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MONITORING OF MANGROVE ECOTOURISM AREA USING NDVI, NDWI, AND CMRI IN DODOLA ISLAND, MOROTAI ISLAND REGENCY, INDONESIA

MONITORING KAWASAN EKOWISATA MANGROVE MENGGUNAKAN NDVI, NDWI, DAN CMRI DI PULAU DODOLA, KABUPATEN PULAU MOROTAI, INDONESIA

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ABSTRACT

The development of tourism infrastructure causes land-use change or land conversion from green open spaces into tourism economic areas. The utilization of mangrove areas as an ecotourism attraction needs to be monitored regularly so that facilities and infrastructure development do not threaten the sustainability of mangrove vegetation. This article aims to identify the distribution of mangroves using the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Combined Mangrove Recognize Index (CMRI) model in Morotai Island Regency, North Maluku Province, Indonesia. The perspective of sustainable ecotourism is used to discuss the socio-cultural context of the Morotai community, especially the people of Kolorai Island. This study adopted a mixed-method. Data processing is divided into two stages: the first stage, mapping the distribution of mangroves on Dodola Island using Landsat 8 Operational Land Imager (OLI) satellite imagery from 2013-2021 based on NDVI, NDWI, and CMRI calculations; the second stage, triangulation. The results of this study indicate that in 2017, there was a decrease in the value of NDVI and CMRI in Zone 1, Zone 2, and Zone 3 as a mangrove ecotourism area on Dodola Island. It indicates a threat to the mangrove ecosystem if infrastructure development causes a decrease in the value of the vegetation index significantly significant from year to year. Thus, it is necessary to control infrastructure development programs by involving local communities in the maintenance of mangrove ecosystems.

Keywords: CMRI, ecotourism, mangrove, NDVI, NDWI

ABSTRAK

Pembangunan infrastruktur pariwisata menyebabkan alih fungsi lahan atau konversi lahan dari ruang terbuka hijau menjadi kawasan ekonomi pariwisata. Pemanfaatan kawasan mangrove sebagai daya tarik ekowisata perlu dimonitoring secara berkala agar pembangunan sarana dan prasarana tidak mengancam keberlanjutan vegetasi mangrove. Artikel ini bertujuan mengidentifikasi sebaran mangrove menggunakan model normalized difference vegetation index (NDVI), normalized difference water index (NDWI), combined mangrove recognize index (CMRI) di Kabupaten Pulau Morotai, Provinsi Maluku Utara, Indonesia. Perspektif ekowisata berkelanjutan digunakan untuk mendiskusikan konteks sosio-kultural masyarakat Morotai khususnya masyarakat Pulau Kolorai. Penelitian ini mengadopsi metode campuran. Pengolahan data terbagi menjadi dua tahap yakni: tahap pertama, pemetaan sebaran mangrove Pulau Dodola menggunakan citra satelit Landsat 8 Operational Land Imager (OLI) dari tahun 2013-2021 berdasarkan kalkulasi NDVI, NDWI, dan CMRI; tahap kedua, trianggulasi. Hasil penelitian ini menunjukkan bahwa pada tahun 2017, terjadi penurunan nilai NDVI dan CMRI di Zona 1, Zona, 2, dan Zona 3 sebagai kawasan ekowisata mangrove Pulau Dodola.. Hal ini menunjukkan adanya ancaman ekosistem mangrove apabila pembangunan infrastruktur menyebabkan penurunan nilai indeks vegetasi secara signifikan dari tahun ke tahun. Dengan demikian, diperlukan program pengendalian terhadap program pembangunan infrastruktur dengan melibatkan masyarakat lokal dalam pemeliharaan ekosistem mangrove.

Kata kunci: CMRI, *ekowisata*, *mangrove,* NDVI, NDWI

I. INTRODUCTION

Mangroves are ecosystems that can protect the sustainability of small islands, coastal areas, and watersheds threatened with erosion or abrasion due to waves of sea and river water. The mangrove ecosystem is one of the coastal ecosystems with a high level of productivity (Aswin *et al*., 2021). The mangrove existence can enrich the coastal area and maintain the balance of the ecosystem (Mas'ud *et al*., 2020). Each area has different mangrove characteristics and marine biota and other ecosystems in the mangrove area. Rumalean & Purwanti (2019) stated that the structure and composition of mangroves in each area are different. Several mangroves have the lowest distribution, such as *Bruguiera gymnorrhiza*, *Nypa fruticans*, and *Terminalia catappa*.

Previous research used remote sensing techniques to analyze the distribution of mangrove forests. Wijaya & Huda (2018) analyzed the dominant mangrove species in each mangrove zone using a principal component approach to identify the correlation between the distribution of mangrove species and the parameters of salinity and immersion height. In addition, Singgalen *et al.* (2021) use remote sensing, namely the NDVI model, to monitor mangroves in each archipelagic zone, then recommend priority programs to develop mangrove areas with the lowest NDVI value. Saputra *et al.* (2021) conducted an object-based study of changes in mangrove land cover using satellite imagery, namely the Classification Based on Object (OBIA) approach and the Support Vector Machine (SVM) algorithm. It shows that the analysis of the distribution of mangroves to identify the dominant mangrove species and changes in land cover can use a remote sensing approach.

Studies on mangroves in Indonesia still need to be improved in response to environmental degradation due to disaster, climate change, or infrastructure development in coastal areas, watersheds, and archipelagic areas. Djamaluddin *et al.* (2019) stated that the condition of mangroves needs to be analyzed periodically from time to time. Regular monitoring is required to identify changes caused by climate change, natural disasters, infrastructure development, and land conversion for local communities' economic benefit. Furthermore, Nurdiansah & Dharmawan (2021) argue that mangroves' functionality is highly dependent on the size, community structure, and quality of the ecosystem. However, mangrove ecosystems play an essential role in the existence and provision of community ecosystem services on small islands. Therefore, the value of the vegetation index of the mangrove area needs to be monitored regularly so as not to experience damage and disrupt the ecosystem.

Mangroves in Indonesia can be developed as a tourism destination that brings economic and social benefits to the surrounding community. From a socio-cultural perspective, the existence of mangroves in Indonesia has a spiritual meaning related to customs. Singgalen *et al.* (2019) reported that the existence of mangroves is considered a guardian of the natural balance, which supports people's livelihoods in coastal areas, especially fishermen and subsistence farmers. The local community's belief in the critical role of mangroves gave rise to myths and taboos for rural communities so as not to damage mangrove forests, let alone cutting down mangrove trees as fuel (firewood) instead of kerosene. Otherwise, Singgalen (2020) stated that mangrove areas managed in a participatory manner can be developed as an important economic area for preserving mangroves and endemic fauna that are attractive to tourists with special interests. It shows that mangrove-based ecotourism development can be an alternative to economic, social, and environmental sustainability.

This study aims to analyze the condition of mangroves on Dodola Island as part of the icon of one of the priority destinations in Indonesia, namely the Morotai Island Regency. Morotai Island has the characteristics of various tourist attractions, namely the historical tourist attraction of the 2nd world war, the natural tourist attraction, and the beach and marine tourism attraction. The main focus of this research location is the mangrove ecotourism area on Dodola Island, which is divided into Zone 1, Zone 2, and Zone 3. This research method adopts remote sensing techniques, namely Normalize Difference Vegetation Index (NDVI), Normalize Difference Water Index, and Combined Mangrove Recognition Index (CMRI). Based on the NDVI, NDWI, and CMRI values, a comparison of the mangrove conditions on Dodola Island can be analyzed from 2013 and 2021 and discussed with a participatory approach that supports the sustainability of Dodola Island mangrove ecotourism.

The distribution of mangroves in coastal areas and islands can be identified and classified using the Normalized Difference Vegetation Index (NDVI) model. In addition, the Normalized Difference Water Index (NDWI) is generally used to analyze water bodies. The NDWI can be used in conjunction with NDVI to assess the context of areas of change on the surface. NDWI can also be used to analyze the distribution of mangrove forests. However, NDWI and NDVI need to be calculated as CMRI techniques to get optimum results (Gupta *et al.*, 2018) which uses Combined Mangrove Recognition Index (CMRI) data to identify and analyze mangrove conditions. CMRI is the result of subtracting NDVI with NDWI. In addition, NDWI and NDVI values can be used to evaluate the damage to mangroves in coastal areas and island areas (Winarso & Purwanto, 2017). Meanwhile, the spatial data used is Landsat 8 OLI with UTM 84 WGS 52N.

II. RESEARCH METHODS

2.1. Time and Study Site

This research was conducted from December 2020 to August 2021 in Dodola Island, Morotai Island Regency, North Maluku Province, Indonesia (Figure 1). The considerations for choosing the area of this

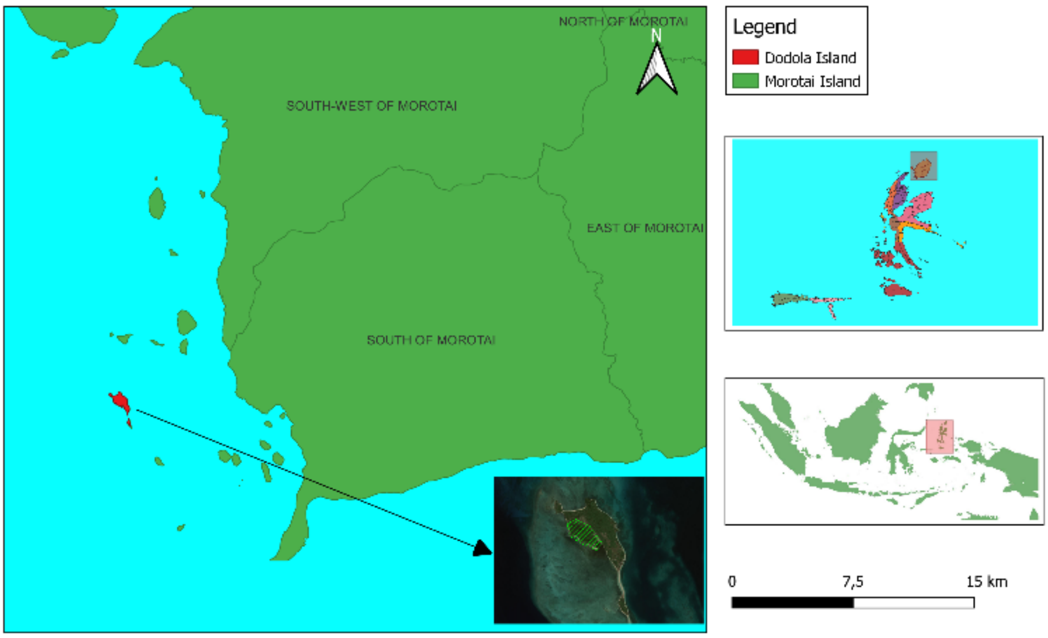

Figure 1. Research Location in Dodola Island.

research are as follows: Morotai Island Regency was selected to be one of the priority National Tourism Destinations (DPN); Dodola Island in Morotai Island Regency has become a tourism icon in North Maluku Province; Dodola Island has a mangrove ecosystem developed using an ecotourism approach; The development of mangrove ecotourism on Dodola Island needs to be balanced with scientific studies on changes in the mangrove vegetation index based on a specific period.

Figure 1 is a research location map on Dodola Island, Morotai Island Regency, North Maluku Province, Indonesia. Meanwhile, the travel time from Daruba port to Dodola Island is ± 20-30 minutes. In addition, Dodola Island can be accessed directly from North Halmahera Regency using a speedboat with a travel time of ± 45-55 minutes. Dodola Island consists of two islands known as Big Dodola Island and Small Dodola Island. Both are connected when the tide is low and will separate when the tide is high. On Dodola Island, accommodation is available for tourists as a place to stay with a capacity of four to six people and a rental price of IDR 500.000 – IDR 1.000.000/night. In addition, the Dodola Island tourist destination manager also provides various facilities for snorkeling, diving, and cycling activities in the mangrove area of Dodola Island.

In the mangrove area of Dodola Island, infrastructure in the form of a 500-meter wooden bridge has been built as access for tourists who walk or cycle around the mangrove area on Dodola Island. Accommodation in the form of cottages on Dodola Island is equipped with two rooms and one bathroom so that tourists who come with a capacity of four to six people can use one house. It shows that the local government has paid attention to the intensity of tourist visits by building various supporting infrastructures according to travel needs. Nevertheless, it is necessary to conduct a comprehensive study of changes in the vegetation index caused by the development of tourism infrastructure on Dodola Island and the various consequences that threaten the sustainability of ecotourism on Dodola Island Morotai Island Regency, North Maluku Province, Indonesia.

2.2. Material and Data: NDVI, NDWI, CMRI

The transverse Mercator (UTM) on Landsat 8 operational land imager (OLI) satellite imagery data is set based on the 1984 world geodetic system (WGS) datum. Furthermore, The results of the NDVI, NDWI, and CMRI are limited to mangrove areas, which are divided into three zones, namely zone 1, zone 2, and zone 3. Meanwhile, Landsat 8 OLI satellite imagery is processed using CMRI to analyze changes in the condition of mangrove forests on Dodola Island in each area from 2013-2021. The process of calculating Landsat 8 OLI raster data for NDVI, NDWI, and CMRI can be seen in Figure 2 below.

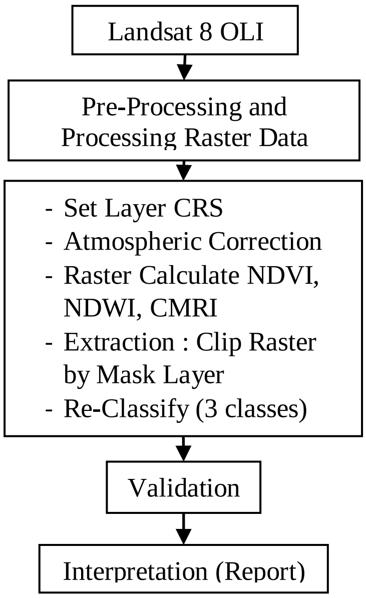

Figure 2. Data Processing Using NDVI, NDWI, CMRI in QGIS 3.20.

Figure 2 is a data processing stage divided into two steps, namely pre-processing and data processing. Pre-processing data in this QGIS 3.20 application uses the Semi-Automatic Classification plugin to correct the atmosphere on Landsat bands 4, 5, and 6 by applying DOS 1 atmospheric correction. Furthermore, raster data calculations are carried out in the data processing stage based on each approach, as shown in Table 1 below.

Tabel 1. Method and formula of NDVI, NDWI CMRI.

Method	Formula
NDVI	(NIR-RED)/(NIR+RED)
NDWI	(NIR-SWIR)/(NIR+SWIR)
CMRI	NDVI-NDWI

Source : Gupta *et al.* (2018)

This study uses the NDVI, NDWI and CMRI to identify the mangrove vegetation index (Bhavsar *et al.*, 2017). Thus, the distribution and standard criteria for mangrove damage can be seen as stated in the Decree of the Minister of Environment Number 201 of 2004 in Table 2.

Table 2 is the criteria for damage to mangrove forests as stipulated by the Decree of the State Minister of the Environment Number 201 of 2004. After analyzing and interpreting changes in the NDVI, NDWI, and CMRI from 2013-2021, the situation of mangroves in Dodola Island will be discus with ecotourism and sustainable development perspective.

2.3. Data Analysis: Ecotourism and Sustainable Development Perspective

In the data analysis stage, NDVI, NDWI, and CMRI will discuss the idea of ecotourism and sustainable development. Indonesia has its characteristics of ecotourism development by considering cultural, linguistic, and religious diversity. Oka & Larantika (2021) offers the concept of community-based ecotourism, which is relevant to the Indonesian context, as shown in Figure 3.

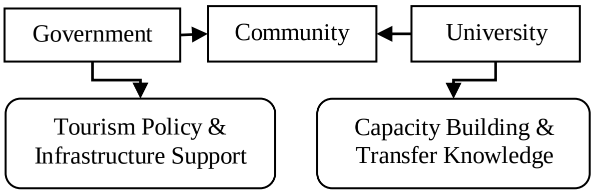

Figure 3. Ecotourism Model (Oka & Larantika, 2021).

Figure 3 is an ecotourism model that emphasizes local community participation in program implementation. In addition, the role of government and universities as stakeholders that support the success of the ecotourism program. The government can formulate policies, build supporting infrastructure. Meanwhile, the University assists the community by sharing knowledge to increase human resource capacity in the tourism sector. Mafruhah *et al.* (2019) argue that ecotourism can also support sustainable development that encourages people to continue to hone knowledge about resources, carrying capacity, and strategies to optimize resources to have a selling value in the tourism industry. On the other hand, Valentina & Qulubi (2020) stated that mangrove areas developed using a community-based ecotourism approach can provide economic, social, and environmental

Tabel 2. Mangrove damage standard criteria.

Criteria		C	D	NDVI
Health	Dense	≥ 75%	> 1500	0,43 ≤ NDVI ≤ 1,00
	Moderate	≥ 50 - <75	≥ 1000 - < 1500	0,33 ≤ NDVI ≤ 0,42
Unhealthy	Sparse	< 50	< 1000	-1,0 ≤ NDVI ≤ 0,32

Notes: C= Cover (%), D=Density (Tree/ha), NDVI=Normalized Difference Vegetation Index. Source: (Decree of the State Minister of the Environment Number 201 of 2004).

benefits. Considering the relevance of the concept of mangrove ecotourism and sustainable development, the output of this study will discuss the results of the CMRI, NDVI, NDWI data calculations as a description of the condition of mangroves on Dodola Island with the concept of sustainable mangrove ecotourism that previous researchers have constructed.

III. RESULTS AND DISCUSSION

3.1. Mangrove Distribution Analysis Using NDVI, NDWI, CMRI

The mangrove ecosystem on Morotai Island has an essential role in supporting the sustainability of people's livelihoods. Community settlements on Morotai Island are more dominant in coastal areas and archipelagic areas, so that fishing activities as subsistence fishers are a form of strategy to meet the needs of clothing, shelter, and food. In the socio-cultural context of the people of Morotai Island, the existence of the mangrove area has a relationship with the cultural dimension. Local community beliefs about mangroves as protectors of coastal areas and islands affect behavior in using mangrove resources carefully (Singgalen *et al.*, 2019).

In Dodola Island, the distribution of mangroves has a different structure and composition. Idrus & Kusman (2021) reported that the types of mangroves on Dodola Island could be classified based on type, location, number of trees, number of saplings, and seedlings, as shown in Table 3.

Table 3 shows the number of trees, saplings, and seedlings from mangroves on Dodola Island. Idrus & Kusman (2021) showed that there were 140 *Bruguiera gymnorrhiza*, 177 *Ceriops decandra*, 1 *Lumnitzera racemosa*, 12 *Phempis acidula*, 1 *Rhizophora apiculata*, 84 *Rhizophora mucronata*, and 39 *Sonneratia alba* mangrove trees. On the other hand, the mangrove species *Ceriops decandra*, *Bruguiera gymnorrhiza*, *Sonneratia alba*, *Phempis acidula* were found in Zone 1, Zone 2, and Zone 3. In addition, species of *Rhizophora apiculata* and *Lumnitzera racemosa* were only found in Zone 1 and Zone 2. Meanwhile, the mangrove species *Rhizophora mucronata* was located in Zone 3. Thus, Mangroves in each zone need to be rehabilitated to maintain their existence.

The condition of mangroves on Dodola Island in 2021 based on the results of the NDVI analysis shows that the mangrove area of Dodola Island has (Zone 1, Zone 2, and Zone 3) has a maximum value of 0.40 and a minimum value of 0,02. Partially, Zone 1 has a maximum value of 0,39 and a minimum value of 0,09. Zone 2 has a maximum value of 0,40 and a minimum value of 0,02. Meanwhile, Zone 3 has a maximum value of 0,38 and a minimum value of 0,12. It shows that the mangrove area of Dodola Island is in the moderate category as according to the mangrove damage criteria from Decree of the Minister of Environment Number 201 of 2004.

Tabel 3. Types of mangroves in Dodola Island.

Species	Number of Tree	Number of Sapling and Seedling
Bruguiera gymnorrhiza	140	477
Ceriops decandra	177	755
Lumnitzera recemosa	1	0
Phempis acidula	12	9
Rhizophora apiculata	1	2
Rhizophora mucronata	84	167
Sonneratia alba	39	17
Total	454	1427

Source: Idrus & Kusman (2021).

Specifically, Zone 3 is the location for the growth of mangrove species *Ceriops decandra*, *Bruguiera gymnorrhiza*, *Sonneratia alba*, *Phempis acidula*, and *Rhizophora mucronata*. Based on the comparison of the maximum NDVI values in 2021, Zone 3 has the lowest value. It indicates the need to control mangrove vegetation in Zone 3 to ensure that the mangroves are healthy. Meanwhile, the types of mangroves that need to be prioritized are those with the least number of trees, saplings, and seedlings in Zone 3, namely *Sonneratia alba* and *Phempis acidula.*

Previous research has shown that fluctuations in the vegetation index value need to be identified by tracing the vegetation index value based on the NDVI calculation of earlier years (Pamungkas *et al.*, 2020). The causes of decline in vegetation index need to be identified and analyzed in-depth to map the issue contextually. Furthermore, to determine the occurrence of a decrease or increase in the NDVI value of the mangrove area of Dodola Island in each Zone, it is necessary to analyze the results of raster data calculations based on the NDVI technique from 2013 to 2021, as shown in Figure 4.

Figure 4 is the result of processing 8 OLI satellite image data using the NDVI technique in the mangrove area of Dodola Island from 2013-2021. Based on the comparison of the vegetation index value in each zone, the NDVI value can be interpreted that the decline in the vegetation index occurred in 2017. In the same year, the tourism infrastructure development program in the form of an woodbridge in the mangrove area began to be built. The average NDVI value of the mangrove area of Dodola Island in 2017 was 0,34, which is decreased in 2017 to 0,14, then gradually recovered to 0,32 in 2021. It indicates that mangrove forest damage occurred from moderate to a sparse category based on the Decree State Minister for the Environment No 201 of 2004. Otherwise, it is necessary to compare the results of NDVI calculations with NDWI and CMRI, as shown in Figure 5.

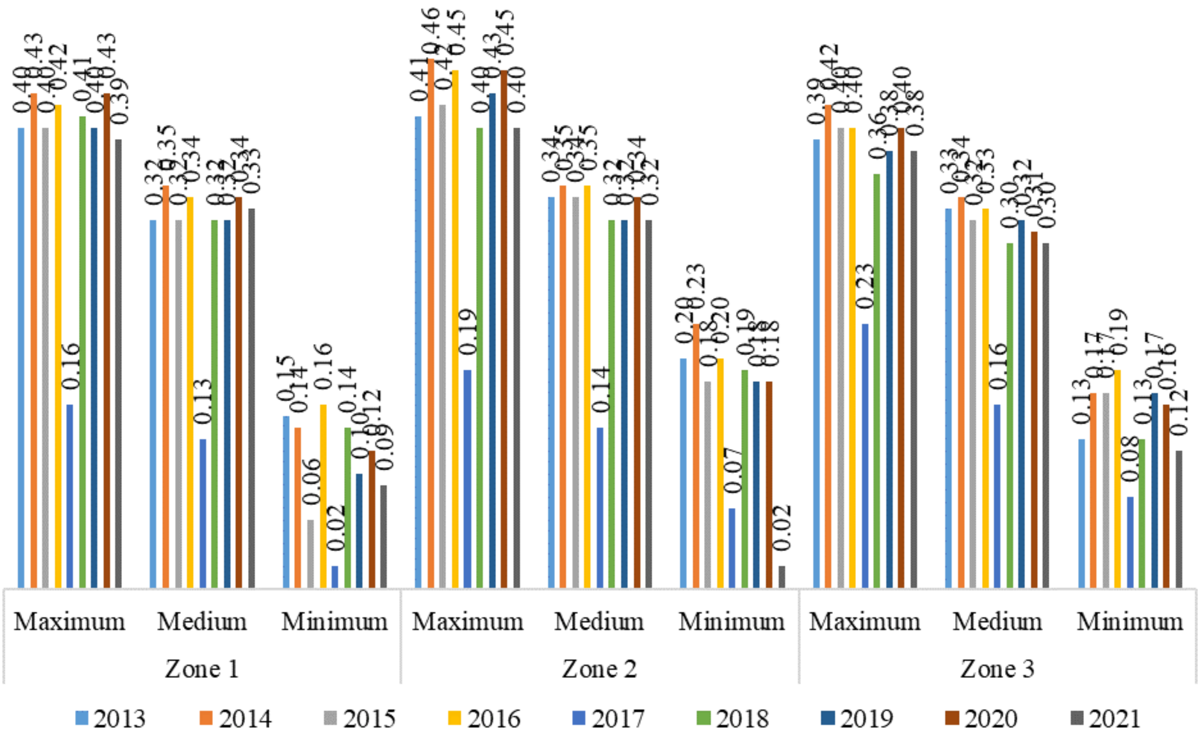

Figure 4. NDVI of Mangrove Area in Dodola Island 2013-2014.

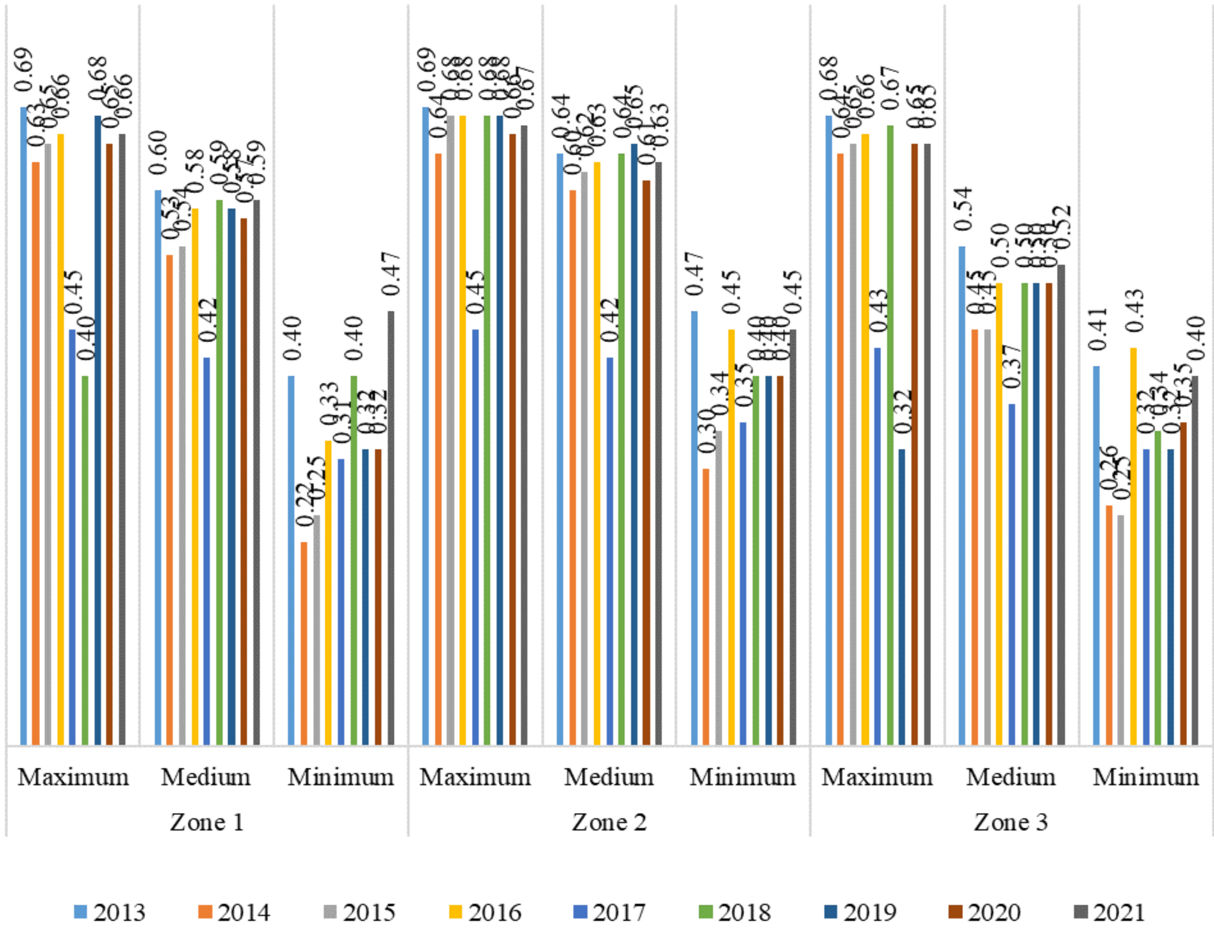

Figure 5. NDWI of mangrove area in Dodola Island 2013-2014.

Figure 5 is the result of processing data from Landsat 8 OLI satellite imagery using the NDWI technique in the mangrove area of Dodola Island from 2013-2021. The Normalize Difference Water Index (NDWI) has a value between -1 to 1. Generally, the NDWI value of water bodies is more significant than 0,5. At the same time, vegetation has a much smaller value, so that the difference between vegetation and water bodies is easy to detect (Xu, 2006). In addition, the average NDWI value of the mangrove area of Dodola Island in 2016 was 0,59, which decreased in 2017 to 0,42 and then increased by 0,61 in 2021. Fluctuations in the value of NDWI show the location of mangrove growth related to temperature, pH, salinity, and substrate.

The Normalized Difference Water Index (NDWI) is generally used to analyze water bodies. The NDWI can be used in conjunction with NDVI to assess the context of areas of change on the surface. NDWI can also be used to analyze the distribution of mangrove forests. However, NDWI needs to be combined with CMRI techniques, such as Gupta *et al.* (2018) which uses Combined Mangrove Recognition Index (CMRI) data to identify and analyze mangrove conditions. CMRI is the result of subtracting NDVI with NDWI. In addition, To evaluate the damage of mangroves, previous researchers used NDWI and NDVI data (Winarso & Purwanto, 2017). Thus NDWI and NDVI need to be calculated through the CMRI model to interpret mangroves' conditions. Otherwise, the CMRI result can be seen in Figure 6.

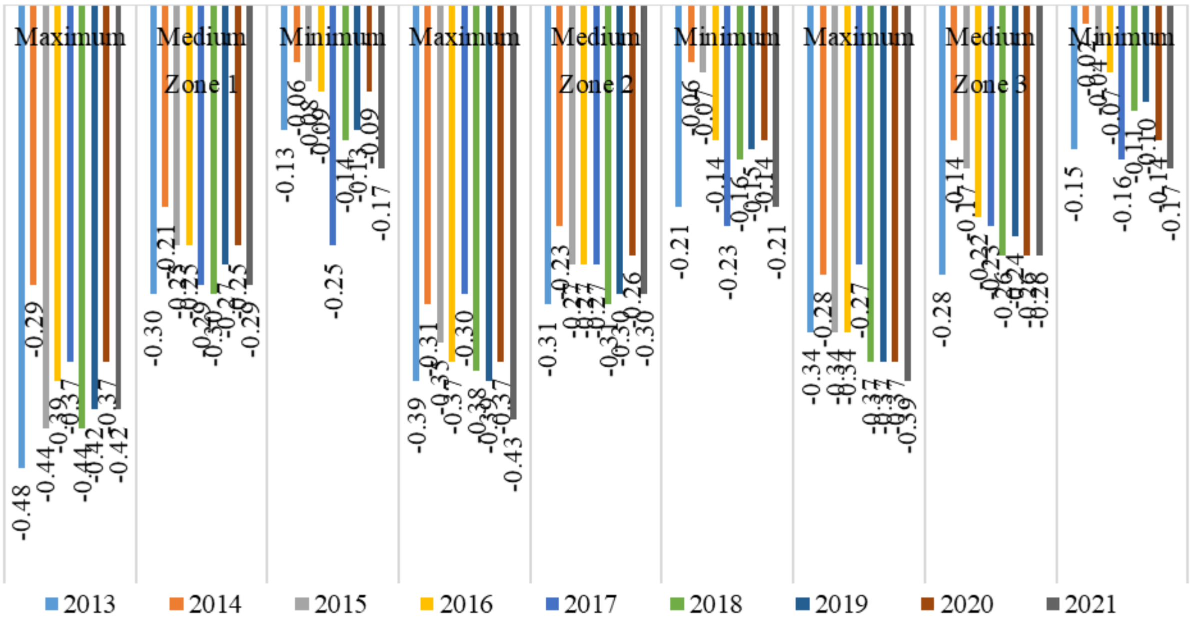

Figure 6. CMRI of mangrove area in Dodola Island 2013-2014.

Figure 6 is the result of the CMRI calculation obtained from the sum of the NDVI and NDWI values. Based on the results of the correlation test for the average value of NDVI and NDWI using Pearson Correlation, it can be seen that there is a perfect correlation between the average value of NDVI and the average value of NDWI in 2013-2021, which is 0,908 with a significance value of 0,001. Specifically, in Zone 1, it is known that there is a perfect correlation on the average value of NDVI and NDWI of 0,863 with a significance value of 0,003. In addition, in Zone 2, there is a perfect correlation between NDVI and NDWI of 0,932 with a significance value of 0,000. Also, in Zone 3, there is a strong correlation between NDVI and NDWI of 0,746 with a significance value of 0,021. In addition, the CMRI calculation results show that the mangrove area of Dodola Island in 2016 was -0,25, which increased to -0,27 in 2017 and increased to -0,29 in 2021. Furthermore, the average CMRI value in each zone shows a significant difference.

The results of the calculation of the CMRI value ensure that the decline in the vegetation index in 2017 needs to be taken seriously by establishing a mangrove rehabilitation program based on species and family. Although the condition of mangrove vegetation is gradually improving from year to year, infrastructure development plans for economic and social interests will continue to increase. It is precarious for the sustainability of the mangrove area of Dodola Island if policies and institutions do not accommodate it.

3.2. Mangrove-Based Ecotourism Sustainability in Dodola Island

The existence of mangroves in a tourism perspective is a natural resource with educational and economic value. In fact, in the socio-cultural context, mangroves have cultural values that are a source of livelihood for coastal communities, watersheds, and islands. In the context of Dodola Island, the mangrove ecotourism approach is very strategic in maintaining the sustainability of the ecosystem. Rustdi *et al.* (2020) reported that the mangroves distribution in each coastal area and islands have diverse families and types. This diversity leads to the uniqueness of the ecosystem that has a competitive value. It also encourages the development of mangrove areas as tourist destinations that have educational value about the environment and fauna habitat in mangrove areas.

The people of Kolorai Island, which is adjacent to Dodola Island, should be encouraged as actors in developing Dodola Island tourism, which plays an essential role in maintaining the sustainability of the mangrove area. Through participatory mangrove development, the rehabilitation process of damaged mangroves can be planned systematically, applied in a coordinated manner, and evaluated periodically to anticipate environmental damage due to infrastructure development and tourism activities.

Based on data on changes in the vegetation index in 2016, 2017, and 2021, the mangrove rehabilitation program needs to be accommodated institutionally and by policy to anticipate environmental degradation with fatal levels of damage. The visualization of the NDVI calculation results in the mangrove area in 2016, 2017, and 2021 can be seen in Figure 7.

Figure 7 shows that the average value of NDVI in the mangroves area in 2016 was 0,34 and decreased significantly to 0,14 in 2016. In 2021, the average value of NDVI in the mangrove area of Dodola Island is 0,32. The decline in the mangrove vegetation index needs to be anticipated by all stakeholders. The consequences of the damage to the mangrove area on Dodola Island hamper tourism activities and have the potential for erosion or abrasion, which slowly erodes the coastal area of Dodola. Wijaya & Huda (2018) reported that changes in the NDVI value of the mangrove vegetation index in ecotourism development areas need to be identified and explicitly

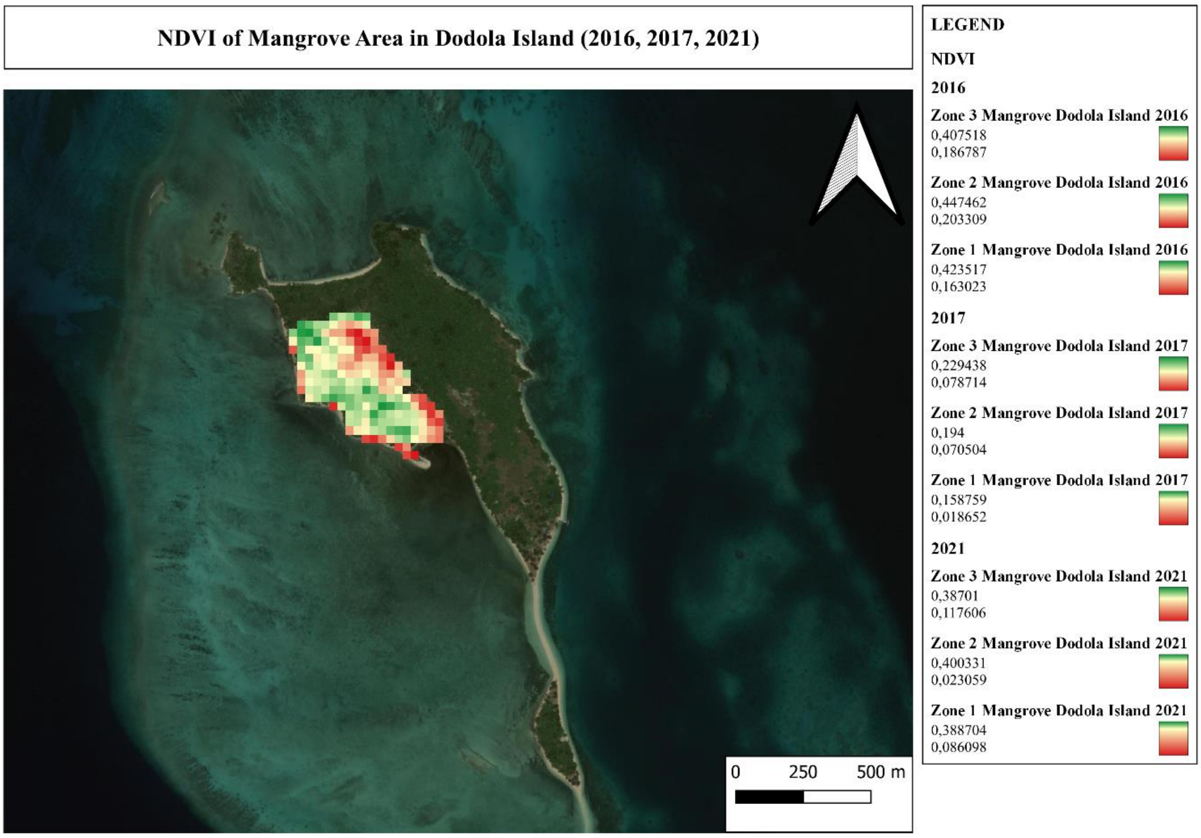

Figure 7. NDVI of mangrove area in Dodola Island 2016, 2017, and 2021.
Source : NDVI calculation result using QGIS 3.20

mapped the factors that cause the index value to decrease. It is required to determine strategic steps to increase the value of the mangrove vegetation index as an ecotourism attraction through a mangrove rehabilitation program using a participatory approach. Nisa *et al.* (2019) stated that the strategy of developing ecotourism in mangrove areas is not only guided by natural beauty or scenery, vegetation diversity, and biota diversity. Things that need to be considered are supporting facilities and adequate accessibility. In addition, mangrove-based ecotourism destination management must balance (environmental, economic, and social) to be sustainable.

The regional government has not structurally determined the management of mangrove ecotourism on Dodola Island through the tourism office. Nevertheless, the participation of the community of tourism observers in preserving the environment also participates in maintaining sustainability on Dodola Island. It shows public awareness about the importance of environmental sustainability on Dodola Island as a motivating factor for voluntary participation. Suharti *et al.* (2016) stated that the flow of institutional synergy needed to increase the potential of ecotourism areas is divided into five parts of institutional development, namely human development, business development, resource development, environment, and infrastructure development, and disaster preparedness and climate change development. These components need to be accommodated in formal institutions and mobilized by local government policies, namely the tourism office. Thus, community participation in ecotourism development can increase capacity related to the broader function of ecotourism development.

The development of mangrove ecotourism on Dodola Island requires the synergy of private, public, and community interests. The challenge of synergistic ecotourism development is the diverse preferences of ecotourism development. Wahyono & Rahmawati (2017) argue that the development of mangrove ecotourism should consider the popularity of attractions related to tourist demand. These are challenges for stakeholders to prepare supporting infrastructure; conduct educational training on ecotourism; assist local communities; increase business capital; optimize coordination functions; carry out promotions through various media; improve accessibility to ecotourism areas without disturbing the sustainability of the ecosystem. Also, to increase the capacity of human resources to optimize mangrove ecotourism destinations, the role of universities is essential in training programs, socialization, and local mentoring communities (Dwidinita & Endrotomo, 2016; Wati & Idajati, 2017). Thus, the government, community, and universities can work together to develop mangrove ecotourism.

IV. CONCLUSION

Based on the results of NDVI, NDWI, and CMRI from 2013-2021 on the condition of mangroves on Dodola Island, it can be seen that there was a decline in the value of the vegetation index in 2017, which is coincided with the implementation of the infrastructure development program to support tourism on Dodola Island. The average NDVI value of the mangrove area of Dodola Island in 2017 was 0,34, which is decreased in 2017 to 0,14, then gradually recovered to 0,32 in 2021. It indicates that mangrove forest damage occurred from moderate to a sparse category based on the Decree State Minister for the Environment No 201 of 2004. In addition, the average NDWI value of the mangrove area of Dodola Island in 2016 was 0,59, which decreased in 2017 to 0,42 and then increased by 0,61 in 2021. Fluctuations in the value of NDWI show the location of mangrove growth related to temperature, pH, salinity, and substrate. In addition, the CMRI calculation results show that the mangrove area of

Dodola Island in 2016 was -0,25, which increased to -0,27 in 2017 and increased to -0,29 in 2021. Furthermore, the average CMRI value in each zone shows a significant difference. It shows that the rehabilitation of mangroves in each location must consider the family and types of mangroves. In addition, the mangrove-based ecotourism approach through local participation is the right strategy to maintain environmental sustainability while obtaining economic and social benefits. Also, it is recommended that the provincial government form a legal community to run a mangrove rehabilitation program and formulate a mangrove ecotourism development policy contextual to the conditions of Dodola Island Morotai Island Regency, North Maluku Province, Indonesia.

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