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Water Carrying Capacity on Small Islands Tourism: Case Study of the Tidung Islands, Jakarta

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Abstract

This study examines the water carrying capacity of the Tidung Islands, a popular small island tourism destination in Jakarta, Indonesia. The research aims to measure the availability of water resources and assess the balance between water supply and demand, focusing on both domestic and tourism needs. Using a water balance approach, the study analyzes seasonal fluctuations in precipitation, evapotranspiration, runoff, and changes in water storage. The results indicate that while Tidung Islands currently have a surplus of water resources, projected increases in population and tourism will lead to periods of water deficit by 2040. The study highlights the critical need for sustainable water management practices, including rainwater harvesting, efficient water use, and community involvement in conservation efforts. Implementing these strategies is essential to ensure long-term water security and support the continued growth of tourism and local development in Tidung Islands.

Keywords: Water Carrying Capacity, Small Islands, Tourism, Environmental Sustainability, Tidung Islands.

Introduction

Water plays a crucial role in supporting life and environmental sustainability. It is a vital component for human needs and ecological balance (Sudipa, Mahendra, Adnyana, & Pujaastawa, 2020). However, over half of the world's population lives in areas experiencing physical or economic water scarcity (Cahyadi, Sasongko, & Ramadhoan, 2018). The irreplaceable ecological function of water makes it essential for human development and environmental health (Hengky, 2022);(Demanega et al., 2021);(Budiharjo, 2020). Clean water is not only vital for human survival but also enhances the quality of human resources throughout Indonesia (Mayasari, 2017).

Urbanization and tourism in coastal areas pose significant challenges to water resources. The rapid growth of coastal populations and the limited availability of water on small islands often lead to water balance imbalances (Cahyadi, Hidayat, & Wulandari, 2013). Urbanization increases water demand, and this is particularly problematic on small islands where water resources are naturally limited (Putri et al., 2019; Taryana,

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2016). For instance, small islands like Tidung in Jakarta face challenges in maintaining a balance between water availability and demand, exacerbated by the influx of tourists and the limited natural freshwater resources (Priyana, 1994).

Tidung Islands, part of the Seribu Islands in Jakarta, is renowned for its tourism potential. The islands attract numerous visitors due to their scenic beauty and marine tourism opportunities. The tourism industry in Tidung Islands has grown significantly, leading to increased pressure on local water resources. Tourist activities, combined with the local population's water needs, often result in water scarcity during peak seasons (Abedin, Collins, Habiba, & Shaw, 2019). This scenario highlights the critical need for sustainable water management practices to ensure that water resources can meet both domestic and tourism demands without degrading the environment (Hussain, Muscolo, Farooq, & Ahmad, 2019).

Marine tourism in Tidung Islands is a significant attraction in Indonesia. Small islands like Tidung are valuable for their natural beauty and marine tourism opportunities. Tidung's development as a tourist destination has significantly impacted its water resources, as tourism growth often leads to increased water demand. The objective of this study is to measure the water carrying capacity concerning domestic and tourism water needs in Tidung Islands by assessing the water balance. The Tidung Islands are divided into Tidung Besar and Tidung Kecil, connected by a bridge built in 2010. The islands' tourism potential is vast, attracting visitors with activities like snorkeling, diving, and exploring marine conservation areas. The proximity to Jakarta makes it a popular destination, but this popularity also increases the demand for water, particularly during peak tourist seasons.

The primary objective of this research is to measure the water carrying capacity of the Tidung Islands, considering both domestic and tourism water demands. By understanding the water availability and demand, it is possible to develop strategies to ensure sustainable water use on the islands. The water balance approach will be used to assess whether the available water resources can meet the needs of the local population and tourists (Tekken & Kropp, 2015). Understanding the water balance is crucial for determining the carrying capacity of water resources. This involves evaluating the input and output of water within the hydrological system. By calculating the water balance, we can identify periods of surplus and deficit, which are critical for planning sustainable water management strategies (MacEwan et al., 2017). The findings from this study will provide insights into the sustainability of water resources in Tidung Islands and guide future water management practices to support both local and tourism needs.

Method Research

Water Availability

Water resources in a hydrological system are evaluated through the water balance method. According to Triatmodjo (2010), the water balance equation is a quantitative estimate of the hydrological cycle based on the principle of mass conservation:

$P = Ro + Ea \pm \Delta S$

where:
P = Precipitation (monthly average)
Ro = Runoff
Ea = Actual Evapotranspiration
ΔS = Change in water storage

Precipitation (P) is the monthly average rainfall over a specific period. Runoff (Ro) is the surface runoff resulting from rainfall that flows over land surfaces that are either saturated or impervious. Runoff is calculated using the Rational Method (Triatmojo, 2010):

Q = 0.278 x C x I x A

where:
Q = Runoff (m^3/s)
C = Runoff coefficient
I = Rainfall intensity (mm/h)
A = Area (km^2)

The runoff coefficient (C) in this study is based on land cover types, while rainfall intensity (I) is derived from rainfall data, and area (A) represents the study area of Tidung Island, which spans 1936 hectares. The runoff value (Ro) represents the dependable flow, predicted throughout the year with a minimal risk of failure to meet the demand (Mayasari, 2017). Evapotranspiration (Ea) is the total water loss through evaporation and transpiration processes. Meteorologically, potential evapotranspiration (ETp) is calculated using the Thornthwaite-Mather method (Thornthwaite & Mather, 1995):

$$ETp = 16 \times \left(10\frac{T}{I}\right)^{a}$$

where:
T = Mean monthly temperature
a = Empirical coefficient set as follows:

$$a = 6{,}756 \times 10^{-7} \times I^3 - 7.71 \times 10^{-5} \times I^2 + 1{,}79 \times 10^{-2} \times I + 0{,}49239$$

I = Annual heat index calculated as:

$$I = \sum_{n=1}^{n=12} i_n = \sum_{n=1}^{n=12} \left(\frac{T}{5}\right)^{1.514}$$

$$i = \left(\frac{T}{5}\right)^{1{,}514}$$

Actual evapotranspiration (ETa) is used in small island conditions where soil moisture and humidity are considered. ETa reflects the actual water consumption by plants, considering soil texture and plant conditions, which are assumed as Water Holding Capacity (WHC). If ETp is lower than P, WHC is interpreted as Soil Moisture Storage (SM); otherwise, SM is calculated as:

$$SM = WHC\ x\ e^{(\frac{APWL}{WHC})}$$

ΔSM=P−ETp

where APWL is the accumulated potential water loss. ETa is assumed equal to ETp if ΔSM is greater than ETp; otherwise, it is determined as follows:

ETa = P+ΔSM

To determine water storage (ΔS) in the island's water balance, the equation can be reformulated as:

ΔS = P – (Ro + Ea)

This island water balance indicates the natural water equilibrium between availability and demand within the hydrological cycle of Tidung Island. Meteorological data, such as rainfall and temperature, influence water storage estimates, while other necessary data include soil types and land cover.

Water Demand

Domestic water demand (DA) is calculated as:

$$D_A = N\ x\ KHL_A$$

where:

N = Number of inhabitants

$KLHA$ = Per capita water requirement (432 m³/year)

Tourism water demand (DA_w) is estimated as:

DAw = n × t × 90

where:

n = Number of tourists

t = Duration of stay (days)

Population projections are calculated as:

$Pn = P0 \times e(r \times n)$

where:

Pn = Population in year

$P0$ = Current population

r = Population growth rate

n = Number of years

e = Exponential constant (2.718281828)

Water Carrying Capacity

Water carrying capacity is determined by comparing water availability (SA) with demand (DA):

$$\begin{cases} \text{Surplus, if } SA > DA \\ \text{Deficit, if } SA < DA \end{cases}$$

Result and Discussion

The analysis of water availability in Tidung Islands reveals seasonal fluctuations influenced by varying rainfall patterns throughout the year. As shown in Table 1, precipitation levels are highest in January and December, which significantly contributes to water availability during these months (Gummadi et al., 2018). However, during the dry season, the precipitation levels drop, leading to lower water availability. This

fluctuation emphasizes the need for effective water storage and management systems to ensure a steady water supply throughout the year.

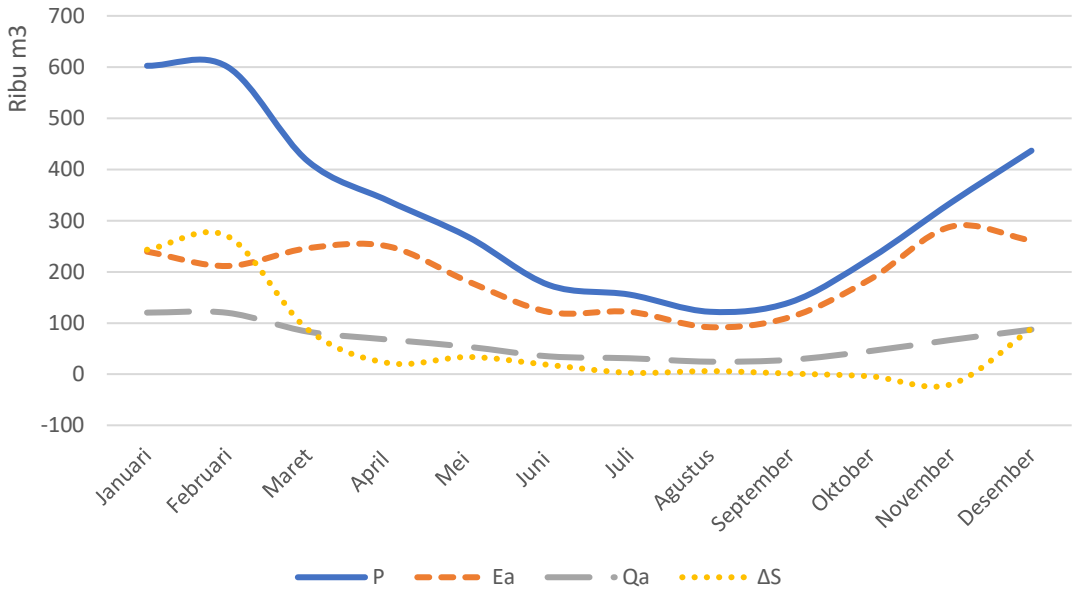

Figure 1. Meteorological Water Balance in Tidung Islands

Evapotranspiration (Ea) rates, which peak during the warmer months, are crucial for understanding water loss from the surface and vegetation. Higher evapotranspiration during the dry season further exacerbates water scarcity issues, necessitating measures to mitigate water loss and enhance water conservation practices (Minhas, Ramos, Ben-Gal, & Pereira, 2020). The runoff (Ro) values, derived from the Rational Method, indicate significant water flow during the rainy season. The runoff values are higher in months with heavy rainfall, such as January and December, reflecting the excess water that flows over the land surface (Yaduvanshi, Sharma, Kar, & Sinha, 2018). This runoff, if not properly managed, can lead to water wastage and flooding, highlighting the importance of effective runoff management to capture and store excess water for use during drier periods.

Analyzing the change in water storage (ΔS) provides insights into the net gain or loss of water within the hydrological system. Positive values of ΔS indicate periods of water surplus, while negative values signify a deficit. The data shows that the Tidung Islands experience both surplus and deficit periods, underlining the necessity for robust water management strategies to balance the water availability throughout the year. The population projections for Tidung Islands illustrate a steady increase in both local residents and tourists, which directly impacts water demand. The growing population exacerbates the pressure on the limited water resources, especially during peak tourist seasons. As depicted in the population projection graph, the rising trend calls for proactive measures to enhance water supply infrastructure and management practices to accommodate the increasing demand (Alemu & Dioha, 2020).

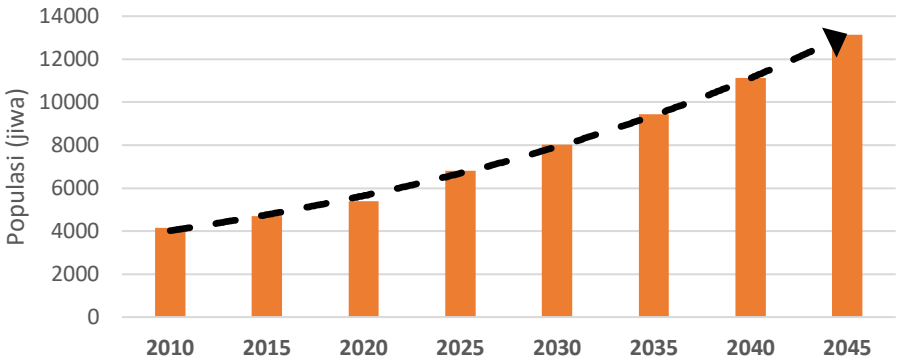

Figure 3 Population Projection in Tidung Islands

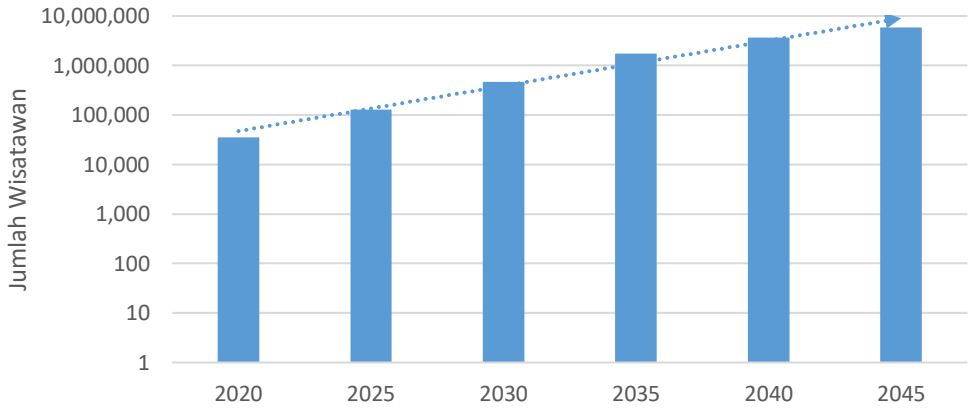

Figure 4 Tourism Projection in Tidung Islands

The calculation of domestic and tourism water demand, as shown in Table 2, indicates that the water requirements are projected to increase significantly over the next two decades. The water demand for domestic use is based on the average per capita water requirement, while the tourism water demand is calculated based on the average stay duration and water usage per tourist (Nepal, Al Irsyad, & Nepal, 2019). These projections highlight the urgent need for sustainable water management practices to ensure the availability of sufficient water resources to meet the growing demand.

Table 1 further illustrates the water carrying capacity of Tidung Islands, comparing the water availability with the projected water demand. The data indicates that while the islands currently have a surplus of water resources, the situation is expected to change as water demand increases. By 2040, the islands are projected to experience a water deficit, emphasizing the critical need for sustainable water management practices to ensure long-term water security (Sudipa et al., 2020).

Table 1 Water Carrying Capacity in Tidung Islands

Year	Water Availability (m^3/year)	Water Demand (m^3/year)	Surplus/Deficit (m^3/year)	Status
2020	746621.2	304,584.0	442,037.3	not exceed
2025		387,569.9	359,051.3	not exceed

2030	471,292.9	275,328.3	not exceed
2035	607,947.9	138,673.4	not exceed
2040	788,677.0	-42,055.8	Exceed
2045	999,271.3	-252,650.1	Exceed

The results underscore the importance of implementing integrated water management strategies that consider both the natural water cycle and human activities. Measures such as rainwater harvesting, efficient water use, and conservation practices are essential to mitigate the impacts of seasonal water fluctuations and increasing water demand. These strategies will help maintain the balance between water availability and demand, ensuring the sustainability of water resources in Tidung Islands.

Additionally, the study highlights the significance of community involvement and awareness in water conservation efforts. Educating the local population and tourists about the importance of sustainable water use can foster a culture of conservation and responsible water management. Engaging the community in water management initiatives can lead to more effective and long-lasting solutions to the water challenges faced by Tidung Islands.

In conclusion, the comprehensive analysis of water availability, demand, and carrying capacity in Tidung Islands highlights the critical need for sustainable water management practices. The findings from this study provide valuable insights into the current and future water challenges, guiding the development of strategies to ensure the sustainability of water resources in Tidung Islands. By adopting integrated water management approaches and fostering community involvement, the islands can achieve long-term water security and support the continued growth of tourism and local development.

Conclusion

The study reveals that Tidung Islands have a surplus of water resources under current conditions, but this balance is threatened by increasing tourism and population growth. Sustainable water management strategies are essential to maintain the water carrying capacity and support the long-term viability of tourism and domestic needs in the islands. Ensuring an adequate water supply for both locals and tourists is vital for the sustainability of Tidung Islands as a tourism destination.

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