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Utilization of Unmanned Aerial Vehicles (UAVs) for Mapping the Distribution of Water Hyacinth and Evaluating Water Quality Dynamics in Lake Tondano

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Abstract

Lake Tondano, a vital water resource and cultural icon in North Sulawesi, Indonesia, is under increasing ecological stress. This study addresses the dual threat of uncontrolled proliferation of water hyacinth (Eichhornia crassipes) and a concerning decline in water quality. The extensive surface coverage by water hyacinth disrupts the aquatic ecosystem by blocking sunlight, lowering dissolved oxygen (DO), and impairing the lake's aesthetic and economic functions. This research utilized Unmanned Aerial Vehicle (UAV) technology to provide an efficient, high-resolution solution for rapidly mapping the spatial distribution and estimating the extent of the water hyacinth infestation. High-resolution RGB aerial imagery was collected, and water quality was simultaneously assessed through laboratory analysis of samples taken from both infested and clear areas. The mapping results identified a significant 1,034-hectare water hyacinth cover in the Paleloan Village area of the lake. Crucially, the study established a stark water quality dichotomy: areas free of water hyacinth maintained relatively good conditions, largely meeting Class II water quality standards (Government Regulation No. 22 of 2021). In sharp contrast, areas under water hyacinth cover showed severe degradation, evidenced by extremely poor readings for critical parameters, including high Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS), alongside dangerously low Dissolved Oxygen (DO). This research provides compelling evidence of a strong negative correlation between the presence of E. crassipes and the deterioration of essential water quality parameters, advocating for urgent and targeted management interventions informed by remote sensing data.

Keywords: Lake Tondano; UAV; Water Hyacinth (Eichhornia Crassipes); Water Quality

1. Introduction

The use of drone technology in the environmental field has shown significant developments in the last decade. Various studies and reports have revealed that drones are not only able to increase efficiency in environmental data collection, but also provide better accuracy and range than conventional methods. The integration of drones with the Object-Based Image Analysis (OBIA) approach and satellite imagery for the identification of shallow water habitats and the monitoring of environmental changes spatially. This technology enables high-resolution, real-time data collection, which is crucial for data-driven decision-making [1] [2]. By implementing a community-based monitoring approach using drones in the coastal area of Karawang, the results showed that this initiative not only increased community involvement in environmental monitoring but also accelerated responses to changes in ecosystem conditions [3]. In the context of tropical forest restoration, the SLIC-UAV method was able to identify key species through aerial imagery to assess the effectiveness of environmental rehabilitation programs [4]. Technological innovation is also seen in the development of drone-based air emission monitoring systems and the Internet of Things (IoT) which enables spatial and dynamic air quality detection [5]. Drone technology also plays a role in monitoring disaster-prone areas. A multi-node sensor system based on wireless communication mounted on a drone to monitor volcanic activity [6]. In addition to technical aspects, institutional policies related to drone use highlight the role of the Ministry of Environment and

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Forestry in regulating and encouraging drone use in environmental monitoring activities [7]. Drones are now a crucial tool in environmental conservation, including for monitoring biodiversity and ecosystem changes with high precision [8]. The Geographic Information System mapping developed can make it easier for users to find the geographic location information they need [9]. Overall, drone technology has proven its significant contribution to improving the quality of environmental monitoring and management. Integration with spatial systems, smart sensors, and community participation make drones a leading technological solution in supporting sustainable development and natural resource conservation.

Three water quality index approaches, namely the Pollution Index, the CCME-WQI (Canadian Council of Ministers of the Environment Water Quality Index), and the NSF-WQI (National Sanitation Foundation Water Quality Index), were used to evaluate the water quality status of the Surabaya River. Findings showed that water quality varied from mild to moderate pollution, depending on the location and evaluation method used [10]. The parameters measured were Nitrate, nitrite, phosphate, total dissolved solids (TDS), electrical conductivity (EC), pH, and water temperature, and obtained results that there were seasonal fluctuations in water quality parameters, with an increase in nutrient loads and moderate levels of pollution, most likely due to urban and agricultural activities around the river [11]. The parameters measured were: pH, turbidity, and total dissolved solids (TDS), with the result that the system succeeded in monitoring water quality parameters effectively [12]. The development of an IoT-based water quality measuring tool for the agricultural sector with the measured parameters: Total Dissolved Solids (TDS), concluded that the tool designed using a TDS sensor and microcontroller succeeded in measuring water quality effectively, providing data that can be used for decision making in agricultural practices [13]. The river water quality monitoring system uses temperature, pH, TDS and turbidity sensors, with data sent in real-time via a smartphone application using the Blynk and Telegram Bot platforms, thus enabling efficient and responsive water quality monitoring, supporting environmental conservation efforts [14].

2. Methodology

The research was conducted in the area adjacent to Paleloan Village, South Tondano District, Minahasa Regency, North Sulawesi, Indonesia. This location was selected due to the visibly high concentration of water hyacinth infestation.

A field survey was conducted using a commercially available UAV equipped with a high-resolution RGB camera. The drone flights were executed at a pre-determined altitude with sufficient overlap to generate high-resolution orthophotography of the study area. The acquired aerial imagery was processed using photogrammetry software to create a georeferenced Ortho mosaic map. This map was then used to perform object-based image analysis (OBIA) to classify and delineate the area covered by the water hyacinth, allowing for the calculation of the total coverage area in hectares.

2.1. Water samples were collected at two distinct, pre-determined points

- Point 1: Located in an area of the lake free of water hyacinth cover.
- Point 2: Located directly under the dense water hyacinth mat.

All samples were immediately preserved and transported to an accredited laboratory for analysis. The following key water quality parameters were analyzed: Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and ph. The measured values were then compared against the Class II Water Quality Standard as stipulated in the Government Regulation of the Republic of Indonesia No. 22 of 2021 concerning the Implementation of Environmental Protection and Management.

3. Results and Discussion

3.1. Water Hyacinth Distribution Mapping

The UAV mapping successfully produced a high-resolution spatial representation of the water hyacinth infestation (Figure 1).

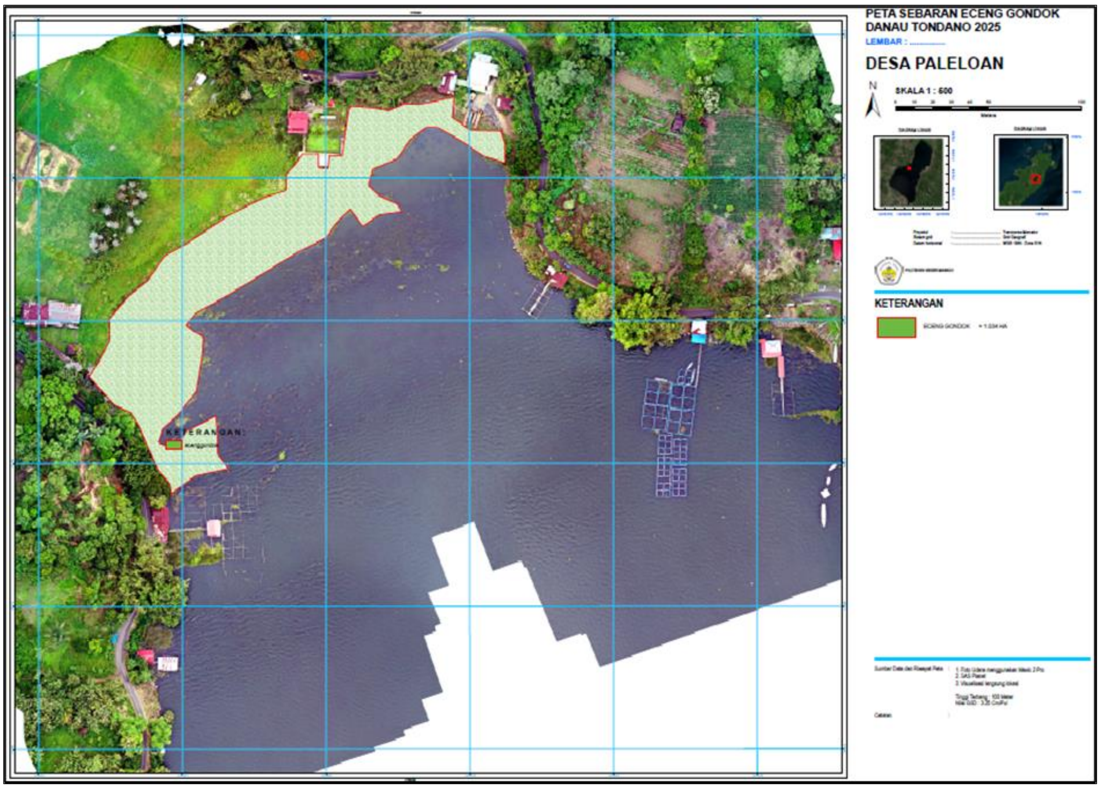

Figure 1 Water Hyacinth Distribution Map of Paleloan Village, Lake Tondano

The analysis of the aerial imagery revealed that the total area covered by water hyacinth in the Paleloan Village study location was 1,034 hectares.

The spatial analysis of the distribution map indicates a specific pattern

- The largest and densest concentrations of E. crassipes are located along the water's periphery, particularly on the western and northwestern sides, which are typically shallower and more sheltered.
- The infestation exhibits an asymmetrical pattern, being significantly wider on the west side than on the east.
- The central, mid-water areas remain relatively free of the plants, indicated by the darker, clear water color. This suggests a pattern of "spreading from the edge to the center" that has not yet reached complete surface dominance, likely due to wind action, deeper water, or stronger currents in the center.

3.2. Water Quality Analysis

The laboratory results for the water samples taken from the two contrasting points are presented in Table 1, along with the national Class II quality standards.

Table 1 Results of Water Quality Tests on Lake Tondano

No.	Parameter	Unit	Result		Quality Standards
			Point 1	Point 2	
1	Biochemical Oxygen Demand (BOD)	mg/L	1	3	3
2	Chemical Oxygen Demand (COD)	mg/L	13	221	25
3	Dissolved Oxygen (DO)	mg/L	7	0,7	4
4	Total Dissolved Solids (TDS)	mg/L	60	180	1000
5	Total Suspended Solids (TSS)	mg/L	3	138	50
6	pH		7,1	7.0	6 - 9

3.2.1. Water Quality in Non-Infested Areas (Point 1)

The water quality at Point 1, free of water hyacinth, demonstrated generally good conditions. All parameters met the stringent Class II standards. The high DO value (7 mg/L) indicates a healthy, well-oxygenated environment capable of supporting diverse aquatic life. The low BOD (1 mg/L) and COD (13 mg/L) suggest minimal organic and chemical pollution loads in the main body of the lake.

3.2.2. Water Quality in Infested Areas (Point 2)

The results for Point 2, located under the dense water hyacinth mat, reveal a severe and critical decline in water quality, clearly indicating a strong correlation with the plant's presence:

Dissolved Oxygen (DO): The value of 0.7 mg/L is extremely low, falling far below the 4 mg/L standard. This hypoxic to near-anoxic condition is a direct consequence of the physical barrier created by the macrophyte mat, which prevents atmospheric reaeration, and the high oxygen consumption from decomposing plant material and associated microbial activity. Such low DO levels are lethal to most fish species and critical aquatic organisms, creating a dead zone.

Chemical Oxygen Demand (COD): The COD value of 221 mg/L is nearly nine times higher than the 25 mg/L standard. This huge increase indicates a massive load of oxidizable organic and inorganic pollutants. In this context, the primary source is the large, decaying biomass of the water hyacinth itself and the accumulated detritus it traps.

Total Suspended Solids (TSS): The TSS reading of 138 mg/L significantly exceeds the 50 mg/L standard. The plant mats likely trap fine sediments, organic debris, and decomposition byproducts, resulting in highly turbid water with adverse effects on light penetration and benthic habitats.

The contrast between the two points is striking, highlighting a sharp spatial dichotomy in Lake Tondano's health. The presence of 1,034 hectares of water hyacinth cover in the Paleloan Village area represents not just a surface obstruction but a significant ecological threat, driving localized but extensive water quality degradation.

4. Conclusion

This study successfully utilized Unmanned Aerial Vehicle (UAV) technology to accurately map and quantify the water hyacinth infestation in Lake Tondano, revealing a total affected area of 1,034 hectares in the Paleloan Village vicinity.

The most critical finding is the establishment of a severe water quality dichotomy in Lake Tondano. While areas free of water hyacinth cover demonstrated water quality that was largely compliant with Class II standards, areas directly beneath the macrophyte mats exhibited drastically deteriorated conditions. Key parameters such as COD, DO, and TSS were in severe non-compliance with environmental standards. Specifically, the near-anoxic DO levels and extremely high COD values strongly suggest that the dense water hyacinth cover is directly responsible for inhibiting reaeration and accumulating a significant load of decomposing organic matter.

This research underscores the effectiveness of UAV-based spatial mapping as an essential tool for rapid assessment and management of invasive aquatic vegetation. The data confirms the urgent need for comprehensive management strategies that focus on the removal and control of E. crassipes to restore ecological balance and protect the vital water quality of Lake Tondano.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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