andika et al., 2018). Mapping the distribution and health of mangrove forests is vital for monitoring, planning, and policy-making.

To avoid more damage to mangrove forests, conservation efforts are needed. Healthy plants also have a good growth rate, and their health status is indicated by the canopy density or pile of leaves carried (Oladejo, et al., 2018). NDVI can be used to quantify vegetation greenness with the principle of radiation from visible red light which is absorbed by chlorophyll and then reflected (Williams, 2012). Based on these characteristics, mangrove health can be analyzed using the NDVI method (Maulidyah et al., 2019).

Therefore, this study aimed to create a map of Normalized Difference Vegetation Index (NDVI) values and environmental quality parameters' spatial distribution, as well as to analyze the health of Tahura Ngurah Rai mangrove forest based on both. This study's novelty is the analysis of mangrove forests' health by overlaying NDVI values and the

determination of environmental parameters' spatial distribution using the kriging spatial interpolation method.

2. The Methods

Study Area

This study was conducted at Tahura Ngurah Rai, administratively located within the Badung Regency and Denpasar City which includes 12 coastal villages in three Districts, namely South Kuta, Kuta, and South Denpasar. Tahura Ngurah Rai area management is included in the Forestry Service of UPT, Bali Province. Its land coverage comprises 1,132.00 ha Mangrove Forest, 16.27 ha Settlements, 49.35 ha Open Land, and 144.01 ha Water Body (BPKH Region VIII Denpasar, 2016). Furthermore, the forest park is situated in Benoa Bay, which is a strategic location for both business and tourism promoting the developments in this area. The reclamation of Serangan Island, Benoa Harbor, and the Toll Road are some developments that have been recorded.

Variable and Data Collection

Several variables were used in this study, namely the NDVI values and environmental quality parameters consisting of temperature, salinity, pH, and substrate texture. Moreover, they were obtained through Sentinel-2A and data sampling from the field. Primary and secondary data were collected for the NDVI variable, where the primary was obtained from field sampling to evaluate the number of greeneries in one unit area. The secondary was administrative and Sentinel-2A satellite image data collected from November 18, 2020, at Tahura Ngurah Rai, Bali. Data collection for both samples of total vegetation number in the unit area and environmental quality was carried out at 40 selected points using the purposive random sampling method according to the vegetation health level based on the NDVI value classification and road accessibility in mangrove forests. The number of tree stands was sampled by previously making a 10 x 10 meters plot.

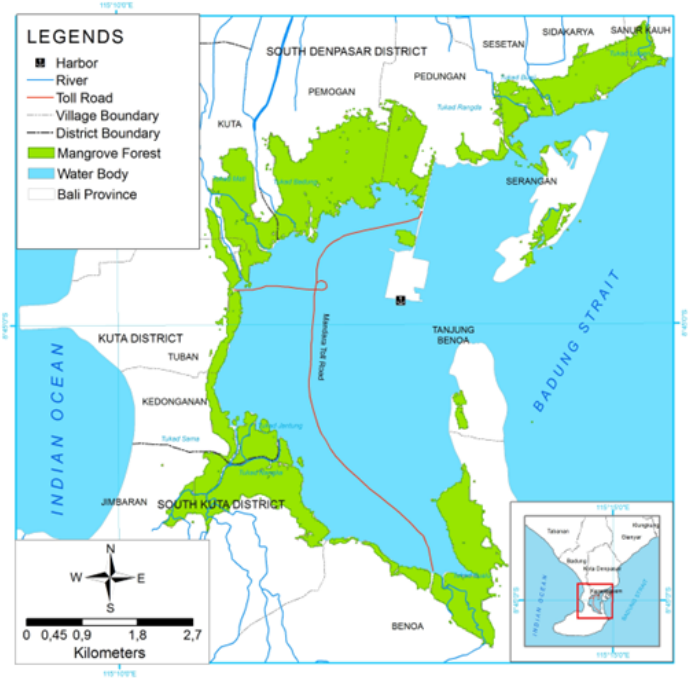

Figure 1. Distribution of Mangrove Forest NDVI Values

Mangrove Forest NDVI Distribution

Several references were used to examine the mangrove forest's health. This included studies by Razali et al. (2019), Kawamuna et al. (2017), Awaliyan and Sulistyoadi (2018), and Maulidyah et al. (2019) which assessed the vegetation health level based on NDVI reported by VITO (2017) and did validation with the value of species density in the field.

To map mangrove forest distribution, first, land cover classification was carried out using the supervised classification method. Supervised classification is the process of grouping image pixels into a certain class based on a sample (training) that has been determined by the user as a reference (LAPAN, 2015). The accuracy test of the mapping results was conducted by making a confusion or contingency matrix. The next stage of image data processing was NDVI transformation to determine canopy density level. The NDVI values range from -1 to 1 and are transformed using the following formula (Green, et al., 2000):

$$NDVI = (NIR-RED)/(NIR+RED)$$

Where:
NIR = Near Infrared Band
RED = Red Band

The data of total mangrove vegetation in one unit area were obtained from 40 field samples, then processed by calculating the vegetation density with the following equation formula (Gunawan, et al., 2011):

$$D_i = (n_{(i)})/(A(ind/m^2))$$

Where:

D_i = Species i Density

(i) = Total vegetation of species i

(ind/m^2) = total sampling area (class) or (unit/pixel)

Environmental Quality Distribution

Another reported mangrove health analysis method used environmental quality data including pH, Temperature, Salinity (Schaduw, 2018), and Mangrove Forest Substrate (Imamsyah et al., 2020; Razali et al., 2019) as a study variable. Previously, water quality was mapped with the aforementioned parameters (Nagalakshmi et al., 2016; Yasrebi et al., 2009; Suhadirman et al., 2013) through the kriging spatial interpolation method.

Steps for creating the mangrove forest distribution map commenced with tabular data processing, followed by the calculation of experimental semi-variograms of environmental quality data (temperature, pH, salinity, and substrate texture) with a Geostatistical Software called GS+. The experimental semi-variogram was then matched with theoretical semi-variogram models, namely Exponential, Spherical, and Gaussian. Next, an environmental parameter distribution map was created using the Ordinary Kriging method.

Mapping the Mangrove Forest Health

The NDVI values were used as one of the variables in assessing mangrove forests' condition, and the health data were processed based on classifications provided by Vito (2017). Another variable was the forest's environmental quality obtained from the interpolation of water temperature, salinity, pH, and substrate texture, which were categorized according to the optimal range for mangrove

health. The map for each parameter was then overlaid to produce a distribution map of the Tahura Ngurah Rai environmental quality. An overlay of the two maps for NDVI values and environmental quality was performed to generate a mangrove forest health distribution.

Data analysis

A statistical analysis of correlation and regression was conducted for the distribution of NDVI values. The correlation was used to determine the relationship between variable x which is the vegetation index transformation data and y. Meanwhile, regression evaluated the magnitude of effects caused by changes in each unit of the independent variable x. Descriptive spatial analysis was conducted for the NDVI values. The mangrove environmental quality distribution based on temperature, salinity, water pH, and soil texture parameters was also analyzed descriptively. The results of overlay data processing for both were analyzed in a tabular and spatial descriptive manner.

3. Result and Discussion

Mangrove Forest NDVI Distribution

Mangrove land cover extends along with the coastal villages of Kuta, South Kuta, and South Denpasar Districts. The forest area generated from supervised classification was then tested for accuracy with a confusion matrix. The results showed an overall accuracy of 94% which indicated that the classification can be used. The Tahura Ngurah Rai mangrove forest had a total area of 1,083.37 ha in 2021. The largest area of 520.71 ha was found in South Denpasar, then South Kuta had 347.7 ha, and the smallest was in Kuta, namely 214.96 ha.

The statistical test results showed a real or significant relationship between the NDVI and mangrove vegetation density values. The value of correlation (R) between both variables was 0.818 with a significance level of less than 0.05, and its magnitude indicated a positive relationship. Based on the distribution results presented in Figure 2, the NDVI value of the Tahura Ngurah Rai mangrove forest in 2020 ranged from 0.000754717 to 0.789031, which was quite high and the average was 0.5118. Low values can be found on the riverbanks and beaches directly facing the sea. The NDVI also appeared to decrease at the mangrove forest fringe close to housing and land.

Environmental Quality Spatial Distribution

Water Temperature Distribution

Based on kriging results, mangrove forest water temperature is at least 28.63oC with a maximum temperature is 33.32oC. The temperature in South Denpasar District ranged between 28.63ºC-32.53ºC. Low-temperature waters are located in the northern part of Benoa Bay, precisely in Pemogan, Serangan, and Pedungan Villages in South Denpasar District where the temperature is in the range of 28.63ºC - 30.19ºC. In Sesetan Village, Sidakarya, Sanur Kauh, and Serangan Island, the mangrove forest waters have a temperature range between 30.2ºC and 31.75ºC. The temperature of Kuta District, which is located in the western part of Benoa Bay, lies between 28.63oC and 32.53oC and it increases from North to South.

According to the State Minister for Environment (2004), the ideal temperature for mangrove health is 28-32°C. The environmental quality of mangrove forest waters based on temperature is presented in Figure 4. The quality which is classified as unhealthy can be found in South Kuta and Kuta Districts, precisely in Kedonganan and Jimbaran Villages. The temperature is not optimal because the mangrove forest waters in this area flow from 3 different rivers, namely Tukad Jantung, Tukad Nangka, and Tukad Sama. Among the twelve coastal villages in the Tahura Ngurah Rai area, Jimbaran is also one of those with the highest population.

Water Salinity Distribution

The salinity in Tahura Ngurah Rai ranges from 5.12 to 32.82%, and the average is 21.57%. This distribution shows that high salinity values can be found on the coast and riverbanks of the mangrove area. South Denpasar District

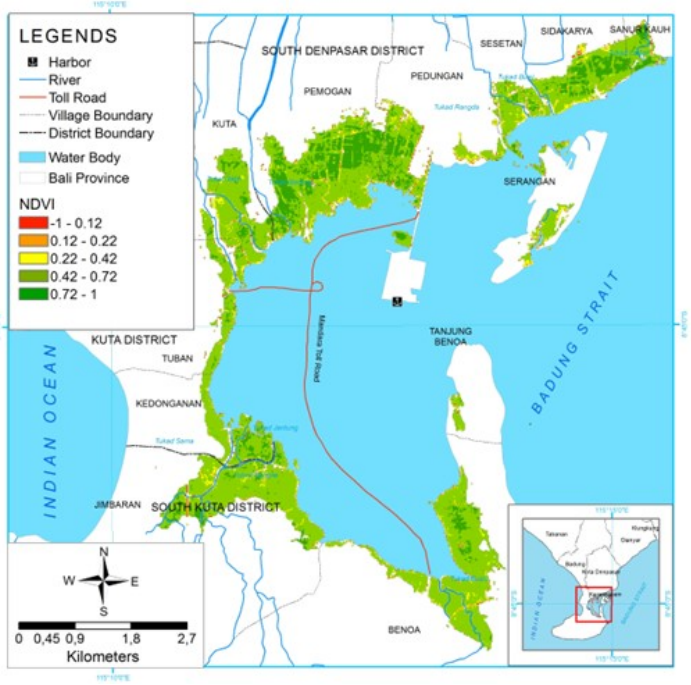

Figure 2. Distribution of Mangrove Forest NDVI Values

Table 1. Comparison of Mangrove Forest Health Area by District

Classification	Reference Data			Total	User Accuracy
	Non-Mangrove	Water Body	Mangrove		
Non-Mangrove	3	2	0	5	60%
Water Body	0	4	1	5	80%
Mangrove	0	0	40	40	100%
Total	3	6	41	50	
Producer's Accuracy	100%	66.67%	97.56%		
Overall Accuracy	94%				

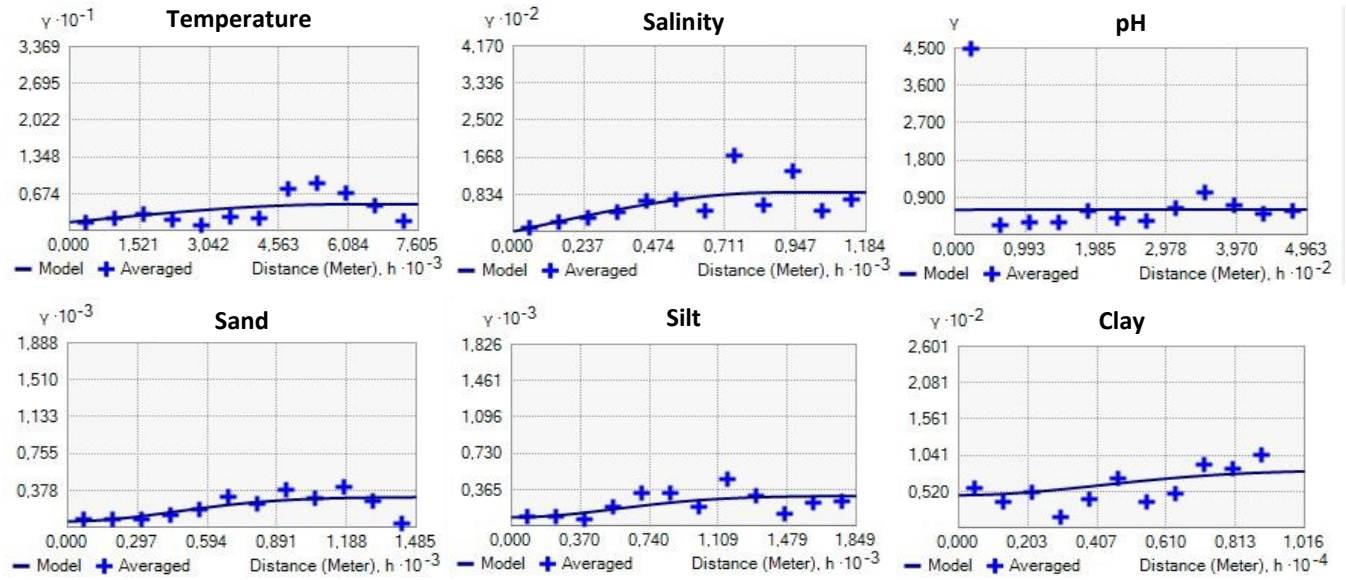

Figure 3. Semi-variogram for Environmental Quality Parameters

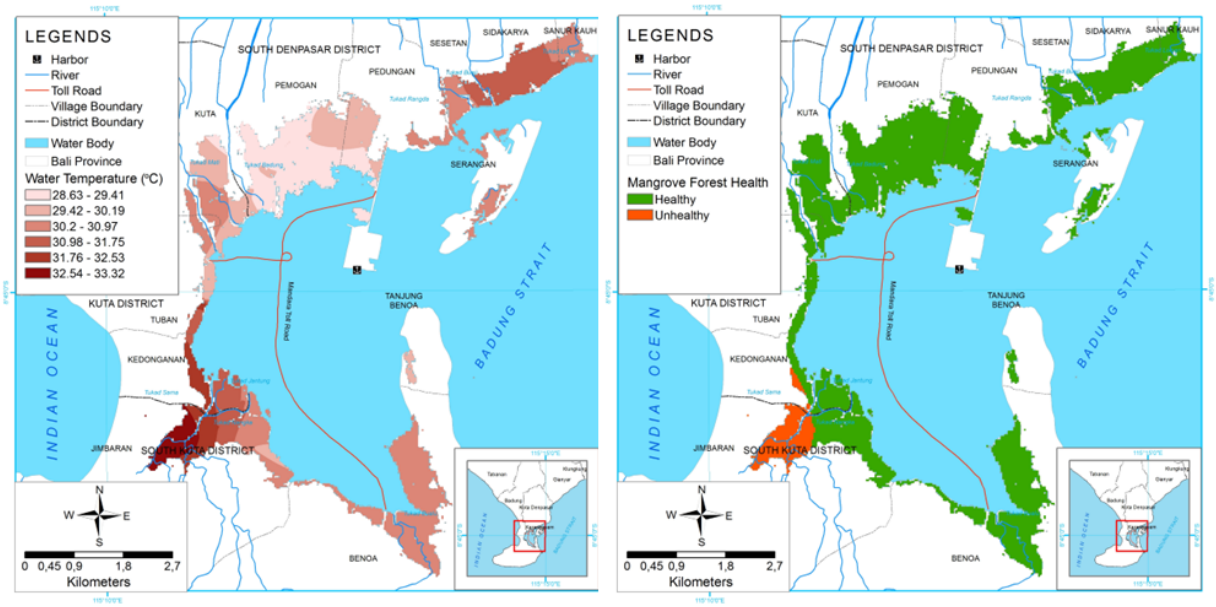

Figure 4. Distribution of Environmental Quality Based on Temperature Parameters

has a higher salinity than Kuta and South Kuta, specifically in the Sanur Kauh, Serangan, Sidakarya, and Sesetan villages with values between 18.98% and 32.82%. Moreover, the ranges are 5.12 to 32.82% in Pedungan and Pemogan villages, 14.37 - 29.21% in Kuta, and 5.12 to 32.82% in South Kuta.

The environment of mangrove plants thriving in estuarine areas has values ranging from 10 -30 (Wantasen, 2013). In Figure 5, areas with non-optimal water salinity are located in Benoa, Jimbaran, Pemogan, and Sesetan Villages. In Benoa and Pemogan which are quite close to the mainland, the salinity value is the lowest. Other areas containing unhealthy parameters are situated on the coast with a value exceeding 30.

Distribution of Water pH

Based on kriging results, the water pH in the mangrove forest is at least 6.9 and 7.5 maximum, with an average value of 7.13. The area with low pH is located in the northern and southern parts of Benoa Bay, precisely in South Denpasar with 6.9 - 7.4 and South Kuta District. Kuta District in the western part of Benoa Bay has 7.01 - 7.5 with an increasing distribution from North to South. In South Kuta District, the pH is higher in the west, precisely in Jimbaran and Benoa Villages with a pH range between 6.9-7, while Tanjung Benoa has 7.11-7.2.

The environmental quality distribution map based on pH can be seen in Figure 6, where the optimal value for healthy mangrove forests ranges from 7.0-8.5 (Wantasen, 2013). The non-optimal values are found in a small part of the South Denpasar District, namely Pedungan and Sesetan Villages. They are also present in the Benoa Village of South Kuta with values ranging from 6.9 to 7. The water pH values in Tahura Ngurah Rai as a whole does not vary much. This is because a balance exists between the acidic mangrove litter decomposition process and the influence of buffer capacity by salts in alkaline seawater. However, areas with a pH of less than 7 were due to the amount of mangrove litter in the water which decomposes and produces organic acids.

Distribution of Substrate Texture

The substrate texture in the South Denpasar District is dominated by sandy loam texture. There is a substrate with a clay texture and dusty clay in mangroves near the

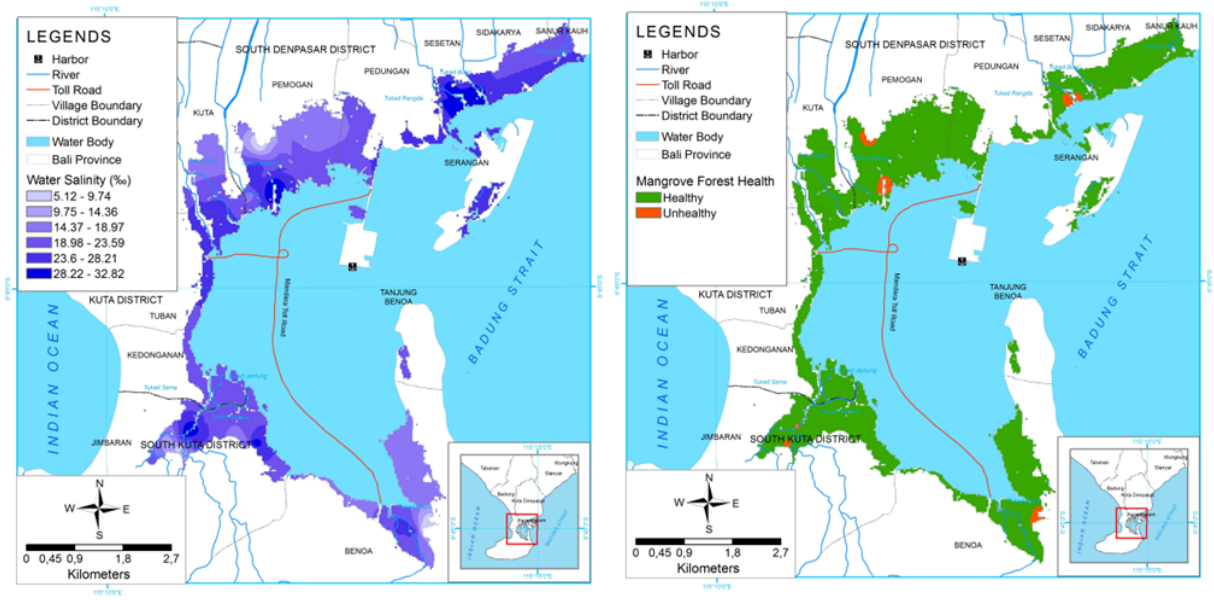

Figure 5. Distribution of Environmental Quality Based on Salinity Parameters

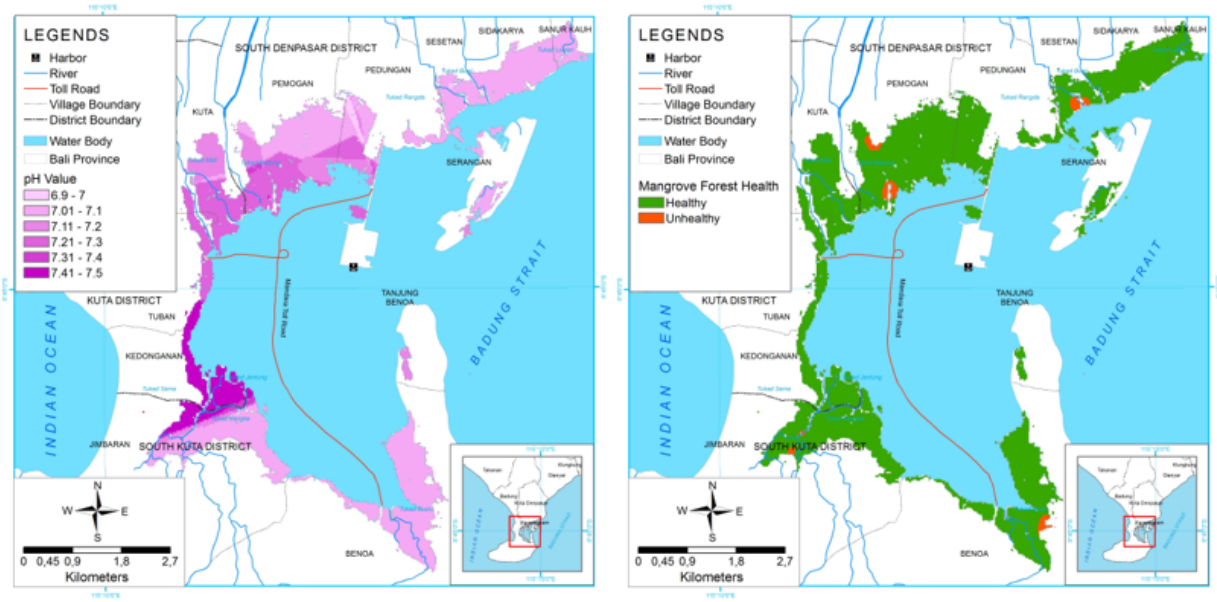

Figure 6. Distribution of Environmental Quality Based on pH Parameters

mainland of Pemogan Village, and sandy clay loam is found close to the coast on Sesetan and Sidakarya border. Moreover, Kuta District contains sandy clay, while South Kuta majorly has sandy loam. Several clay-textured areas in Benoa Village are close to Tukad Bualu.

The distribution of substrate textures in Tahura Ngurah Rai shows that all types present in this area are still in the optimal range for the mangrove forest health because they appear to be clay based on the substrate fraction content. The clay texture affects the water content and nutrient conditions. Mangroves grow healthy on clay-textured soils that have a larger surface area to promote water-holding capacity and the provision of high nutrients (Mahmud and Bau, 2014). The environmental quality distribution based on the substrate texture is demonstrated in Figure 7.

Mangrove Forest Health Analysis

From the NDVI values and environmental quality, an overlay was processed to visualize mangrove forest health distribution at Tahura Ngurah Rai in 2021 as presented in Figure 8. The area of mangrove health per district can also be seen in Table 2.

The quality of mangrove forests based on NDVI values with a range of 0.22-1 is included in the healthy category and those with a range of -1-0.21 are unhealthy. In South Denpasar, up to 490.53 ha were in healthy condition and 30.18 ha were unhealthy. Furthermore, its healthy category amounts to 94.2% of the total area and has the best condition among other districts in Tahura Ngurah Rai. Healthy mangrove forests are mostly found in Sesetan, Sidakarya, Pemogan, and Pedongan. Meanwhile, the unhealthy category is located around Tukad Buaji and Tukad Rangda in Sesetan and Sidakarya because of wastes disposed into the river and the very high community density of 6,806.90 and 5,242.93 people/km2 respectively, compared to other coastal villages (Central Bureau of Statistics, 2020). Waste from the surrounding community and other activities influence the forest's environmental quality which then affects the mangroves' health. For example, both conditions caused the water temperature and salinity to be no longer optimal for the mangroves. This occurrence can be found at the Tukad Rangda estuary on Sesetan and Sidakarya border, as well as on the coast of Pemogan Village.

Kuta has a mangrove forest stretching across an area of 214.96 ha consisting of a healthy 207.87 ha and an unhealthy 7.09 ha. The unhealthy categories are widely spread on the beach and edge of Tukad Mati in this District as well as at the estuary of three different rivers in Kedonganan Village that carries coastal community wastes. Tukad Mati is a large river that irrigates Kuta and is designated as one of the tourism sites in Tahura Ngurah Rai. Several areas of mangrove forest in Kedonganan Village and at the edge of Tukad Mati, have non-optimal water temperatures. High intensity of human activities such as tourism and community waste disposal tend to damage mangrove forests.

Out of the total mangrove forest area in South Kuta, 273.68 ha is healthy and 74.02 ha is unhealthy. Among the three places, this district has the worst condition. Unhealthy mangroves are widely scattered on the shores of the estuary areas of Tukad Sama, Tukad Jantung, and Tukad Nangka in Jimbaran Village, and some are close to the mainland in Benoa. The water flowing in this area is influenced by three different rivers, namely Tukad Sama, Tukad Jantung, and Tukad Nangka. This can be observed in the environmental water quality, namely a high temperature ranging from 32.54 - 33.32 °C which exceeds the optimal limit of 28 - 32 °C stated by the State Minister for Environment (2004). However, the unhealthy vegetation in Jimbaran Village is not on the riverbank or the beach which is influenced by the forest water salinity level, and some areas have values between 5.12 and 9.74. Meanwhile, a low level or lack of salinity is found in the eastern part of Benoa Village, namely close to Tukad Bualu, which is caused by ocean currents that cannot reach the area. A large amount of plastic waste is also discovered in the surrounding settlements.

Out of the three districts, unhealthy mangroves can be found on forest edges close to the mainland or sea due to human activities. This is supported by the Pratama et al. (2019) study performed in Tahura Ngurah Rai, which indicated lower mangrove forest density on both sides of the border with the sea and land. This is generated from waste disposal, Airport expansion, as well as the construction of Benoa Harbor and toll road. Suteja and Dirgayusa (2018) also found pollution from rivers emptied into Tahura Ngurah Rai. Hamuna et al. (2018) reported the distribution of mangroves with low density or high damage in the outermost part of Taman Wisata Alam Teluk Youtefa Jayapura forest.

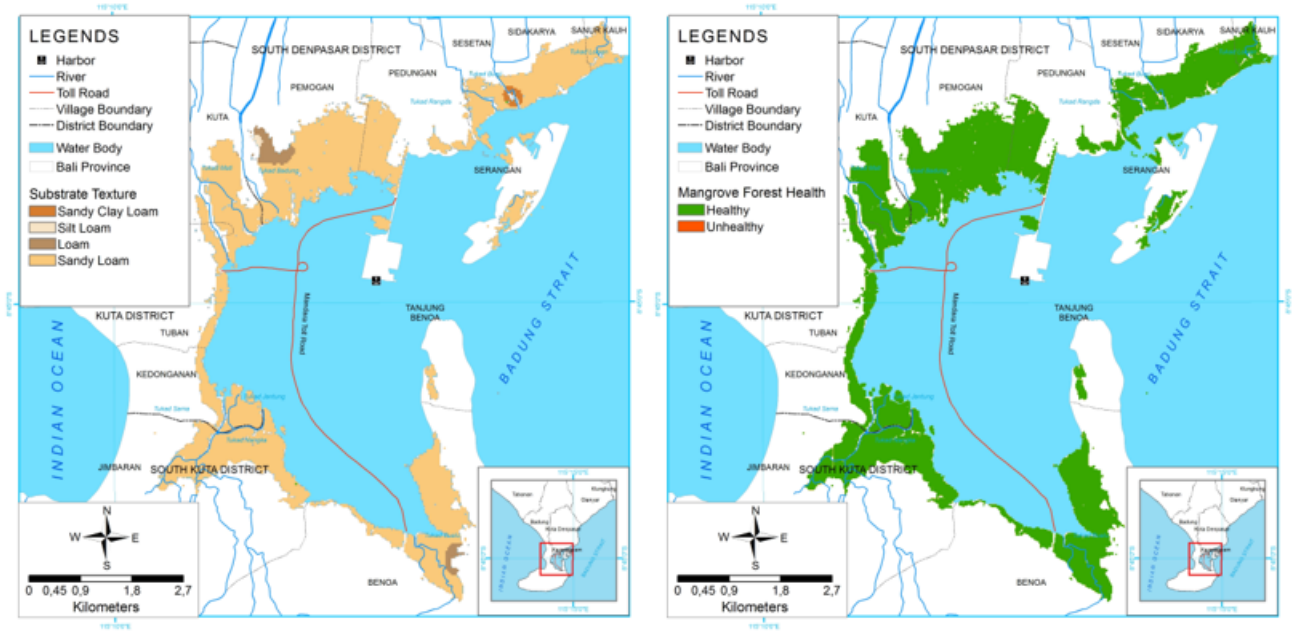

Figure 7. Distribution of Environmental Quality Based on Substrate Texture

Table 2. Comparison of Mangrove Forest Health Area by District

District	Vegetation Health	Pixel	Area (ha)	Area (%)
Kuta	Healthy	20,787	202.43	94.17
	Unhealthy	709	12.53	5.83
	Total		214.96	100
South Kuta	Healthy	27,368	273.68	78.7
	Unhealthy	7,402	74.02	21.3
	Total		347.7	100
South Denpasar	Healthy	49,053	490.53	94.2
	Unhealthy	3,018	30.18	5.8
	Total		520.71	100
	Grand Total		1,083.37	

Source: secondary data processing

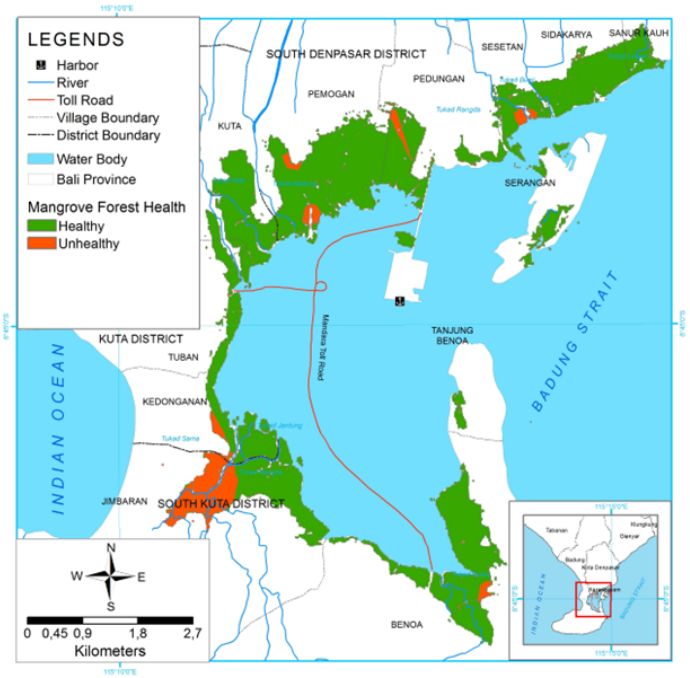

Figure 8. Distribution of Mangrove Forest Health Based on NDVI Values and Environmental Quality

Mangrove forest monitoring and mapping are crucial for ecosystem conservation and management, knowing its significant role in coastal life. The mangrove forest previously monitored in Tahura Ngurah Rai using Landsat 8 reported the area to be approximately 1,040.04 ha (Nurhaliza, et al., 2021), but this current study confirms 1,083.37 ha as the actual size. Furthermore, the better spatial resolution of the Sentinel-2A used showed a more detailed result leading to more precise analysis. The advantage of Sentinel-2A is that its images are available more frequently than Landsat and the device allows image replacement whenever clouds cover a study area (Selamat et al., 2020). The NDVI is the most widely applied variable in various studies and it tends to explain vegetation phenology. NDVI values and environmental quality parameters of the mangroves are used to analyze forest health. However, other parameters, specifically biotic factors and more sample points can be added to obtain a more accurate health distribution in Ngurah Rai Forest Park.

4. Conclusion

The spatial distribution of mangroves in Tahura Ngurah Rai in 2021 indicates that the NDVI value reduces once closer to the forest area edge. The environmental quality parameters are dominated by the healthy category. Unhealthy environmental quality in terms of the water temperature, pH, and salinity is found on the edge of river estuaries and mangrove forest areas bordering the mainland. Meanwhile, the substrate textures were healthy for vegetation growth. Based on the analysis results, the best mangrove forest health, NDVI values, and environmental quality parameters were discovered in South Denpasar, followed by Kuta, and South Kuta District which has the worst conditions among the three. Also, the forest health gets poorer near the shore and riverbanks. Healthy mangroves tend to have optimal environmental quality conditions and vice versa, due to the surrounding community activities such as waste disposal.

Acknowledgment

The authors are grateful to the Ministry of Research and Technology/National Research and Innovation Agency for the support rendered through the contract number NKB-2649/UN2.RST/HKP.05.00/2020. The authors are also grateful to the National Institute of Aeronautics and Space (LAPAN) for the satellite imagery provided, which is the most crucial requirement.

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