Land management semi-arid archipelago based on water carrying capacity: Studies on Labuan Bajo, East Nusa Tenggara

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Abstract

Archipelago areas have high marine tourism resource potential, so they are often exploited for tourism needs. The characteristics of the Labuan Bajo region in the form of islands with geomorphological conditions in the form of hills have the potential to reduce the carrying capacity of the environment. Regional development in Labuan Bajo, classified as a semi-arid area for tourism purposes, can potentially cause a clean water crisis. This study aimed to analyze the environmental carrying capacity related to water availability to support the development of the Labuan Bajo region to become a super-priority tourism destination. The research method used is quantitative in the form of spatial analysis, literature studies, and water-carrying capacity analysis based on the Decree of the Minister of Environment and Forestry No. 297 of 2019. The research data were obtained from field observations and government agencies. The results show that the carrying capacity of water in 56.87% of the area in West Manggarai Regency has a deficit status. Most areas experiencing a deficit are on the mainland of Flores Island, especially in the urban area of Labuan Bajo. This is due to low rainfall, low soil ability to absorb water, and high anthropogenic activity from both local residents and tourism activities. In addition, the content of salinity, detergent, and BOD (biological oxygen demand) in groundwater samples in the urban area of Labuan Bajo has exceeded the water quality standard threshold. The results of this study can be considered for policy directions related to land use for regional development in semi-arid island areas.

Keywords:
archipelago
semi-arid
tourism area
water carrying capacity

Introduction

An archipelagic region is an area that has a vast ocean with many small islands to form a group of islands (Leatemia, 2011), as well as having the same ecosystem and modality or administrative boundaries (Harun, 2021). Indonesia is the largest archipelagic country in the world, with an ocean area of 5.9 million km² (Lasabuda, 2013). In addition, several regions in Indonesia are also classified as islands, such as West Nusa Tenggara, East Nusa Tenggara, Maluku, North Maluku, North Sulawesi, Southeast Sulawesi, Bangka Belitung, and the Riau Archipelago (Puspitawati, 2020). Semi-arid areas have lower rainfall than potential evapotranspiration (Messakh et al., 2015), i.e. rainfall intensity of less than 2,000 mm per year, a dry season that lasts for more than seven months with rainfall below 100 mm per month (Mulyani and Sarwani, 2013). This causes semi-arid areas to have limited availability and continuity of clean water sources (Messakh et al., 2015). In semi-arid areas, large rock outcrops are also found due to less intensive weathering of parent rock, such as in wetlands.
Other characteristics of semi-arid areas are very high rainfall intensity during the rainy season (Sardjono et al., 2003), low vegetation and soil conditions containing little organic matter (Mays, 2014).

Development activities in archipelago areas generally occur due to tourism potential resulting in regional urbanization (Pons et al., 2014; Wibisono et al., 2019). However, the tourism sector in archipelagic areas often exploits natural resources without considering environmental sustainability, causing environmental degradation and pressure on natural resources, especially water resources (Gössling et al., 2012). As happened in the Galapagos Islands, namely the tourism sector is the primary sector that uses much clean water, amounting to 55% of the total use of clean water in the islands (Reyes et al., 2017), as well as in the Nusa Penida tourism area (Cahyani et al., 2018; Sudipa et al., 2020). Not all semi-arid areas in Indonesia are archipelago areas. However, in the eastern region of southern Indonesia, most of them are dominated by semi-arid island areas, which are prone to problems with the availability of clean water (Suryati, 2016).

All human activities for the utilization of water, if it is not balanced with proper management of water sources, can affect the quality and quantity of water resources (Habiebah and Retnaningdyah, 2014). The carrying capacity of the availability of clean water is essential for the archipelago's development. Its caused the archipelago has a high potential for a clean water crisis due to the limited water catchment area and the vulnerability to seawater intrusion (Cahyadi, 2012). Environmental carrying capacity is defined as a combination of thresholds that cause spatial-temporal changes or damage to natural resources, assimilation of environmental capacity, ecosystem services, social environment and environmental structure and function (Maulana et al., 2020). Through overlapping and scoring techniques (Nabila et al., 2017), environmental carrying capacity can be determined by knowing the environment's capacity and existing resources (Sari et al., 2021). Analyzing the environment's carrying capacity requires the main variables of land potential and population (Tong et al., 2018). This is because increased built-up land and high human activities reduce water quality (Rimba et al., 2021).

Labuan Bajo is one of the areas currently designated as a National Tourism Strategic Area to support economic growth (Kodir et al., 2020). The primary water sources in Labuan Bajo are water from Municipal waterworks (PDAM) and groundwater, but at certain times groundwater sources from dug wells cannot be used because they smell and taste salty (Wolo et al., 2020). In terms of quality, groundwater in the coastal area of Labuan Bajo cannot be used for drinking water because it has exceeded the water quality threshold (Wolo et al., 2020). Overall, the West Manggarai Regency area needs to intensify ecosystem services and environmental carrying capacity, especially in the coastal environment (Tussadiah et al., 2021).

This research focused on analyzing the environment's carrying capacity related to clean water due to tourism development activities in the semi-arid archipelago. Much research has been done on the carrying capacity of the water environment in tourism and island areas, such as Achmad et al. (2020) and Renfors (2021). However, not much research has been conducted in archipelagic areas with the characteristics of semi-arid areas with high tourism activity, even though most of the southeastern region of Indonesia has a semi-arid climate with problems with the availability of clean water (van Cooten and Borrell, 2000).

Materials and Methods

Study area

This research is located in West Manggarai, one of the districts on Flores Island, East Nusa Tenggara Province. West Manggarai Regency has 12 districts spread across the coast to the highlands, with the centre of government and tourism activity in Labuan Bajo, Komodo District. West Manggarai Regency has a land area of approximately 3,141.47 km², which consists of the mainland of Flores Island and several large islands such as Komodo Island, Rinca Island, Bidadari Island, Longos Island and 182 other small islands. Geographically, West Manggarai Regency is located between 08°14'09"00' South Latitude and 119°21'–120°20’ East Longitude (BPS West Manggarai, 2021). The population of Manggarai Regency is 256,317, with the highest population density in the Komodo District, which is 53,724 people. West Manggarai Regency has quite varied geomorphology from flat, sloping, hilly, undulating and mountainous topography with a height of more than 1000 meters above sea level, as well as soil types dominated by cambisol soil (BPS West Manggarai, 2021). The research location is shown in Figure 1.

The research location has relatively dry rainfall with an average annual rainfall of around 1500 mm/year. The rainy season is relatively short, starting in November - March, with the number of rainy days ranging from 100-180 days a year. The type of rainfall is classified as the monsoonal rain type, namely, rain that only occurs once a year. The distribution of rainfall is shown in Figure 2. Meanwhile, the land use condition in the study locations was not plentiful, dominated by forest land use with an area of 117,151.85 ha or 37.31%. These forests are widely spread from the north to the centre of the mainland of the West Manggarai area on Flores Island. Meanwhile, coastal areas and small islands are dominated by land cover in the form of grassland and savanna (Figure 3).
Figure 1. Map of research location.

Figure 2. Map of rainfall.
The research location has unique landscape conditions compared to other archipelago areas, namely on the mainland of Flores Island and on small islands dominated by hilly landscape conditions, which cover an area of 139,007.35 ha or 44% of the entire West Manggarai area. The morphology of the hills is widely spread along the coastal area with an altitude of 100-500 meters above sea level.

The distribution of the landscape of the study locations is shown in Figure 4.

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*Figure 3. Map of land use and land cover in West Manggarai.*

*Figure 4. Map of geomorphology of West Manggarai.*
The condition of the slopes at the research location is dominated by rather steep slopes both in the area of small islands and on the mainland, which is 201,356.48 ha or around 64% of the total area of West Manggarai. The relatively steep slope of the slopes is spread evenly over almost the entire West Manggarai area, both in coastal and mountainous areas. Its correlates with the condition of the landscape, where there are many hills. The condition of the landscape and slope is shown in Figure 5. The distribution of the condition of the landscape and slope in the research area is shown in Table 1.

![Slope Map West Manggarai](image)

**Figure 5. Map of slope in West Manggarai.**

**Table 1. Distribution of landscapes and slopes.**

<table>
<thead>
<tr>
<th>No</th>
<th>Morphology</th>
<th>Type</th>
<th>Area (ha)</th>
<th>Slope (%)</th>
<th>Type</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hilly</td>
<td>139,007.4</td>
<td>44%</td>
<td>0-2%</td>
<td>Flat</td>
<td>17,065.36</td>
</tr>
<tr>
<td>2</td>
<td>Undulating</td>
<td>68,348.39</td>
<td>22%</td>
<td>2-5%</td>
<td>Ramps</td>
<td>18,567.96</td>
</tr>
<tr>
<td>3</td>
<td>Mountainous</td>
<td>43,804.23</td>
<td>14%</td>
<td>5-15%</td>
<td>Ramps</td>
<td>70,764.7</td>
</tr>
<tr>
<td>4</td>
<td>Flat</td>
<td>36,918.37</td>
<td>12%</td>
<td>15-40%</td>
<td>Rather steep</td>
<td>201,356.5</td>
</tr>
<tr>
<td>5</td>
<td>Sloping</td>
<td>25,904.06</td>
<td>8%</td>
<td>&gt; 40%</td>
<td>Steep</td>
<td>62,26.9</td>
</tr>
</tbody>
</table>

Source: Data analysis (2022).

**Data collection**

This study used secondary data from several government agencies and primary data in water sampling to answer research objectives. The data used were rainfall data and the long intensity of sunlight from BMKG Komodo. Data on soil types, land use conditions, slope, and morphological data were obtained from the Cipta Karya Office for spatial planning and water resources in West Manggarai Regency. Data on aquifer productivity conditions were obtained from the portal website esdm.go.id. Population density data were from West Manggarai BPS, and water quality condition data were from the West Manggarai Environment Agency. Water sampling was carried out at four locations, provided the location conditions were in coastal and non-coastal areas with different water sources. The water sample was a sample of groundwater in a coastal location right around the hotel or tourism service, namely Kampung Ujung, in Labuan Bajo. Other water samples are groundwater and springs in the non-coastal area around Komodo Airport, namely in Lamtoro Labuan Bajo Village, and rainwater samples collected from the...
urban area of Labuan Bajo. The determination of the water source used for the research sample was based on the water source most used by the people in Labuan Bajo. In addition, this research also used secondary data from river water samples obtained from the West Manggarai Regency Environmental Service to complement water quality. The locations of water sampling are shown in Figure 6.

![Water Sampling Location Map Labuan Bajo Urban Area West Manggarai](image)

Figure 6. Map of water sampling location.

**Data analysis**

Research data were analyzed using spatial analysis techniques using Arcmap 10.3, analysis of laboratory test results and descriptive analysis. The spatial analysis included analysis of morphological conditions, slope conditions, soil type conditions, rainfall conditions, aquifer productivity conditions, and the carrying capacity of the water environment. The descriptive analysis included the sun exposure duration and the results of laboratory tests on water samples. Analysis of water carrying capacity was based on the provisions of the Minister of Environment and Forestry Decree No 297 of 2019 concerning National Water Carrying Capacity and Capacity, namely by overlaying a map of land cover conditions, rainfall, average water demand, and population of each village. The rainfall distribution map was overlaid with the land use map by entering the land cover coefficient values for each land cover using a 30 x 30 cm grid based on village administrative boundaries. Furthermore, the results of the support map were correlated with the actual environmental conditions around it. Water sample test analysis was carried out using 11 parameters. The parameters were determined based on the Minister of Health Regulation No. 32 of 2017 concerning clean water quality standards for hygiene and sanitation. The salinity parameter was added because the research location is located in a coastal area surrounded by a tourism service area. Hence, it has the potential to experience seawater intrusion and pollution from the surrounding environment. The process of taking water samples was based on technical instructions for taking water samples, namely a minimum of 1.5 liters for one sample and using a container that was closed from exposure to sunlight. The sampling of this water used 1.5 liters bottle containers with as many as two pieces at each water source. The sample was then sent to the Kupang UPTD Laboratory for analysis using the limited detection method.

**Results and Discussion**

**Water environmental condition**

The mapping results show that the research location has unique physical environmental conditions. Areas with steep slopes are in the south and southwest of West Manggarai on the mainland of Flores Island, Rinca Island and Komodo Island. The condition of the landscape and the slope of the slopes in West Manggarai in urban and non-urban areas, as well as in small island areas, is dominated by hilly conditions and rather steep slopes, and the rocks contain limestone. It correlates with the results of field observations in Labuan Bajo urban and non-urban areas, namely in Golomori Village and the Seraya
Besar Island area. Dry physical environmental conditions and soil with lots of large rock and limestone outcrops have resulted in very limited sources of clean water in the study area. In the urban area of Labuan Bajo, one well water source is used by 10-30 households. However, in the coastal area, well water is of poor quality because it tastes brackish, tastes lime, and has a high level of salinity. Environmental conditions in urban areas are shown in Figure 7.

Based on the results of field observations and in-depth interviews, the community’s need for clean water in Labuan Bajo is highly dependent on groundwater. Its because the distribution of PDAM water to the community has not reached evenly due to the accessibility of the location, where there are many hilly areas and steep slopes, which cause obstacles to the installation of pipeline transmission networks. In addition, people in the small island area and tourism services such as “pinisi” cruise also buy water from the urban area of Labuan Bajo. It starkly contrasts with the soil conditions in Labuan Bajo, which have little groundwater content.

**Environment carrying capacity**

The availability of clean water is closely related to groundwater conditions. West Manggarai Regency, an area with relatively low rainfall and a landscape condition dominated by karst outcrops, also has relatively low groundwater potential conditions. Low rainfall is accompanied by sun exposure in West Manggarai, classified as total irradiation >60%. Based on data from the Komodo Meteorology, Climatology and Geophysics Agency (Komodo BMKG) shows that the average sunshine duration in Labuan Bajo is 78%, with the lowest radiation duration being in January by 55%. Meanwhile, the highest irradiation duration occurs from April to October, which is more than 80%. Based on groundwater productivity data obtained from the official portal of the Ministry of Energy and Mineral Resources, the geology section, aquifer conditions are dominated by productive aquifers with a local distribution of 392,320.23 hectares or 38% of the total area (ESDM, 2022). However, this aquifer also includes aquifers with rare groundwater conditions in the West Manggarai region on the mainland of Flores Island.

In small islands, aquifer productivity conditions are dominated by minor productive aquifers. Highly productive aquifers with wide distribution are only available in the southern part of the mainland of Flores Island.

In addition to quantity, carrying capacity analysis is also carried out on water quality. Based on laboratory tests on four samples of water sources in the urban area of Labuan Bajo, namely two samples of groundwater, one sample of water from a spring, and one sample of rainwater, several parameters exceeded the threshold water quality. The laboratory test parameters refer to clean water quality standards according to Minister of Health regulations No 32 of 2017, Government Regulation No 22 of 2021, and an additional parameter in the form of salinity.

Laboratory test results presented in Table 2 show that water sources in the urban area of Labuan Bajo have several parameters that exceed the clean water quality standards. Groundwater test sample 1, located in RT 008/014 Lamtoro, Labuan Bajo, contains detergent exceeding the quality standard of 1.95 mg/L. The groundwater test sample 2 had hardness, detergent, TSS and salinity levels that exceeded the quality standards. This condition indicates that the groundwater sample at Kampung Ujung, Labuan Bajo, has experienced seawater intrusion and is unsuitable for drinking or cooking water consumption. This is due to the well's location in the coastal area. Rainwater test samples in the Wae Mata area, Gorontalo Village, contained detergents that exceeded the quality standard but had a lower value than other spring water sources.

The spring test sample was taken in the RT 008/014 Lamtoro, Labuan Bajo Village, containing detergent exceeding the quality standard, namely 1.875 mg/L. This condition is caused by people often washing and bathing right at the location of the spring water resource. CaCO₃ levels in groundwater and springs are quite high, although only the water in the
second sample of well water exceeds the quality standard. The high level of CaCO\textsubscript{3} material not only causes health impacts but can also cause a reduction in pipe diameter due to scale buildup, thereby reducing the flow rate in the water distribution process (Mussli and de Fretes, 2016).

This study also used river water quality data for 2022 obtained from the West Manggarai Regency Environmental Service. River water quality in the urban area of Labuan also has conditions that have been polluted in Labuan Bajo, namely the Wae Ara River, the Air Kemiri 1 River, and the Air Kemiri 2 River. The water quality data in the three rivers have a total phosphate content that has exceeded the quality standard. There is both upstream, midstream and downstream. Phosphorus levels above the quality standard threshold indicate that the river water has been polluted by chemical compounds that can come from pesticides, fertilizers, or detergent waste (Asrini et al., 2017). This is in accordance with field conditions and the results of interviews with local people that in the middle of the river, there are many rice fields for residents, where these rice fields massively use pesticides during the planting season, and many people wash their clothes in the river bodies. River water quality data is shown in Table 3.
The content of fecal coliform was also found to exceed the quality standard threshold in all parts of the Air Kemiri 1 River, the upstream and downstream parts of the Wae Ara River, and the middle part of the Air Kemiri 1 River. Fecal coliform content that exceeds quality standards indicates that the river water has been contaminated with human and animal faeces (Sulistyorini et al., 2016). This is following the field conditions that many residents live on the riverbanks and dispose of waste in the river body. The BOD content that exceeds the quality standard threshold. The BOD content that exceeds the quality standards indicates that the water has been polluted by organic matter around the river. BOD levels indicate the amount of oxygen aerobic microorganisms need to decompose almost all dissolved and suspended organic matter in water (Ningrum, 2018).

**Water carrying capacity**

Clean water sources for surface water types in West Manggarai Regency are 15 rivers and one lake. However, only 25% of rivers can flow throughout the year, with the average total surface runoff in West Manggarai Regency being 2,008.5 million m$^3$/year (RPJMD West Manggarai Regency 2021-2026, 2021). The water carrying capacity map in Figure 6 shows that the condition of the water carrying capacity in the uplands and a small part of the coastal area has been exceeded. In contrast, it has not been exceeded in the area of small islands and most of the coastal areas.

The total area in West Manggarai that has exceeded the carrying capacity of water is larger than the area that has not been exceeded, namely 178,557 ha or 56.87% of the total area of West Manggarai. This is caused by four factors.

First, the number of residents in the mainland area of Flores Island, based on BPS 2021 data, is more than the number of residents on small islands, while the rainfall conditions in these locations are classified as dry.

Second, land use in the mainland area is still dominated by forests, but most plant species that grow are dry plant types such as teak, Mahogany, Sengon and Jabon plants, namely plants that do not store much water content. This is supported by the condition of the soil type, which is dominated by Cambisol Soil, which is soil that has little water content.

Third, most of the community and tourism services in Labuan Bajo use clean water as the main source, either obtained from suctioning private wells or purchased from mobile water vendors.

Fourth, the small islands around Labuan Bajo do not have a water source, be it well water, springs, or river water, so residents on small islands get clean water from the Labuan Bajo urban area.

Tourism services such as "pinisi" cruise sailing around the small islands of Labuan Bajo do the same, namely buying clean water from the urban area of Labuan Bajo. This, if left unchecked, could potentially cause land degradation in the area of Flores Island as the mainland of Labuan Bajo. The condition of the Labuan Bajo landscape, dominated by hills with urban areas located in coastal areas, can exacerbate the carrying capacity related to water quality. This is because groundwater extraction in coastal areas can exacerbate seawater intrusion into the surrounding groundwater and, in the long term, can change the process of water circulation in groundwater basins in the hydrological cycle (Mays, 2014). It is necessary to strengthen the community's role on small islands by developing irrigation infrastructure that can independently meet the needs of the small island population. The massive tourism development in the research location that occurs in the coastal area also affects the environment's carrying capacity. Based on data from the West Manggarai Tourism and Culture Service, currently, there are 115 hotels or inns, most of which are located in the urban area of Labuan Bajo, and the average tourist visit reaches 119,174 people per year.
The tourism development also increases the potential for decreasing water quality. The development activities in coastal areas will cause environmental changes (Wibowo, 2018), especially water availability in semi-arid areas (Kent et al., 2002). Small islands are generally vulnerable to development for tourism but have limited accessibility and resources, so they are very dependent on the mainland area (Kerstetter and Bricker, 2012). In fact, not all water-carrying capacities in tourism areas are in deficit status if they have ecosystem services with high rainfall and large water catchment areas (Harianto et al., 2020). Therefore water management in Labuan Bajo needs to optimize the use of surface water, such as river water and rainwater, during the rainy season. Optimization of river water can be carried out using the technique of constructing constructed wetlands to ensure the quality of the wastewater discharged into the environment is at most the quality standard. This technique utilizes pumice media, *Thypa latifolia* sp., Lemongrass and *Melaleuca* trees as filtering pollutants (Rozari et al., 2020a, 2020b; Greenway et al., 2022). Management in this way is expected to reduce pollutant loads in rivers, especially in the upstream and middle riparian areas with levels of phosphorus and fecal coliform pollution that exceed quality standards.

**Conclusion**

The carrying capacity of water in West Manggarai Regency in most areas has exceeded the carrying capacity of water, which is 178,557 hectares or 56.87% of the total area with a deficit status, especially in the urban area of Labuan Bajo. The factors causing the environment's carrying capacity to be in a larger deficit status are the large population but relatively low rainfall, the condition of the type of soil that is hydromorphic, and the high use of groundwater for the community's clean water needs and tourism services. The status of water carrying capacity that experiences a water deficit is more common in the mainland of Flores Island than in the small islands around Labuan Bajo. This condition does not mean that the small island areas are still safe from scarcity of clean water. However, this condition shows that the dependence on water sources on small islands with the mainland of Flores Island is still very high.

There is a need for water management based on the use of surface water, such as the use of rainwater and the creation of artificial wetlands in river border areas. Its to prevent land degradation due to high groundwater extraction. Ultimately, this research is limited to analyzing landscape conditions, water quality, and water carrying capacity. Further research is expected regarding the potential for sustainable land use for tourism activities in coastal areas and small islands without causing environmental degradation.

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