Characteristics of Rainfall-Discharge and Water Quality at Limboto Lake, Gorontalo, Indonesia

Luki Subehi[1,2,*], Hendro Wibowo[1] & Kwansue Jung[2]

[1]Research Centre for Limnology, Indonesian Institute of Sciences, LIPI Cibinong Science Centre (CSC) Cibinong 16911, Indonesia
[2]International Water Resources Research Institute, Chungnam National University, Daejeon 305-764, South Korea
*E-mail: luki@limnologi.lipi.go.id

Abstract. Problems of high turbidity, sedimentation, water pollution and siltation occur at Limboto Lake, Gorontalo, Indonesia. The objective of this study was to analyze the rainfall-discharge relationship and its implications for water quality conditions. Secchi disk (water transparency), chlorophyll-*a* (chl-*a*), and total organic matter (TOM) were measured in May 2012, September 2012 and March 2013 at three sites of the lake (L-1, L-2 and L-3) to observe the impacts on the surrounding catchment. Based on representative stations for rainfall data from 2004 to 2013, monthly averages of rainfall in March-May (166.7 mm) and September (76.4 mm) were used to represent the wet and dry period, respectively. Moreover, sediment traps at these three sites were installed in September 2012. Based on the analysis it is suggested that rainfall magnitude and land use change at the Alopohu River catchment influenced the amount of materials flowing into the lake, degrading the water quality. Specifically, the higher average rainfall in May (184.5 mm) gave a higher average total sediment load (4.41 g/L/day). In addition, water transparency decreased with increasing chl-*a*. This indicates that the concentrations of sediment and nutrients, reflected by the high amount of chl-*a*, influenced the water quality conditions.

Keywords: *Alopuhu River; discharge; Limboto Lake; total sediment*; *water quality.*

1 Introduction

Limboto Lake is a low basin and is also referred to as a type of flood-plain lake. It is a part of the Bone and Bolango catchment area, which is located at the heart of Gorontalo Province. It provides important ecological and hydrological functions, as well as socio-economic support for this province. As for its economic value, Balihristi [1] noted that fish production was 877 ton/year in 2004. It also provides clean water, a habitat for plants and animals, transportation, recreation, sports, fishery, flood control, regulates hydrological functions, etc.

As it is located only about 3 km west of the city of Gorontalo, its presence has a very strong interaction with this city. The high ratio of its watershed area to its

Received September 4th, 2015, 1st Revision February 1st, 2016, 2nd Revision May 10th, 2016, Accepted for publication July 19th, 2016.
 ISSN: 2337-5779, DOI: 10.5614/j.eng.technol.sci.2016.48.3.4

surface water area, which reaches 30, indicates that the watershed plays an important role in the sedimentation problems of the lake. Wetzel [2] reported that water quality conditions of small lakes with big catchment areas are varied because they are more sensitive to environmental changes and have a short retention time.

Limboto Lake is one of 15 national priority lakes because it has serious environmental problems. The extensive shrinkage of its area due to siltation is the primary problem. In 1932, the surface area and the average depth of Limboto Lake were 7,000 ha and 30 m, respectively. It has been reported that the erosion rate of the Limboto Lake catchment area reached 9,902,588.12 tons/year and the lake area was now less than 3,000 ha with an average depth of 2.5 m in 2006 [3]. Therefore it is necessary to exercise erosion control efforts in the lake catchment area.

Moreover, there are 23 rivers, including small rivers, which flow into the lake [1,4] in the northern and the western part. The outlet of the lake at Topadu River is in the eastern part. Meanwhile, data reported in 2002 by a JICA study team [4] showed that the Biyonga, Meluopo and Alopohu Rivers are the main sediment suppliers of the lake.

Eutropication of the lake has led to a fast growing population of water hyacinth, which covers the surface of the lake. Based on Landsat 2012, water hyacinth covers 1,777 ha or 51% of the lake area during the dry season [5]. This causes a widespread shrinking of the littoral zone of the lake, which contributes to the decline of fish production. The littoral zone provides a habitat for various kinds of aquatic organisms and plays an important role in supporting the productivity of the lake [6,7]. In addition, Numazawa, *et al*. [8] reported that the littoral zone could also function in the improvement of water quality conditions in shallow lake areas.

Furthermore, the seasonality of rainfall characteristics affects the discharge of inlet and outlet, so that dilution, flow velocity and sedimentation influence the water quality in the lake [9]. The relations among the physical, chemical and biological processes in a river’s ecological system are very complex [10]. An evaluation of the river’s attributes can possibly be used as an index to evaluate its ecology [11]. This implies that land use changes in the river catchment area also influence water quality and ecological conditions in the lake.

According to the functions and benefits of Limboto Lake as discussed above, it is important to develop a sustainable lake management in order to protect its functions. No studies have been conducted on the aspects of rainfall-discharge and water quality characteristics of the lake, therefore, this study was carried out to analyze the rainfall-discharge relationship and its implications on water quality conditions at Limboto Lake.

2 Materials and Methods

The studied lake is located over a wide longitudinal range from 122° 57’ 40” E to 123° 02’ 14” E and latitude from 0° 31’ 58” N to 0° 34’ 50” N (Figure 1), at an elevation of 25 m above sea level with an 89,000 ha catchment area.

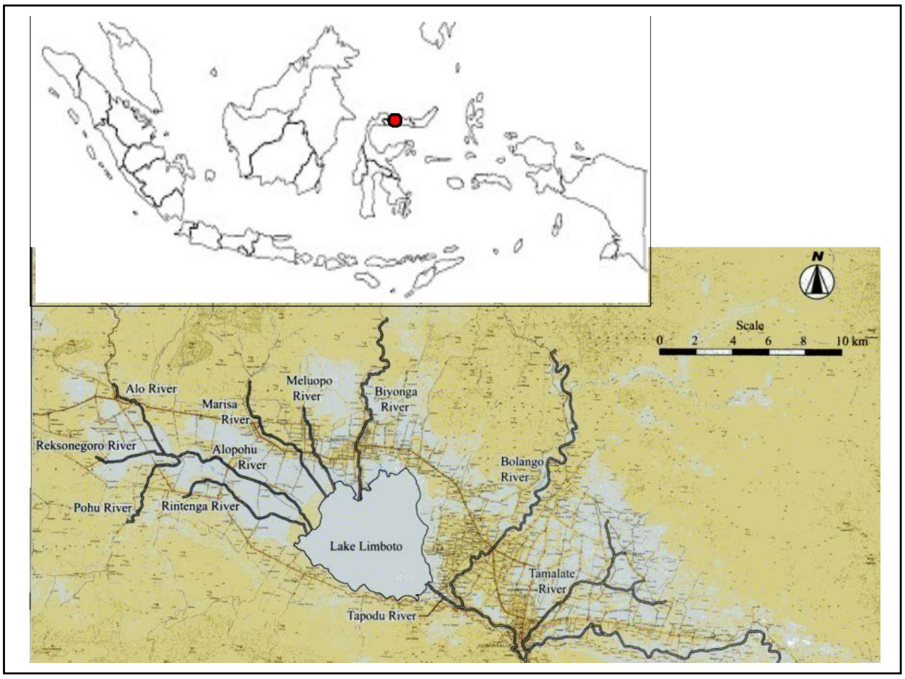


Figure 1 Location of the study area (modified after Balihristi [4]).

Daily rainfall was obtained from a representative station, Jalaluddin meteorological station, from 2004 to 2013. In order to describe the lake’s seasonal water quality conditions, we observed the water quality in two seasons, divided depending on the amount of precipitation: below 100 mm for the dry periods (August-October) and above 100 mm for the wet periods (January-July and November-December). Monthly averages of rainfall from March-May (166.7 mm) and September (76.4 mm) were used to represent the wet and the dry period, respectively, as related to measuring water quality sampling periods.

Water quality measurements were conducted at three sites of the lake in May 2012, September 2012 and March 2013 (Figure 2). These three sites were located at the outlet (Topadu River, indicated by the C arrow), the middle and the inlet of the lake (Biyonga and Alopohu Rivers, indicated by the B and A arrows, respectively). Theyare labeled as Limboto 1/L-1, Limboto 2/L-2 and Limboto 3/L-3, respectively. At each site, we measured secchi disk (water transparency), chlorophyll-*a* (chl-*a*), and total organic matter (TOM). Water samples were collected and analyzed in the laboratory referring to the APHA standard method [12]. In addition, water quality data in 2006 from Krismono, *et al*. [13] are also provided for comparison.

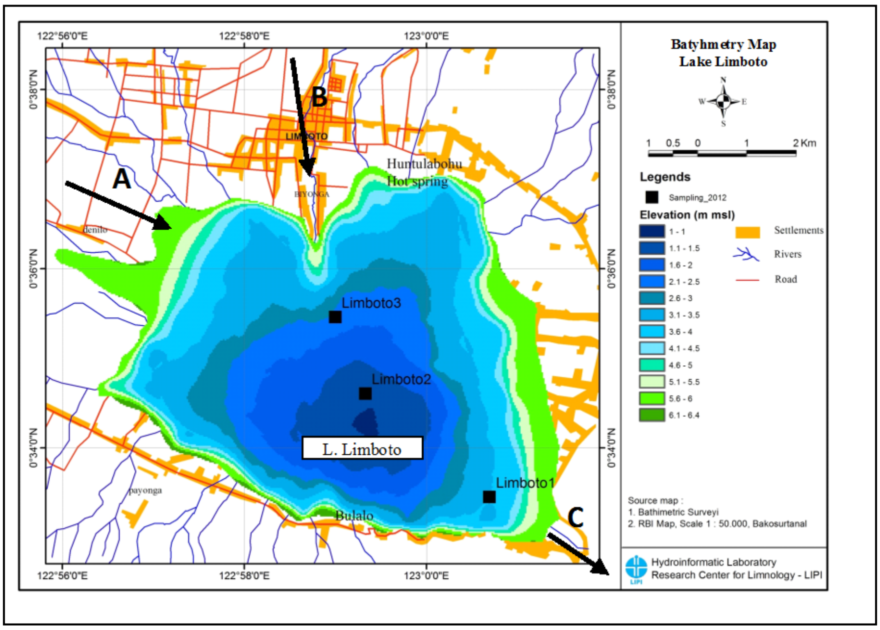


Figure 2 Bathymetry map and sampling points at Limboto Lake (Alopohu River, Biyonga River, and Topadu River).

Next, daily water discharge (*Q*) and rainfall (2006, 2009 and 2010) were obtained from the Public Works Department and Jalaluddin Meteorological Station (the station nearest to the lake, about 15 km). The relationships between *Q*-inlet (Alopohu and Biyonga Rivers) and *Q*-outlet (Topadu River) were analyzed. In addition, the relationship between rainfall and *Q* of each river was also investigated.

Sediment trap measurements in the lake support watershed materials input prediction for evaluation of the dynamical sediment transport [14]. Sediment traps at the three sites of the lake were installed at 2/3 of the depth of the lake during field measurements in September 2012 for two days. Four PVC tubes with a height and diameter of 25 cm and 8 cm respectively were used.

Meanwhile, sediment data from 2004 and 2005 [15] were analyzed for comparison. In addition, the *F*-test was used with a value of $p < 0.05$, which indicates the statistical significance of the precision of the data spread from two samples (similar or dissimilar).

3 Results and Discussion

In order to show how serious the lake condition is, an exponential regression equation that explains the surface area and depth reduction versus time is shown in Figure 3. Based on field measurements from 2012 [5], the average depth and surface area decreased to 2.2 m and 2,500 ha, respectively. From historical data of surface area and depth dynamics of Limboto Lake it is assumed that environmental degradation at Limboto Lake has occurred.

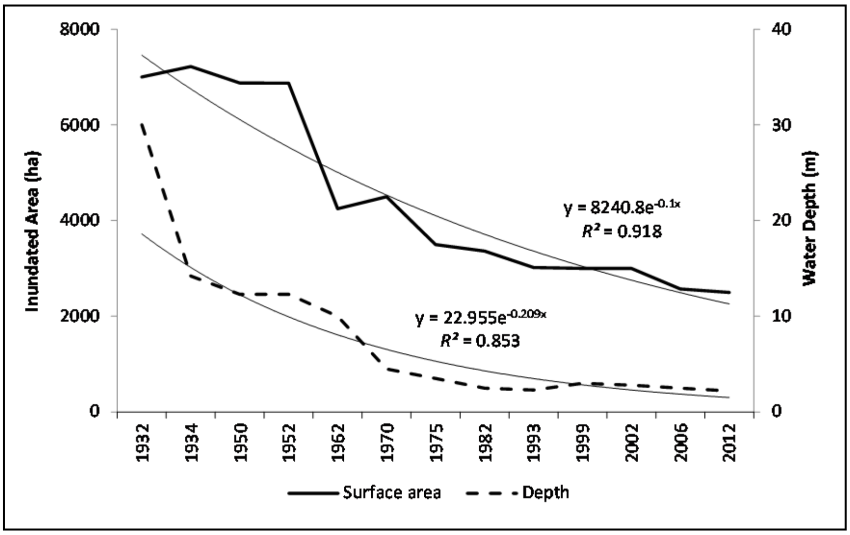


Figure 3 Inundated area and water depth conditions at Limboto Lake (1932-2012) (modified after Balitbangpedalda [16]).

Figure 3 shows that siltation has occurred slowly and exponentially after the 1990s. Based on the historical data of area and depth dynamics of Limboto Lake, the equations are as in Eqs. (1) and (2):

$$A = 8240.8e^{-0.10t} \tag{1}$$

$$h = 22.955e^{-0.21t} \tag{2}$$

where A = surface area (ha), h = depth (m) and t = time (year). This could be called a disappearing lake phenomenon, with no adaptive and management efforts in the lake [17]. Moreover, analysis of the lake surface only is insufficient to evaluate the directions of lake development and shrinkage [18].

3.1 Water Quality Analysis

The monthly average rainfall was 104.9 mm, 148.0 mm and 157.7 mm in 2006, 2012 and 2013, respectively. Figure 4 shows water quality parameters at each site of the lake during the wet (March and May) and the dry (September) season. Water depth in particular followed and depended on the season. For 2012, it increased (3.5 m) and decreased (0.9 m) in May and September, respectively. The average water depth and total rainfall in 2012 (2.0 m and 1,776.0 mm, respectively) were higher than those in 2006 (1.6 m and 1,259.0 m, respectively).

On the basis of measuring water transparency by secchi disk (SD), the average water transparency was higher during the wet period (0.55 m) (March-May) than that during the dry period (0.38 m) (September). It was affected by the condition of a smaller volume of water and a higher concentration of sediment. This could be explained by a larger concentration of stored sediment materials and lower water transparency during the dry period.

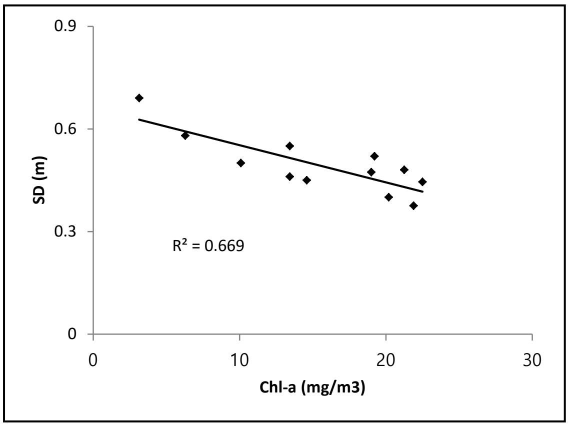
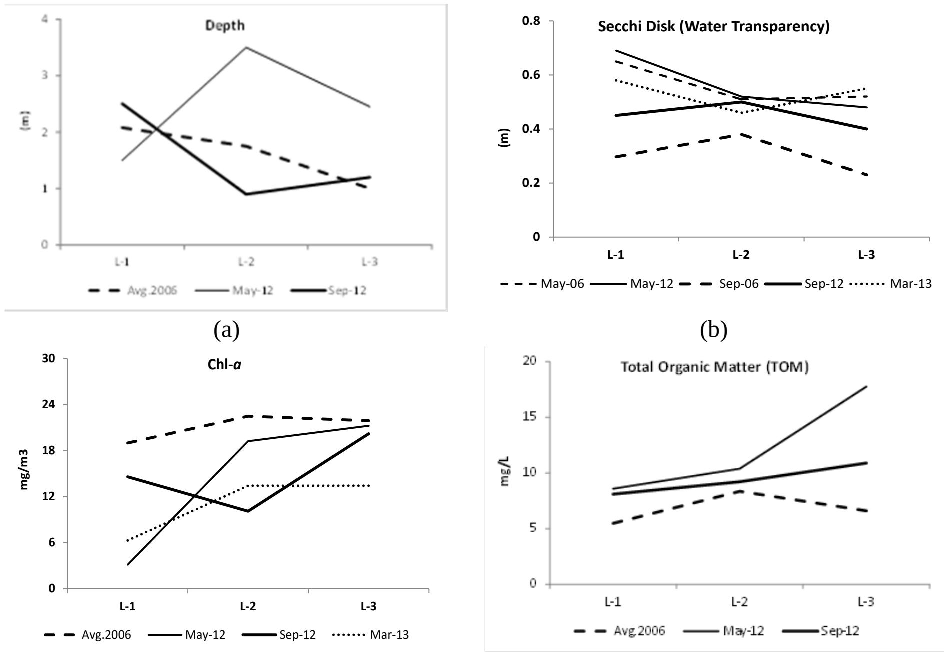


Figure 4 Correlation between chl-a and sechhi disk (SD) (years: 2006, 2012 and 2013).

The average amount of chl-*a* in 2006 (21.1 mg/m^3) was larger than in 2012 and 2013 (14.8 mg/m^3 and 11.1 mg/m^3, respectively). On the other hand, the average TOM concentration in 2006 (6.8 mg/L) was lower than in 2012 (10.8 mg/L). The decrease in fishery activities influenced the concentration of TOM and chl-*a* [5,19]. Balihristi [1] stated that fish production was higher in 2012 than in 2006. It was suggested that the amount of fish increased in 2012 with the decrease of phytoplankton (chl-*a*) as fish feed. On the other hand, the concentration of TOM increased, as a result of the abundance of water hyacinth. In addition, interactions between the remaining fish feed and nutrients influenced each other. In addition, the water hyacinth as a weed species will speed up the lake siltation and disrupt the transport of water [1]. The existence of water hyacinth reduces the light penetration into the water; when siltation occurs this will impact the physical development of the area concerned. Furthermore, the biomass of the dead plants settles as organic material and accelerates the siltation process [20].



(c) (d)

Figure 5 Depth and water quality parameters at each site of the lake.

The concentrations of chl-*a* and TOM were larger at site L-3, implying that the concentration of nutrients was higher near the inlets of the rivers. Settlement and agriculture discharge nutrients and sediments as their wastes had enough time to settle at the bottom of the lake in the absence of large currents, such as a flushing discharge, as can be observed at the outlet (L-1).

More specifically, the values of chl-*a*, as a phytoplankton biomass measurement which indicates the nutrient level, increased with decreasing water transparency (Figure 4). A similar condition was also observed at higher concentrations of sediment with lower water transparency (Figure 5). This indicates that the concentration of nutrients and/or organics influences water quality [21]. In addition, the F-test indicated that the linear model was statistically significant (p < 0.05, n = 12).

3.2 Inlet - Outlet Discharge Analysis

Fifteen correlations were obtained from the monthly data of rainfall vs. *Q*, and *Q* inlet vs. *Q* outlet (Table 1). Higher values of the correlation coefficient (*R*) were obtained from correlations between rainfall vs. *Q*-Alopohu and *Q*-Alopohu vs. *Q*-Topadu with values of *R* > 0.731 as significant correlations ($p < 0.05$, n = 12).

Table 1 *R* values for Rainfall vs. *Q* and *Q* Inlet vs. *Q* Outlet.

Year	Total rainfall (mm)	Correlations	The values of *R*
2006	1,259.0	Rainfall vs. *Q*-Biyonga	0.703
		Rainfall vs. *Q*-Alopohu	**0.833**
		Rainfall vs. *Q*-Topadu	0.813
		Q-Biyonga vs. *Q*-Topadu	0.778
		Q-Alopohu vs. *Q*-Topadu	**0.823**
2009	1,244.1	Rainfall vs. *Q*-Biyonga	0.539
		Rainfall vs. *Q*-Alopohu	**0.875**
		Rainfall vs. *Q*-Topadu	0.703
		Q-Biyonga vs. *Q*-Topadu	0.222
		Q-Alopohu vs. *Q*-Topadu	**0.887**
2010	2,310.5	Rainfall vs. *Q*-Biyonga	0.652
		Rainfall vs. *Q*-Alopohu	**0.823**
		Rainfall vs. *Q*-Topadu	0.551
		Q-Biyonga vs. *Q*-Topadu	0.541
		Q-Alopohu vs. *Q*-Topadu	**0.731**

Moreover, a large value of *R* for rainfall vs. Q-Alopohu (0.875) was obtained during lower total rainfall in 2009 (1,244.1 mm) compared with 2006 (1,259.0 mm) and 2010 (2,310.5 mm). Similarly, a large *R* value was also obtained for Q-Alopohu vs. Q-Topadu (0.887) in 2009 (Table 1). The explanation could be that during small total rainfall only the Alopohu River provides water and sediment discharge into the lake. Meanwhile, when rainfall is high, several inlet rivers have a role as a source of water and sediment for the lake. Putra, *et al*. [17] pointed out that the river sediment supply from the Alopohu, Marisa and Moluopo Rivers is larger than that of the Biyonga, Bulota and Talubongo

Rivers. In addition, the area of the Alopohu River (15,000 ha) is larger than that of the Biyonga River (6,000 ha). A larger surface flow was also observed at the catchment area of the Alopohu River, due to higher rates of damage due to land use compared to the Biyonga River.

3.3 Sediment Traps Analysis

The quantity of particulate materials sinking in the lake from sediment traps was analyzed. Figure 6 shows that the concentrations of dried mud, gravel and fine sand at site L-1 (0.68 g/L/day, 0.04 g/L/day and 0.13 g/L/day, respectively) were larger than those at L-2 (0.30 g/L/day, 0.01 g/L/day and 0.05 g/L/day, respectively) and L-3 (0.35 g/L/day, 0.02 g/L/day and 0.08 g/L/day, respectively). It was shown that the location of L1 received a high sediment load from some parts of the lake before flowing out through the river outlet. The concentrations of those materials at L-3 was larger than at L-2. The explanation could be that L-3, located near the inlet rivers, received large quantities of waste and materials.

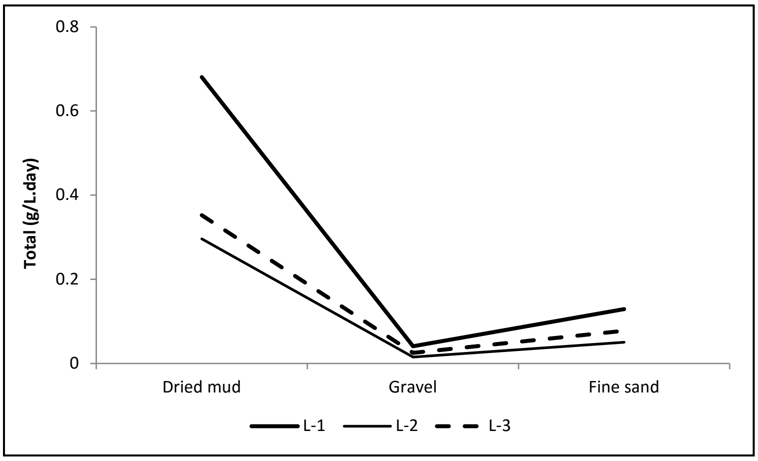


Figure 6 Composition of dried mud, gravel and fine sand collected by sediment trap at each sampling point on September 2012.

The sediment total from sediment traps was also calculated and analyzed and compared with the data from 2004 and 2005 [14]. Table 2 shows the relationship between rainfall and sediment. Higher rainfall in May 2004 and 2005 (average of 184.5 mm) resulted in a higher average sediment load (4.41 g/L/day). It was concluded that rainfall was a contributing factor, bringing some materials from the catchment area and discharge into the lake.

Table 2 Rainfall and sediment trap analysis.

Time	Rainfall (mm)	Sediment load (g/L/day)
May-04	138	1.51
Sep-04	36	0.23
May-05	231	7.31
Sep-05	20	0.12
Sep-12	46	0.58

Based on BPDAS-BB (Bolango-Bone basin authority) in 2010 [22], land use change in 2005 and its projection for 2020 are shown in Table 3.

Table 3 Description of land use change conditions.

Land use	Area – 2005 (ha)	(%)	Projection area – 2020 (ha)	(%)
Lake	3,584.4	0.68	3,535.4	0.67
Forest	425,924.7	81.08	392,619.8	74.74
Field	40,401.5	7.69	37,718.0	7.18
Plantation	22,194.1	4.22	36,740.9	6.99
Settlement	16,894.5	3.22	36,709.4	6.99
Swamp	1,673.0	0.32	1,576.0	0.30
Fice field	14,564.7	2.77	16,337.5	3.11
Pond	83.8	0.02	83.8	0.02
Total	525,320.8	100	525,320.8	100

Source: BPDAS-BB 2010

The forest is ranked as having the highest percentage of reduction of its area in the projection year of 2020 (6.34% – from 81.08% to 74.74%). The explanation could be that the land use change, especially in the forest region, influences the erosion and sedimentation rates of the lake. In addition, Halida [14] reported that the total amount of sediment at the Limboto watershed increased from 8.5 g/L/day in 2004 to 24.4 g/L/day in 2005, consistent with the large critical level of land that reached 3,075 ha. This implies that the magnitude of rainfall and land use change at the catchment area influences the water quality conditions of the lake.

4 Conclusion

Sedimentation and siltation are serious problems at Limboto Lake. Many functions and benefits of Limboto Lake are exploited massively, degrading the water quantity and quality of the lake. A sustainable management is needed in order to protect the functions of the lake.

It was found that land use change at the Alopohu River catchment has significantly influenced the quality and quantity of the lake. In addition, the amount of rainfall has played a role in influencing the level of erosion and sedimentation at the lake. By combining the modeling of discharge runoff, land use change and water quality of the lake, a quantitative understanding of hydrology and water quality conditions could be predicted in future research.

Acknowledgements

This research was supported by a grant (11-TI-C06) from the Advanced Water Management Research Program, which is funded by the Ministry of Land, Infrastructure and Transport of the Korean government. It was also supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2014K2A4A1035053).

References

[1] Balihristi Gorontalo, *Lake Limboto Profile 2009*, Environment Agency, Research and Information Technology – Gorontalo Province, 2009. (Text in Indonesian).

[2] Wetzel, R.G., *Limnology: Lake and River Ecosystems*, Academic Press, San Diego, pp. 985-1006, 2001.

[3] BPDAS-BB, *Technical Planning for Land Rehabilitation and Soil Conservation for Limboto Watershed (Book 1)*, Gorontalo: BPDAS-BB Gorontalo, 2004. (Text in Indonesian).

[4] Japan International Coorperation Agency, *The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia*, Nikken Consultants, Inc and Nippon Koei CO., LTD, 2002.

[5] Subehi, L., Triyanto, Wibowo, H. & Ridwansyah, I., *Analysis of Hydrological Dynamic of Lake Limboto that Related to Fisheries Production*, Proceeding of International Conference of Indonesian Inland Waters III (ISBN 978-602-8380-07-2), Palembang-Indonesia, pp. 37-42, 2012.

[6] Zalewski, M., *Ecohydrology and Fisheries Management,* Italian Journal of Zoology, **65**(1), pp. 501-506, 1998.

[7] Chrismadha, T., Haryani, G.S., Fakhrudin, M. & Hehanussa P.E., *Ecohydrological Application in Lake Management*, Proceeding National Symposium on Ecohydrology, Jakarta, pp. 23-42, 2011.

[8] Numazawa, A., Ichimura, K., Takishita, T., & Ito, H., *Limnological Evaluation of Artificial Development in Littoral Zone of lake Kasumigaura, a Typical Maritime Lagoon Lake in Japan*, Proceedings of Taal 2007: The 12 World Lake Conference, pp. 756-759, 2008.

[9] Latron, J. & Gallart, F., *Runoff Generation Processes in a Small Mediterranean Research Catchment (Vallcebre, Eastern Pyreness)*, Journal of Hydrology, **358**, pp. 206-220, 2008.

[10] Materna, E., *Temperature Interaction; Prepared as Part of EPA Region 10, Temperature Water Quality Criteria, Guidance Development Project*., U.S. Fish and Wildlife Service Environment Protection Agency, (EPA)-910-D-01-004, 2001.

[11] Park B.J., Sung Y.D. & Jung K.S., *A Correlation Analysis of the River Naturalness and Water Quality for Biological Habitat Evaluation*, Journal of Korea Water Resources Association, **39**(8), pp. 637-644, 2006.

[12] American Public Health Association (APHA), *Standard Methods for the Examination of Water and Waste Water*, 21st ed. Amer, Publ. Health Association Inc, New York, pp. 1-1368, 2005.

[13] Krismono, Astuti, L.P. & Sugianti Y., *Water Quality Characteristics at Lake Limboto, Gorontalo*, Jurnal Penelitian Perikanan Indonesia, **15**(1), pp. 59-68, 2009. (Text in Indonesian).

[14] Lewis, S.E., Bainbridge, Z.T., Kuhnert, P.M., Sherman, B.S., Henderson, B., Dougall, C., Cooper, M. & Brodie, J.E., *Calculating Sediment Trapping Efficiencies for Reservoirs in Tropical Settings: A Case study from the Burdekin Falls dam, NE Australia*, Water Resources Research, **49**, pp. 1017-1029, 2013.

[15] Halidah, *Potential of Water and Protected Forest Distribution at Gorontalo Province*, Jurnal Penelitian Hutan dan Konservasi Alam, **5**(1), pp. 43-53, 2008. (Text in Indonesian).

[16] BALITBANGPEDALDA Propinsi Gorontalo, *Regional Environmental Status, Gorontalo Province Year 2005*, Gorontalo: Balitbangpedalda Gorontalo Province, 2006. (Text in Indonesian).

[17] Putra, S.P., Hassan, C., Djudi & Suryatmojom H., *Reservoir Saboworks Solutions in Limboto Lake Sedimentations, Northern Sulawesi, Indonesia*, Procedia Environmental Sciences, **17**, pp. 230-239, 2013.

[18] Lawniczak, A.E., Choinski, A. & Kurzyca, I., *Dynamic of Lake Morphometry and Bathymetry in Various Hydrological Conditions*, Polish Journal of Environmental Studies, **20**(4), pp. 931-940, 2011.

[19] Krismono, *The Relationship between water quality with Chlorophyll-a and its impact on fish populations in Lake Limboto*, Limnotek **17**(2),pp. 171-180, 2010. (Text in Indonesian).

[20] Sittadewi, E.H., *Strategic function of Lake Limboto, ecosystem changes and problems that occured*, Jurnal; Teknik Lingkungan, **9**(1), pp. 59-66, 2008. (Text in Indonesian).
[21] Aisyah, S. & Subehi, L., *Measurement and Evaluation of Water Quality in Order to Support The Management of Fisheries in Lake Limboto*, Proceeding of The National Seminar on Limnology (ISBN 978-979-8163-17-3), Bogor – Indonesia, July 2012, pp. 457-466, 2013. (Text in Indonesian).
[22] BPDAS-BB, *Management of Water Resources in Limboto-Bolango-Bone Basins*, Gorontalo: BPDAS-BB Gorontalo, 2010. (Text in Indonesian).