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Water Resources Management of Lake Tondano in North Sulawesi Province

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Abstract. Lake Tondano is a lake that is used for various purposes. On the other hand, this lake is a source of germplasm, a site where the life cycle of important flora and fauna takes place, and water source that is used for agriculture, livestock production, home industry, and domestic use. Water from Lake Tondano also produces energy through hydropower plant and maintain microclimate. Therefore, lake Tondano is experiencing problems as indicated by the fast growth and wide distribution of water hyacinth that can have a negative impact on the lake itself. The objectives of this research were to identify problems caused by the spread of water hyacinth and to identify water resources management plan for Lake Tondano preservation. This study used primary data such as concentration of nitrate, nitrite, and ammonia in lake Tondano, nitrogen balance in inlet and outlet of the lake Tondano and flow rate of river Leleko and river Panasen, including map or spatial data of Lake Tondano (secondary data) which describe the extent of cover and distribution of water hyacinth in the lake, the negative impact of water hyacinth distribution in the lake, and the utilization of water hyacinth. Secondary data was also used and obtained from various related institutions as well as from the community and other stakeholders. The results show that 88.17% - 99.83% of the lake area was covered by water hyacinth. The biomass growth rate was 9.78-13.39 kg within 7 weeks (Tampi, 2001). Data from BAPPEDA of North Sulawesi province shows that the extent of water hyacinth spread in Lake Tondano in 2014 had reached 277 ha or 5.92% of the lake area. The management of the lake can be performed by controlling the growth of water hyacinth through the utilization of water hyacinth systematically and structurally so that it directly controls the rate of increasing covered area by water hyacinth. Water hyacinth can be utilized as raw material to produce various economic value products, such as organic fertilizer and biogas.

1. Introduction

Lake Tondano has multiple functions. The functions and benefits of Lake Tondano which include ecological benefits, economic and socio-cultural benefits, and specifics/uniqueness are explained in detail in Table 1. The multi-functional utilization of Lake Tondano causes this lake to experience problems that are shown by the growth and distribution of water hyacinth so that it has a negative impact on:

- (a) Disruption of hydropower filters and turbines, so that labor and costs are needed to clean the filter. This activity is carried out every day to make the hydropower turbine functions.



- (b) Inhibition of boat traffic in the lake and rivers, and disruption of fishing activities.
- (c) Disruption of tourism activities on the lake, which includes water skiing, swimming, boat rowing, and fishing.
- (d) The inhibition of the sunlight penetration into lake waters so that it disrupts the lake ecosystem.
- (e) Silting of the lake because dead water hyacinths are piled on the bottom of the lake. In shallow areas, the roots of the hyacinth grow to reach the base and accelerate siltation.
- (f) Decreasing the oxygen content of the water due to floating water hyacinth does not produce oxygen for the waters, even blocking the entry of oxygen (diffusion) from air into the water.

The objectives of this research were to identify problems caused by the spread of water hyacinth and to identify water resources management plan for Lake Tondano preservation.

Table 1. Functions and benefits of Lake Tondano

Functions and Benefit Value	Description
Direct benefits (<i>Direct Function</i>)	
1. Water regulator	As a reservoir of excessive water, including rainwater, surface flow, and underground water sources so that the lake also functions to help overcome flooding.
2. Water needs	As a source of water that can be used by the community either directly (agriculture/livestock, industry, household) or indirectly (source of raw drinking water and energy production through hydropower).
3. Transport line	Lake waters have been used for thousands of years by the community as a means of transportation.
4. Recreation	Lakes, especially those with aesthetic value, can be an attractive location for recreation.
5. Research and education	Many lakes that hold the mystery of science is very interesting to research objects, including for educational activities.
Ecological function	
6. Habitat	As the venue of the life cycle of important types of flora and fauna.
7. Anchoring and contamination bidders	Water bodies and the overall environmental components contained therein can decrease the toxicity of contaminants entering them.
8. Microclimate stabilization	Overall, hydrological conditions and material cycle on wetlands can stabilize the microclimate, especially rainfall and temperature.
9. Global climate control	The lake can absorb and store carbon to act as a controller of carbon-to-air release that is directly related to global climate change.
Production (economic and non-economic)	
10. Provider of water for the community	Since long time ago, the surface water in the lake has been used by the community for various purposes.
11. Groundwater filler	The surface water in the lake can fill the aquifer through the pores of the soil.
12. Water providers for other wetlands	Lake Tondano <i>outlet</i> is the Tondano River that irrigates the wetland ecosystems located in the downstream.
13. Fishery resource	The lake is a habitat for various fishery commodities, such as goldfish, tilapia fish, shrimp (capture fisheries and aquaculture).
Unique (<i>attributes</i>)	
14. It is a habitat of various biodiversity	Various types of flora and fauna make the lake as a habitat both part and the whole life cycle.
15. The uniqueness of tradition, culture, and heritage	Many lakes have distinctive aesthetic values that are part of the cultural development of the local community.
16. Habitat for some or all life cycles of flora and fauna.	Various types of flora and fauna make the lake a breeding, nursery and feeding ground.

Source: [1]

2. Methods

2.1. Research Materials and Tools

The research materials used were the map of Lake Tondano, questionnaires, handheld GPS, camera, and writing instruments. Water sampling was carried out using the composite sampling method in twenty-five location as an inlet of the lake, twenty-nine location in the lake (collected in 2008), and one location in upstream of river Panasen (collected in 2016).

2.2. Data Collection Techniques and Analysis

This study used primary data: water quality such as nitrate, nitrite, ammonia concentration in Lake Tondano, nitrogen balance in inlet and outlet of the Lake Tondano and flow rate the River Leleko and River Panasen, including map or spatial data of Lake Tondano which describe the extent of cover and distribution of water hyacinth in the lake, the negative impact of water hyacinth distribution in the lake, and the utilization of water hyacinth. Secondary data: The growth rate of water hyacinth, nitrate concentration in year 2000 and volume of lake Tondano was also used and obtained from various related institutions as well as from the community and other stakeholders. The data obtained in this study were analyzed using descriptive analysis.

3. Result and Discussion

3.1. Water Condition of Lake Tondano

Water condition of Lake Tondano was influenced by several factors including sediment derived from soil erosion and fish cultivation by communities around the Lake Tondano. Factors that affected the water condition in the lake Tondano were described as follows.

3.1.1. Erosion and Sedimentation

The issue of siltation caused by several factors including land use in the catchment area, which is mostly located in the watershed Noongan and Panasen, which is not in accordance with the ability of the soil and land management is not implementing soil conservation techniques so well that cause soil erosion [2]. Soil erosion that occurs in farmers' fields in addition to lowering soil fertility and productivity, which in turn can lower the income level of farmers, also have negative impacts such as siltation in the Lake Tondano. The predicted erosion rate in the catchment area of Lake Tondano is 54 m³/ha/year, has exceeded the threshold of tolerance, which is 12 m³/ha/year [3]. This situation resulted in vast lakes shrank from 5,600 ha to 4,800 ha and the depth was reduced from 42 meters to 19 meters during the years 1939-1992.

There are twenty-four inlets of lake Tondano consisting of rivers, streams and irrigation channels that contribute to sedimentation in the Lake Tondano. The flow rate of the inlets presented in Table

Based on collected data by Forest Department from river monitoring station around the lake, sediment yield of river Marawas was 1.78 ton/year in 2005, river Touliang Oki was 1.26 ton/year in 2003, a river in Kaayuran Atas was 0.22 ton/year in 2005 [4].

Table 2. Flow Rate of River, Streams, and Irrigation Channel as Inlets of Lake Tondano

No.	Inlets	Flow rate (m ³ /sec)
1.	Koya Stream **)	0.012
2.	Toubeke Stream **)	0.015
3.	Salupokol Stream **)	0.015
4.	Tougela Stream **)	0.044
5.	Outlet 2 **)	0.940
6.	Tougela 1 Stream **)	0.225
7.	Tougela 3 Stream **)	0.124
8.	Tougela 4 Stream **)	0.090
9.	Leleko River *)	0.935
10.	Talikuran River **)	0.895
11.	Irrigation channel 1 **)	0.014

12.	Irrigation channel 2 **)	0.014
13.	Irrigation channel 3 **)	0.015
14.	Irrigation channel 4 **)	0.013
15.	Panasen River *)	8.100
16.	Ranowangko River **)	7.610
17.	Saluwangko River **)	4.860
18.	Irrigation channel (Tandengan) **)	0.114
19.	Irrigation channel (Tounipus) **)	0.014
20.	Irrigation channel (Serawet) **)	0.014
21.	Irrigation channel (Toulumbuten) **)	0.018
22.	Irrigation channel (Tounsukun) **)	0.114
23.	Irrigation channel (Makalonsow) **)	0.105
24.	Irrigation channel (Papakelan **)	1.086

Source: [6, 7]

3.1.2. Water Quality

Wantasen [8] was carried out water quality analysis based on chemical, physical and biological parameters at ten locations around the lake, covering the western, eastern, northern and southern regions. Field sampling was carried out during the dry season in September 1999. Data on chemical parameters including phosphates, nitrates, ammonia residues indicated that allowable threshold limits for B and C class water were exceeded in a number of instances (Table 3).

Table 3. Water Quality Data Lake Tondano, 1999

No.	Sampling Location	Parameter		
		Phosphate (ppm)	Nitrate (ppm)	Nitrite (ppm)
1.	S. Tondano (Kakas)	0.78	0.7	1.13
2.	S. Tondano (Tountimomor)	1.99	2.3	1.25
3.	W. Tondano (Remboken)	1.1	1.3	0.79
4.	E. Tondano (Eris)	3.75	1.1	1.62
5.	E. Tondano (Tounsaru)	1.84	2.9	0.52
6.	W. Tondano (Toulour)	1.84	2.7	0.66
7.	N. Tondano (Tasuka)	0.76	0.6	1.19
8.	E. Tondano (Toulimembet)	1.33	2.3	1.17
9.	E. Tondano (Ranomerut)	1.66	3.1	1.37
10.	E. Tondano (Serawet)	1.73	0.7	1.18
	Class B standard	nr	10	0.5
	Class C standard	nr	nr	0.02

Source: Wantasen, 2015.

Explanation: N, S, W, E refer to the north, south, west and east sides of the lake;

Class B: suitable for drinking after treatment

Class C: suitable for fisheries and livestock cultivation

nr = not regulated

The chemical condition of the lake can be shown by the nutrient balance in the Lake, among others the nitrogen mass balance which has been transformed into nitrate, nitrite, and ammonia in Lake Tondano (Table 3). The average concentration of nitrate, nitrite, and ammonia in Lake Tondano inlet is higher than that in its outlet because nitrate, nitrite, ammonia compound dissolved and drift away in the current. This showed that there were accumulations of nitrogen (nitrate, nitrite, ammonia) at Lake Tondano at this depth. The nitrogen residue concentration (nitrate, nitrite, ammonia) at aquatic environment in the upstream of Tondano Watershed on the growing season in 2013 nitrate

concentration: 0,293-0,408 mg/l; Nitrite 0,001-0,041 mg/l; ammonia 0,04-0,28 mg/l. in the growing season in 2014 concentration nitrate: 0,184-0,628 mg/l; Nitrite 0,02-0,077 mg/l; ammonia 0,002-0,13 mg/l. in the growing season in 2015 concentration nitrate: 0,173-0,585 mg/l; Nitrite 0,001-0,029 mg/l; ammonia 0,05-0,10 mg/l [9]. The nitrogen concentration in Panasen river as an inlet of lakeTondano from 2013 to 2015 presented in Figure 1.

Table 3. Nitrogen Concentration Balance in *Inlet* and *Outlet* of Lake Tondano

No.	Parameter	Concentration in inlet (mg/l)	Concentration in outlet (mg/l)
1.	NO ₃ ⁻	13.29	0.74
2.	NO ₂ ⁻	0.22	0.05
3.	NH ₃ ⁻	1.24	0.09

Source: [6]

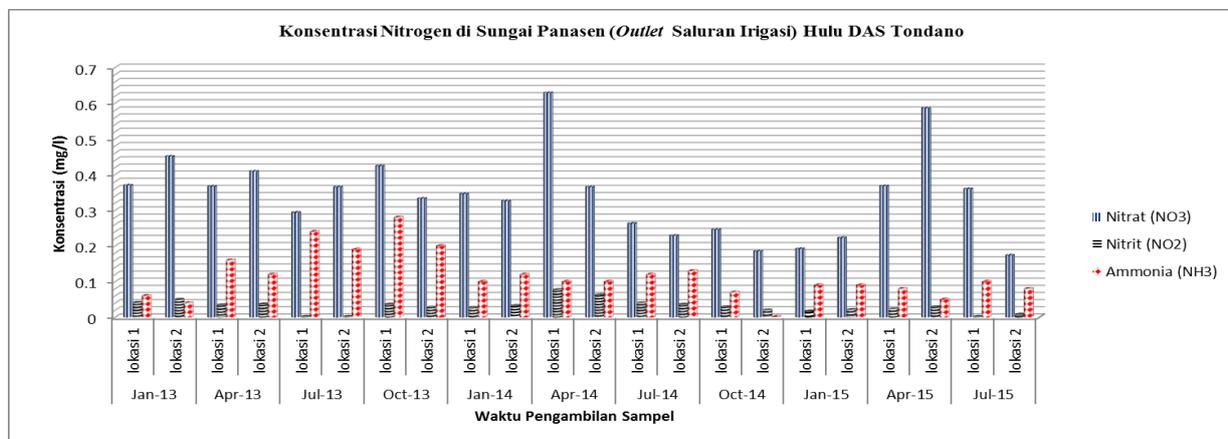


Figure 1. The concentration of Nitrate, Nitrite, and Ammonia in Panasen River from 2013 to 2015

Source : [9]

N mass N in Lake Tondano can be obtained from the calculation of nitrogen concentration (nitrate, nitrite, ammonia) multiplied by the volume of lake water [10]. The water volume of Lake Tondano which is calculated based on bathymetry is 668.57 million m³ [11]. The mass balance of nitrogen (N) in Lake Tondano is presented in Table 4.

Table 4. Nitrogen Mass Balance in *Inlet* and *Outlet* of Lake Tondano

No.	Parameter	N mass in the inlet (tons)	N mass in the outlet (tons)	N mass left on the lake (tons)
1.	NO ₃ ⁻	88,861.63	4,969.63	8,3892.00
2.	NO ₂ ⁻	1,509.11	3,318.65	1,177.24
3.	NH ₃ ⁻	8,300.51	617.72	7,682.79

Source: [6]

The nitrogen mass balance (nitrate, nitrite, and ammonia) is presented in graphic form (Figure 2). The figure shows that the nitrogen mass (nitrate, nitrite, ammonia) in Lake Tondano inlet is higher than that at the outlet. This indicates that most of the nutrients are left on the Lake Tondano which caused nutrient enrichment or eutrophication.

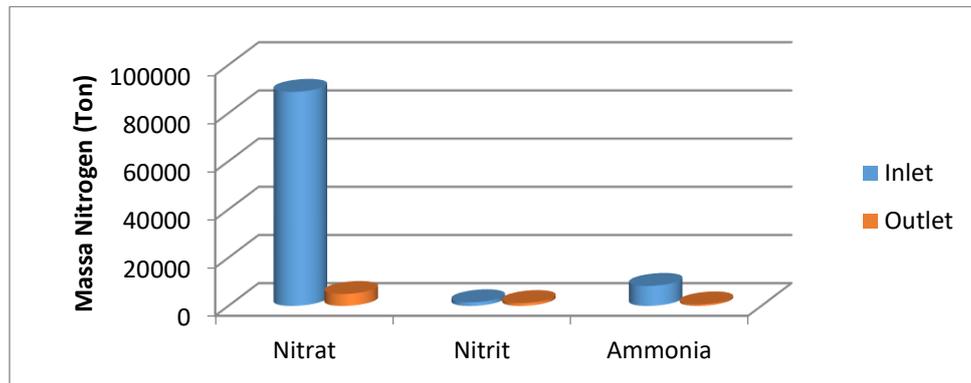


Figure 2. Nitrogen Mass Balance in Lake Tondano
Source :[6]

Nitrogen in nature will undergo transformation through the nitrification process, nitrate reduction, denitrification, mineralization, ammonification, immobilization, washing, evaporation, fixation of N_2 to Nitrogen in the form of NO_3^- , NO_2^- , NH_3 , NH_4^+ , N_2 . Of the five forms of Nitrogen, NO_3^- , NO_2^- , NH_3 , and NH_4^+ can be measured. Research on water quality in the eastern part of Lake Tondano conducted by Korah (2000) for ammonia (NH_3) parameters showed that ammonia concentration on the lake surface was in the range 0.20-0.38 mg/l, but in 2008 the ammonia concentration on the surface of Lake Tondano change in the range of 0.20 mg/l - 0.58 mg/l [6]. The comparison of ammonia concentration at the same location as measured in 2000 and 2008 showed there was an increasing trend of 0.21 mg/l - 0.41 mg/l (Figure 3).

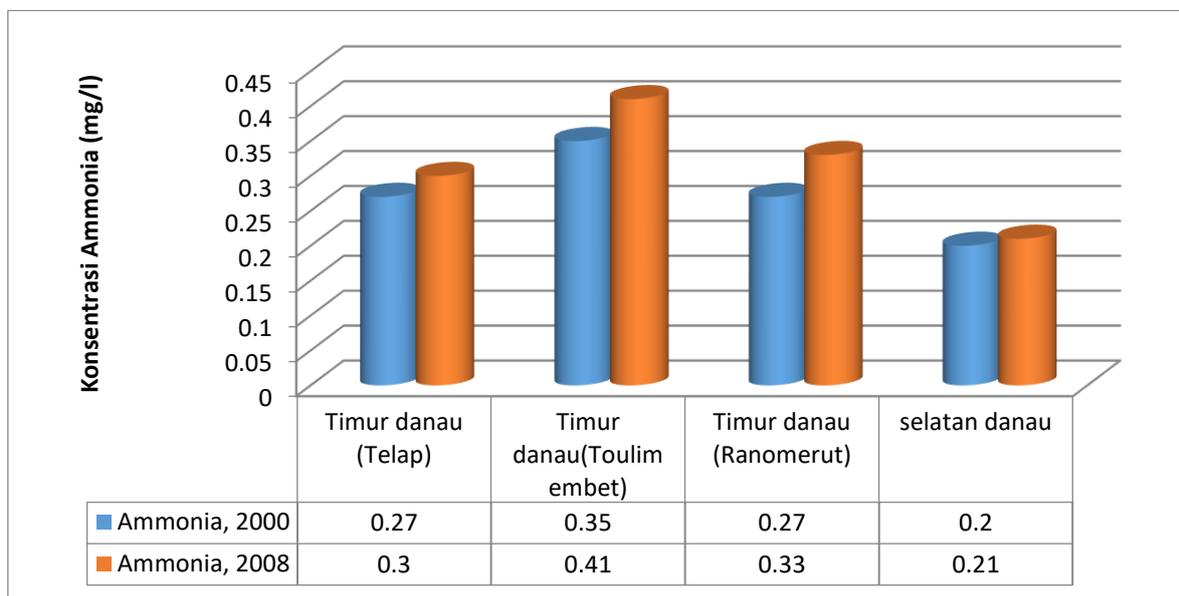


Figure 3. Ammonia concentration in Lake Tondano in 2000 and 2008
Source : [5]

Ammonia concentration on the surface of Lake Tondano exceeds the quality standards required in accordance with Government Regulation Number 82 of 2001 concerning Management of Water Quality and Water Pollution Control (Class I), which is 0.50 mg/l for raw water to be processed into clean water. The highest concentration was found in river estuaries which become lake inlets and in the eastern and central parts of the lake [12].

Nitrite concentration on the surface of Lake Tondano was in the range of 0.001-0.118 mg/l. This nitrite concentration also exceeds the quality standard requirements in accordance with Government Regulation No. 82 of 2001 concerning Management of Water Quality and Water Pollution Control (Class I), where the allowed nitrite concentration is 0.06 mg/l, especially for drinking water needs. The highest nitrate concentration was found in the eastern part of the lake, which was the location of fishing activities in floating net systems. The measured nitrite concentration was in the range of 0.070 mg/l - 0.118 mg/l. The number of floating nets in Lake Tondano in 2008-2009 was around 5250 units [6] and in 2018 around 4500 units [5]. This is related to the ammonia concentration in 2008 averaging 0.31 mg / l, and in 2016 an average of 0.167 mg / l, there was a decrease in ammonia concentration.

The surface nitrate concentration on Lake Tondano ranges from 0.1 mg/l to 1.1 mg/l [6]. The research results conducted by Korah [13] in the waters of the eastern part of lake Tondano showed varying nitrate concentrations on the lake surface, i.e., 0.85 mg/l at the Eris measurement station, 0.65 mg/l in Telap, 0.80 mg/l in Toulimembet and 0.68 mg/l in Kaweng.

The concentrations of nitrate, nitrite, and ammonia in the Panasen River in the upper part of the Tondano watershed (inlet from the irrigation channel outlet) in the 2016 growing season are presented in graphical form in Figure 4.

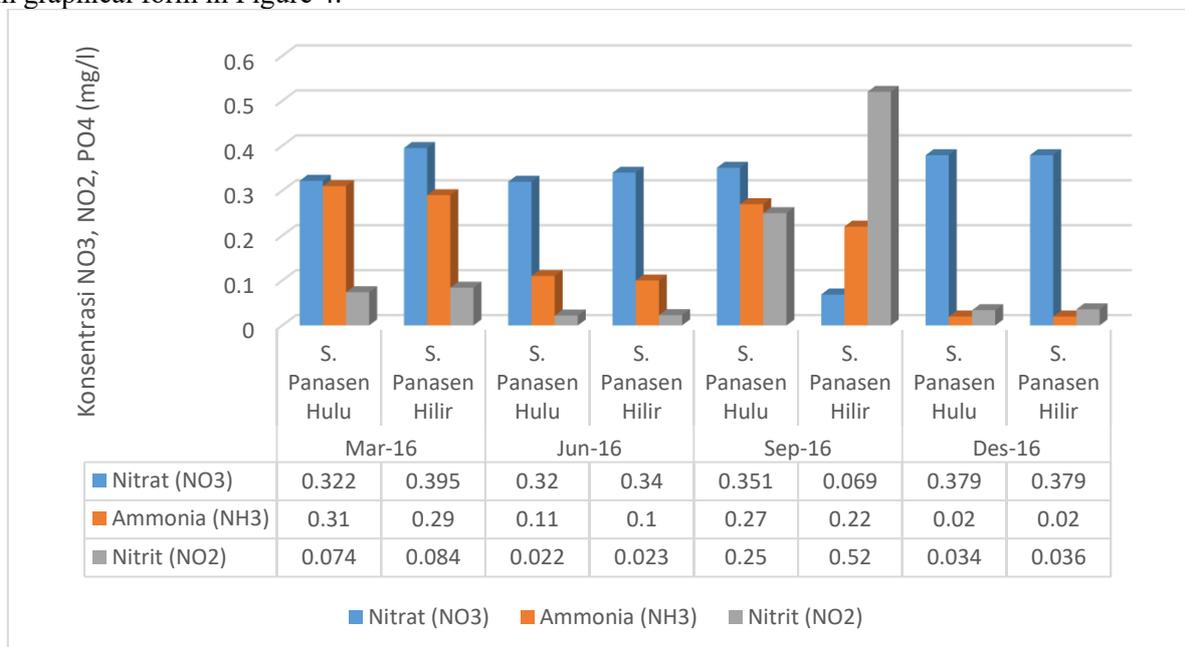


Figure 4. The concentration of Nitrate, Nitrite, Ammonia in Panasen River (Government Regulation PP 82/2001 Class II (nitrate 10 ppm, nitrite 0,06 ppm, ammonia: na))

The Panasen River crosses rice fields from upstream in the Tondano watershed and empties into lake Tondano. There is a significant difference between the concentration of nitrate, nitrite, and ammonia in the Panasen River (the outlet of irrigation channel) when the rice plants in the fields are in active growth period (this condition indicates fertilization) and during harvest [14].

3.2. The Growth Rate of Water Hyacinth

The main cause of the difficulty in eradicating water hyacinth is because these plants breed very quickly. Water hyacinth breeds with stolon (i.e., horizontal branches from the base of the stem that become shoots or seedlings) and with seeds. The generative breeding with seeds is a very slow process because hyacinth seeds have a very long period of dormancy. According to Tampi [15], each water hyacinth flower can produce 413-617 seeds and each hyacinth plant can produce 2,000-7,000 seeds, while dormant period can reach 15 years.

Contrary to generative breeding, vegetative propagation through the stolon takes place very quickly. Experiments conducted by Tampi [15] in lake Tondano (Remboken area) found that from two individual water hyacinths, within 7 weeks they could become 664 small size individuals (initial size of 10 cm), 510 medium-sized individuals (the initial size of 25 cm), and 463 large size individuals (initial size of 40 cm).

Tampi [15] who conducted an experiment using a square of 2 x 2 m² for each size of water hyacinth (small, medium and large) found that the growth rate of the water hyacinth space was 99.83%; 91.17%; and 88.17% for all three sizes within 7 weeks. The biomass growth rate (weight) also provides similar results, which is 13.39 kg; 10.74 kg and 9.78 kg consecutively.

Water hyacinth has become the most invasive weed in the world, whose volume can be doubled in 2 weeks and often clogs the water flow through a mass of 500 tons/ha. The rapid growth of water hyacinth on Lake Tondano is triggered by increasing aquatic fertility (eutrophication) with the most easily seen indicator is the much lower water brightness.

In the observation of 1973-1975, the brightness of Lake Tondano still reached 3.9 - 4.0 meters, while in 2014 it had decreased to the level of 1.5 - 2.0 meters [16]. This decreasing brightness is caused by an increase in phytoplankton biomass as a result of the increase in aquatic fertility. Nutrients that enter the lake waters come from the fish feed that is not consumed in floating net aquaculture, fertilizers from rice fields and plantations around the lake, household waste, livestock waste, and fish metabolites (urine and feces), both those living in floating nets and living wild. Based on the spatial analysis, lake Tondano was covered by water hyacinth and has reached 277 ha or 5.92% of the lake surface area (Figure 5).

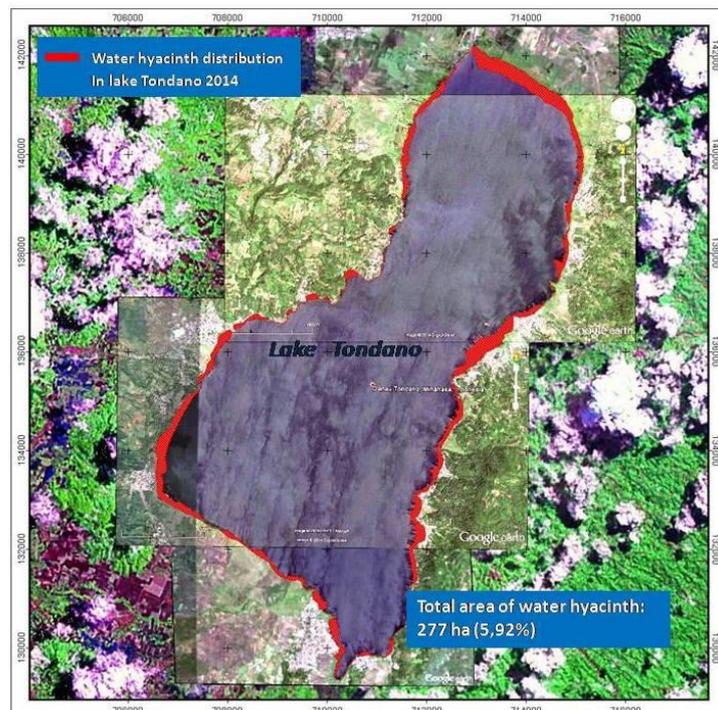


Figure 5. Water hyacinth distribution in lake Tondano in 2014

4. Conclusions

This research showed that the growth rate of water hyacinth in Lake Tondano is so high that the plants can quickly cover the surface of the lake. Therefore the most appropriate management of water resources of Lake Tondano is needed. The proper management of water resources of Lake Tondano can be performed to minimize the rate of erosion in upland area by implementing soil conservation

practices, to reduce sedimentation in the lake, and to control the rate of increase of water hyacinth area by utilizing the plants to produce various products of economic value, such as organic fertilizer and biogas.

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