Impact of land use and socio-economic changes in water catchment area on total suspended solid (TSS) in Lake Toba

A H Harianja1,2, A E Suoth1, E Nazir1, G S Saragih1, R Fauzi1 and M Y Hidayat1

1 Center for Research and Development of Quality and Environmental Laboratory, Gedung 210 PUSPIPTEK Serpong, Banten, Indonesia.
2 e-mail: alfonso_hrj@yahoo.com

Abstract. Changes of socio-economic and land use in the water catchment area are factors that affect the water quality of a lake. This study quantified the impact of socio-economic factors and the dynamics of land covers of Lake Toba water catchment area on the total suspended solid (TSS) parameter, one of the parameters in water quality indicators. Statistical analysis was run by using multiple linear regressions. Parameters observed were TSS, socio-economic related data and land use in Samosir, Tobasa, Simalungun, Humbang Hasundutan and North Tapanuli Regencies in 2008, 2012 and 2016. The results indicated that the water quality of Lake Toba was slightly polluted in 2016 and in 2017. Based on the regression analysis, it was found that some factors significantly affected the concentration of TSS, namely shrubland and dryland farming at 99% confidence level; the number of populations, Location Quotient (LQ) for dry land paddy field and soybean production at 95% confidence level; and settlement land area, geographic population density, LQ for rice and corn production at 90% confidence level. Managing shrubland through a land rehabilitation program and encouraging a rotational cropping system are recommended strategies to manage the increasing TSS in the Lake Toba.

1. Introduction
Lake Toba is a volcanic lake, formed by the eruption of Toba Supervolcano about 70 thousand years ago, in which the process of its formation affected the state of the earth [1–3]. Lake Toba is located at an altitude of 905 m above sea level, 176 km from Medan, the capital of North Sumatra Province. Lake Toba Water Catchment Area (LTWCA) is the upstream of the Asahan River, the outlet of Lake Toba. Administratively, LTWCA is laid within 7 different regencies [4–5], namely North Tapanuli, Toba Samosir, Humbang Hasundutan, Samosir, Simalungun, Karo, and Dairi, covering an area of 275,695,72 ha. The geographical position is 2°21'32"-2°56'28" N and 98°26'35"-99°15'40" E.

The management of LTWCA as one of the national development priorities requires an integrative approach based on its environmental carrying capacity. Being appointed as one of the national tourist destinations in 2016, Lake Toba and the surrounding neighborhoods require a sustainable management
strategy [6–11], by guaranteeing the quantity and quality of water [12–14]. The quantity and quality of the water were lately reported experiencing degradation [5,15].

Previous studies had proven that population growth and land-use changes as the consequence of development were causing degradation of water quality in the river [16–21], lake and reservoir [22–27], coastal and ocean area [28–30]. The activity of the surrounding population can be categorized as domestic activity, agriculture, industry, tourism, and fisheries. Water quality degradation of Lake Toba is also characterized by the decreasing of protected forest areas due to illegal logging activity and tendency of forest conversion to other function (forested area covers 16.2% or about 57,604.8 ha and the area of critical land is 21% of the LTWCA); fishery activities (floating net fisheries in water bodies of the lake that are more than 3,000 units); as well as agricultural activities that use a lot of chemical fertilizer.

Research on the effect of land-use dynamics and socio-economic characteristics of society in LTWCA toward water quality is scanty; in fact, the majority of the populations living nearby the lake utilize the freshwater for their daily needs. This study was designed to evaluate the impact of socio-economic factors and the dynamics of land covers of Lake Toba water catchment area on the TSS parameter, using multiple linear regression. Research findings are expected to provide scientific considerations for local government in formulating LTWCA conservation strategies in order to meet the water quality standard, according to class I water quality standard (based on North Sumatra Governor Regulation Number 1/2009).

2. Methodology

2.1. Location

Sampling method employed is purposive random sampling, based on data availability of land-use, socio-economic characteristics and water quality in the year of analysis (2008, 2012, 2016 and 2017). Fifteen study locations spreading in six regencies around the lake was chosen, they were Onanrunggu, Simanindo, Pangururan, Palipi and Nainggolan in Samosir Regency; Balige, Porsea, Sigao and Ajibata in Tobasa Regency; Parapat, Tigaras and Haranggaol in Simalungun Regency; Silalahi in Dairi Regency, Bakkara in Humbang Hasundutan Regency and Muara in North Tapanuli Regency (figure 1).

2.2. Data Collection and Analysis

2.2.1. Land use dynamics. Data and information on land use on the sub-watershed region were obtained from the land use map issued by Balai Pemantapan Kawasan Hutan (BPKH) Region I, Medan, the Ministry of Environment and Forestry. Land use information was derived from annual Landsat imagery using maximum likelihood supervised classification, where each spectral class described by a distribution probability in a multispectral space [31]. Land-use dynamics then were analyzed by comparing the area of each classified land use in the year of analysis.

The procedure for mapping the land-use change was done as follows:

- Watershed area was delineated based on Minister of Environment and Forestry Regulation No.511/Menhut-V/2011, into sub-watershed and sub-sub-watershed on a topographic map of Indonesia.
- The unit of the map/land in sub-sub-watershed showing land-use similarities was classified as one unit.
- A transect line was created on some sub–sub-watershed where the line crossed most of the map units representing samples for the ground check.
- Each unit of the map then was checked through field survey.
• Land-use change map is done by overlaying the existing land use map on the watershed boundary. The overlay is then interpreted in the year of analysis; they are 2008, 2012 and 2016. We used Geographic Information System/GIS Arc GIS 10 to support this procedure [32]. The land-use parameters in the map were corrected in the field survey [33].

Figure 1. Research Location in LTWCA

2.2.2. Socio-economic Characteristics. Data and information regarding socio-economic characteristics of the population in research location were gathered from the Statistical Bureau (Badan Pusat Statistik), Asahan-Barumun Watershed Management Agency, Agricultural Agency, and Regional Planning and Development Agency. Data include population and growth, regency and district area, sectoral economic growth, production of seasonal crops, and floating net fishery production. The population density was analyzed across the regional economic structures and resulted in population vulnerability on land (table 1) [33].

| No | Population density (person/km²) | Economic Structure | Service |
|----|---------------------------------|--------------------|---------|
| 1  | Low (< 250)                     | 3                  | 2       | 1       |
| 2  | Intermediate (250 – 400)        | 4                  | 3       | 2       |
| 3  | High (> 400)                    | 5                  | 4       | 3       |

The economic base of a sub-sub-watershed was measured using LQ (location quotient) [33], as described in formula 1). In this research, LQ was calculated for seasonal crops production such as
wetland paddy, dry land paddy, corn, peanut, soybean, cassava and sweet potato as the base economy in LTWCA [9, 23, 34].

$$LQ = \frac{q_i}{q_t}$$ \hspace{1cm} \text{.................................................... (1)} \hspace{1cm}

Where: $q_i$ = production of sector i in a selected area (i.e. sub-sub-watershed)
$q_t$ = production of the whole sector in a selected area (i.e. sub-sub-watershed)
$Q_i$ = production of sector i in a bigger area (sub-watershed)
$Q_t$ = production of the whole sector i in a bigger area (sub-watershed)

2.2.3. Water Quality. The water quality parameter was approached using the water pollution index, in which the measured parameters were compared to Class I water quality standards based on the Regulation of the Governor of North Sumatra Number 1/2009. Parameters observed in 2016 include TSS, TDS, pH, BOD5, COD, DO, Total Phosphorus, Nitrate (NO3-N), Nitrite (NO2-N), Total Coliform, Coli Fecal, and detergent-MBAS using formula 2); while for 2017, the water quality status was quoted from an evaluation reported by Asahan-Barumun Watershed Management Agency of Ministry of Environment and Forestry.

$$P_{ij} = \sqrt{\frac{(C_i/L_{ij})^2 + (C_j/L_{ij})^2}{2}}$$ \hspace{1cm} \text{.................................................... (2)} \hspace{1cm}

Where: $C_i$ = parameter concentration of water quality of i
$L_{ij}$ = parameter concentration of water quality of i which is listed on the quality standard of j
$(C_i/L_{ij}) M$ = maximum value of $C_i/L_{ij}$
$(C_i/L_{ij}) R$ = average value of $C_i/L_{ij}$

The criteria of $P_{ij}$ are:
1). Meet the water quality standards or good, if $0 \leq P_{ij} \leq 1.0$
2). Lightly polluted, if $1.0 \leq P_{ij} \leq 5.0$
3). Moderately polluted, if $5.00 \leq P_{ij} \leq 10.0$
4). Heavily polluted, if $P_{ij} > 10.0$

2.2.4. Effect of Land Use and Socio-economic Changes on TSS. Effect of land use and socio-economic changes on the water quality were measured using regression analysis. In the case of statistically significant parameter, then the following analysis using TSS parameter, adopting previous studies [35–37]. Data of TSS in 2008, 2012 and 2016 were gathered from the Regional Environmental Management Agency of North Sumatra Province. Important factors that can affect concentration of TSS ($Y_i$) were land use for water ($X_{i1}$), shrub ($X_{i2}$), secondary forest ($X_{i3}$), plantation forest ($X_{i4}$), bare land ($X_{i5}$), settlement ($X_{i6}$), dryland agriculture ($X_{i7}$), dryland agriculture mixed with shrub ($X_{i8}$), swamp ($X_{i9}$), wetland paddy ($X_{i10}$), dry land paddy ($X_{i11}$); population ($X_{i12}$), population density ($X_{i13}$), population vulnerability on land ($X_{i14}$); floating net fishery production ($X_{i15}$); LQ of wetland paddy ($X_{i16}$), LQ of dry land paddy ($X_{i17}$), LQ of corn ($X_{i18}$), LQ of soybean ($X_{i19}$), LQ of peanut ($X_{i20}$), LQ of cassava ($X_{i21}$) and LQ of sweet potato ($X_{i22}$). The model formulated as follows:

$$Y_i = \alpha_0 + \alpha_1 X_{i1} + \alpha_2 X_{i2} + \ldots + \alpha_k X_{ik} + \varepsilon_i$$ \hspace{1cm} \text{.................................................... (3)} \hspace{1cm}
Where Y represents the dependent variable, X₁, X₂, Xₖ are the independent variables, α₀ is the intercept term, α₁ and α₂ are the partial regression coefficients, ε is the stochastic disturbance term, i is the iᵗʰ observation.

3. Results and Discussion

3.1. General Overview of LTWCA

Lake Toba Water Catchment Area covers 275,695.72 ha (figure 2). Based on administrative management, the largest area is in Samosir Regency (40.36%), followed by Tobasa Regency (25.74%) and Simalungun (7.73%). The rest spreads in Humbang Hasundutan, Dairi, North Tapanuli, and Karo Regencies.

![Figure 2. Land Use Distribution in LTWCA](image)

Asahan-Barumun Watershed Management Agency reported that there were 19 rivers located in LTWCA, namely 1) Sigumbang, 2) Bah Bolon, 3) Guluan, 4) Arun, 5) Tomok, 6) Sibandang, 7) Halian, 8) Simare, 9) Aek Bolon, 10) Mongu, 11) Mandosi, 12) Gopgopan, 13) Kijang, 14) Sinabung, 15) Ringo, 16) Prembakan, 17) Sipultakhuda, 18) Silang and 19) Bah Tongguran. The result of spatial analysis of LTWCA indicated that the largest utilization of that area was for dryland agriculture (48%), followed by secondary forest (12.36%) and plantation forest (11.50%) (table 2).
Table 2. Distribution of Land Utilization in LTWCA

| No | Land Type                          | Area (ha) | Percentage (%) |
|----|------------------------------------|-----------|----------------|
| 1  | Water (shore)                      | 5,083.89  | 1.84           |
| 2  | Shrub                              | 24,313.92 | 8.82           |
| 3  | Secondary forest                   | 34,089.17 | 12.36          |
| 4  | Plantation forest                  | 31,712.85 | 11.50          |
| 5  | Bare land                          | 23,645.04 | 8.58           |
| 6  | Settlement                         | 982.75    | 0.36           |
| 7  | Dryland agriculture                | 13,347.62 | 48.37          |
| 8  | Dryland agriculture mixed with shrub| 1,435.28  | 0.52           |
| 9  | Swamp                              | 1,368.00  | 0.50           |
| 10 | Wetland paddy                      | 19,717.21 | 7.15           |
|    | Total                              | 275,695.72| 100            |

Source: Calculated from Balai Pemantapan Kawasan Hutan Region I Medan [38].

All regencies around Lake Toba share the water area, and the water is utilized for various purposes such as drinking water, agricultural irrigation and jetty (figure 3). The regency that has the largest water body is Samosir. Forested land can be categorized as secondary forest and forest plantations (12.36% and 11.50% of the total area of LTWCA, respectively). In some regions, the shrub area was found, which is part of the converted secondary forest and is not utilized by the community so far. In addition, bare land was discovered to be as much as 8.58% of LTWCA, and this was the result of high urbanization phenomenon, where the productive labor moves to other cities.

Figure 3. Land utilization: (a) Water bodies (b) Secondary forest (c) Shrub (d) Settlement (e) Dry land agriculture (f) Floating net fishery

The smallest part of land-use in LTWCA is for settlement (982.75 ha or 0.36% of LTWCA). The settlements scattered around the roads or on the shores of the lake. Based on the data reported by Asahan-Barumun Watershed Management Agency, 2017, 80% of the population living on the shores
of Lake Toba utilizing the lake’s water to meet their domestic needs; but according to [15], water quality has degraded because of pollution. In addition, the population also utilizes the lake for transportation and other economic activities [39] such as for traditional market, tourism activities [6],[40] and floating net fishery [14, 41].

3.2. Water Quality
Economic development and biophysical factors profoundly affect water quality [19]. Due to its historical formation from a volcanic process, the water quality of Lake Toba is influenced by the hydrothermal process at the bottom of the lake [2], as well as the anthropological factors. The latest status of Lake Toba water quality is presented in table 3 below.

| No | Sampling Point | Stage 1 | Status | Stage 2 | Status | Stage 3 | Status |
|----|----------------|---------|--------|---------|--------|---------|--------|
| I  | Pangururan     | 3.12    | lightly polluted | 1.82 | lightly polluted | 3.17 | lightly polluted |
| 2  | Silalahi       | 3.56    | lightly polluted | 4.32 | lightly polluted | 4.24 | lightly polluted |
| 3  | Tongging       | 3.37    | lightly polluted | 4.39 | lightly polluted | 4.77 | lightly polluted |
| 4  | Haranggaol     | 2.20    | lightly polluted | 4.34 | lightly polluted | 4.35 | lightly polluted |
| 5  | Tao Silalahi   | 2.31    | lightly polluted | 4.33 | lightly polluted | 8.76 | moderately polluted |
| II | Simaindoro     | 2.82    | lightly polluted | 1.81 | lightly polluted |       |         |
| 2  | Salbe          | 1.38    | lightly polluted | 3.71 | lightly polluted |       |         |
| 3  | Ambarita       | 2.76    | lightly polluted | 1.19 | lightly polluted |       |         |
| 4  | Silimalombu    | 2.49    | lightly polluted | 1.12 | lightly polluted |       |         |
| 5  | Tigaras        | 2.62    | lightly polluted | 3.61 | lightly polluted |       |         |
| 6  | Balige         | 2.52    | lightly polluted | 4.34 | lightly polluted |       |         |
| 7  | Lintong        | 2.75    | lightly polluted | 4.63 | lightly polluted |       |         |
| 8  | Sigaol         | 1.16    | lightly polluted | 1.34 | lightly polluted |       |         |
| 9  | Onanrunngu     | 1.32    | lightly polluted | 4.09 | lightly polluted |       |         |
| 10 | Nainggolan     | 3.05    | lightly polluted | 3.37 | lightly polluted |       |         |

Based on the WPI of Lake Toba that is presented in table 3, the pollution index is ranging from 1.16 to 8.76, indicating that the water quality status is lightly and moderately polluted. In 2016, water quality at almost all locations is lightly polluted; whereas only Tao Silalahi sampling point has a moderately polluted status. In 2017, all sampling point has lightly polluted status. This condition was also in agreement with research in Onanrunngu District [43]. The water quality was analyzed using Storet method and categorized in class C (moderately polluted).

Some other studies also reported the decline in the water quality of Lake Toba. This is because Lake Toba was functioned as the final place for the various waste such as agricultural activities in the surrounding area, household waste from settlements and hotels, waste from the fish feed and water transport [15, 40]. As a tourist destination, this area is still lacking environmental hygiene facilities [6] and waste management facilities [10]. Natural and human factors are the main driving force for lake deterioration [5]. This research also highlighted that Lake Toba is very susceptible to human activities because of the very small ratio of total catchment area to the lake surface area (1:3) and the leakage of untreated sewage from domestic waste and agriculture. Excessive nutrients (containing nitrogen and phosphorus) also contributed to water quality [4] influencing eutrophication occurrence.

* Source: Data obtained from Environmental Agency of North Sumatra Province, WPI was calculated.
** Source: WPI was calculated by Asahan-Barumun Watershed Management Agency [42].
3.3. Effect of Land Use and Socio-economic Change on Water Quality

Important variables affecting TSS are land use and socio-economic characteristics which are formulated based on previous research findings [28, 41]. Land utilization area is calculated by using the spatial analysis, which then was categorized into water, shrub, secondary forest, plantation forest, bare land, settlement, dryland agriculture, dryland agriculture mixed with shrub, swamp, and wetland paddy. Socio-economic parameters include a number of populations, population density and population vulnerability on land. To describe the economic activity of the region, LQ value of the basic factors are dryland agriculture, dryland agriculture mixed with shrub, swamp, and wetland paddy. The lack of dominant seasonal crops is used, namely wetland and dry land paddy, corn, soybean, peanut, cassava, and sweet potato.

In this analysis, we use the concentration of TSS representing water quality. TSS is organic and inorganic materials solids suspended in the water that can be filtered by 0.45 µm millipore paper. Suspended material has an adverse impact on water quality because it reduces the penetration of sunlight into the lower part of water bodies which resulting in the increase of the water turbidity leading to disruption of the producer organism’s growth. Previous studies stated that concentration of TSS is an important parameter in water quality indicator [27–29], [42].

Analysis of land-use change and socio-economic factors on TSS was done by multiple linear regressions using the panel data to obtain the best model. The regression analysis showed that the R² value of the model is 63.82%, and it can be interpreted that the influence of the independent variable on the concentration of TSS can be predicted by the model as high as 63.82% and this probability is significant at the 95% confidence level. In this model, there are several variables that influence the concentration of TSS significantly, i.e. at a confidence level of 99%, 95%, and 90%. The variables that significantly affect the concentrations of TSS at a confidence level of 99% are the area of shrubland and dryland farming. The variables that influence TSS at the 95% confidence level are the number of populations, LQ of dry land paddy and LQ of soybean farming. Meanwhile, the variables that affect the TSS at a confidence level of 90% are the land-use area for settlements, population density, LQ of wetland paddy and LQ of corn farming (The results of the analysis are shown in table 4).

Land-use factors are the most significant factor affecting TSS, in this case, the shrubland and dryland farming areas. The coefficient of the shrubland and dryland farming area is 0.0055 and 0.001 respectively. The correlation is positive, which implies that the increase of shrub and the dry land farming area will result in increased concentrations of TSS, hence degrade the quality of the water. According to [45], TSS may be increased suddenly if the land cover of a sub-watershed decreased by up to 30% and agricultural land use increased to more than 50%. Land-use in LTWCA is predominantly for agricultural crops, therefore it is understandable if a significant amount of sedimentation concentration is increasing in the river and lake.

Three variables that are part of the socio-economic factors have a significant effect on TSS at 95% confidence level are number populations, LQ of dry land paddy and LQ of soybean farming, with coefficient value of -0.0003; 6.31; and -317.18 respectively. It is of interest to note that the number of populations correlates negatively on the TSS, which means that the decrease in the number of populations in years of research actually increases the concentration of TSS. The speculation regarding this phenomenon may be related to the increase of abandoned land in the area. The data showed that there are a decreasing number of populations in some areas in the LTWCA from 2008 to 2012. This decrease is mainly caused by urbanization, which is commonly found in LTWCA. Due to the lack of productive human resources, many lands being unutilized, which then turned into bushes or bare land.

The influence of LQ of dry land paddy and soybean farming on TSS is also significant. LQ is defined as the basic economic activities of the region, where the higher the value, the higher the
production value of these commodities in the region and in the group of sub-sectors studied. The LQ coefficient of dry land paddy farming is positive, which means that the larger the area of dry land paddy farming, the higher the concentration of TSS. While the coefficient of LQ soybean is negative, meaning that the increase of soybean farming area caused decreasing in TSS. Soybean farming also functions as a cover crop that can reduce the level of soil erosion.

Table 4. The result of Regression Analysis of Estimated Factors Influencing TSS

| Symbol | Variable                                             | Coefficient | Standard Error | P>|z|  | Sig.  |
|--------|------------------------------------------------------|-------------|----------------|-----|------|
| X_1    | Area of water                                       | -0.016966   | 0.024536       | 0.489| ***  |
| X_2    | Area of shrub                                       | 0.005505    | 0.001980       | 0.005| ***  |
| X_3    | Area of secondary forest                            | 0.000879    | 0.001081       | 0.416|      |
| X_4    | Area of plantation forest                           | -0.000642   | 0.001183       | 0.588|      |
| X_5    | Area of bare land                                   | -0.000316   | 0.000718       | 0.660|      |
| X_6    | Area of settlement                                  | -0.001113   | 0.000606       | 0.066| *    |
| X_7    | Area of dry land agriculture                         | 0.001072    | 0.000366       | 0.003| ***  |
| X_8    | Area of dry land agriculture mixed with shrub       | -0.005655   | 0.012449       | 0.650|      |
| X_9    | Area of swamp                                        | -0.007348   | 0.019141       | 0.701|      |
| X_10   | Area of wetland paddy farming                       | -0.002580   | 0.001837       | 0.160|      |
| X_11   | Area of dry land paddy farming                      | -0.000217   | 0.000340       | 0.524|      |
| X_12   | Number of populations                               | -0.00278    | 0.000114       | 0.015| **   |
| X_13   | Population density                                  | 0.045012    | 0.026726       | 0.092| *    |
| X_14   | Population vulnerability on land                    | -2.044593   | 3.361361       | 0.543|      |
| X_15   | Floating net fishery production                     | -0.000129   | 0.000117       | 0.269|      |
| X_16   | LQ of wetland paddy farming                         | 0.159501    | 0.092059       | 0.083| *    |
| X_17   | LQ of dry land paddy farming                        | 6.318150    | 2.570013       | 0.014| **   |
| X_18   | LQ of corn farming                                  | 0.000578    | 0.000343       | 0.092| *    |
| X_19   | LQ of soybean farming                               | -317.1835   | 128.2860       | 0.013| **   |
| X_20   | LQ of peanut farming                                | 1.507992    | 15.150780      | 0.921|      |
| X_21   | LQ of cassava farming                               | 0.004634    | 0.009726       | 0.634|      |
| X_22   | LQ of sweet potato farming                          | -0.395609   | 0.402446       | 0.326|      |
| α_0    | Constanta                                           | 3.449727    | 8.614890       | 0.689|      |

Model Data Panel (Random-effects GLS regression)
R-Square (Overall) | 0.638200
Prob > chi^2         | 0.0149**
Group variable: Daerah Number of obs | 45
Time variable: Tahun Number of groups | 15

Remarks:
- = significant at α 10%
** = significant at α 5 %
*** = significant at α 1 %

Source: Secondary data, obtained from Balai Pemantapan Kawasan Hutan (BPKH) Region I, Medan, Statistical Bureau of related regencies and Environmental Management Agency of North Sumatra Province.

At a confidence level of 90%, variables that affect TSS significantly are the land area of settlements, population density, LQ of wetland paddy and LQ of corn farming with coefficient value of -0.001113; 0.045012; 0.159501 and 0.000578. The settlement area has a negative effect, which means the decreasing of settlement areas tend to impact the increasing of TSS. Settlement area that is abandoned then became bare land or shrubland, so that increasing the runoff rate which was
contributed to high erosion trends around the lake [21], [26]. Population density, LQ of wetland paddy farming and LQ of corn farming have a positive effect. Population density related to land utilization. The higher the population number will need more land for economics purposes hence decrease water quality or in this case, increase the TSS parameter [19]. Similarly, increasing the area or production of wetland paddy farming or corn farming will increase TSS. The results of [5] stated that the rivers in Sumatra mainland mix with wastewater from wetland paddy farming, which flows into Lake Toba and finally increases the concentration of TSS.

4. Conclusion
The water quality of Lake Toba in the year of 2016 and 2017 was lightly polluted. The variables that significantly affect the concentration of TSS at a 99% confidence level are variable of shrubland and dryland farming areas. The variables that significantly influence at 95% confidence level are variable of the number of populations, LQ of dry land paddy farming and LQ of soybean farming. Meanwhile, the variables that affect TSS significantly at a confidence level of 90% area are the area of settlements, population density, LQ of wetland paddy farming and LQ of corn farming.

Based on the findings of this study, it can be concluded that conservation is needed to minimize the increasing TSS, by controlling the increasing area of shrubland. First, land rehabilitation is needed, especially for critical and bare land areas. Second, the farmers have to be encouraged to apply a rotational crop production system to avoid the tendency of increasing corn and rice production in LTWCA. The rotation required for the seasonal crops which serve as a cover crop to reduce land erosion in LTWCA. Third, the public has to be educated about the importance of waste and wastewater management so they will not dispose of waste directly to Lake Toba. The last, construction of communal wastewater treatment facilities, hence the concentrations of the pollutants in household wastewater are reduced.

References

[1] Stankiewicz JT, Ryberg C, Haberland N, Fauzi and D Natawidjaja, 2010 Geophys. Res. Lett. 37 3–7.
[2] Saepuloh A and C Fitrianingtyas, 2016 in AIP Conference Proceedings, 2016, 1730, 12.
[3] Situmeang R, 2016 MATEC Web Conf 70 5.
[4] Sunaryani AE, Harsono HA, Rustini and S Nomosatryo, 2018 IOP Conf. Ser. Earth Environ. Sci. 118 7.
[5] Sidauruk PB, Pratikno and ER Pujjiindyati, 2018 Atom Indoens. 44 1–7.
[6] Ginting N and A Sasmita, 2018 IOP Conf. Ser. Earth. Environ. Sci. 126 10.
[7] Pasaribu BM, Suastika, and S Yuliani, 2018 ARSITEKTURA 16 275–282.
[8] Pujiono MB, Agustono and F Aulia, 2018 Int. J. Arts. Humanit. Soc. Sci. 3 1–5.
[9] Razali, Z Nasution and Rahmatay, 2014 Int. J. Sci. Technol. Res. 3 1–6.
[10] Sianturi N M et al., 2018 Int. J. Eng. Technol. 7 337–343.
[11] Sihotang HM, YJ Purwanto, W Widiatmaka and S Basuni, 2012 J. Pengelolaan Sumber. Alam Dan Lingkungan. 2 65–72.
[12] Wesi, 2017 Int. J. Eng. Technol. 9 3945–3953.
[13] Wasis B and Izudin, 2012 Media Konserv. 17 125–130.
[14] Rustini H, AE Harsono and I Ridwansyah, 2018 IOP Conf. Ser. Earth Environ. Sci. 118 6.
[15] Indirawati S and A Muntaha, 2018 IOP Conf.Ser. Earth Environ. Sci. 205 9.
[16] Asyhar AH and B Widodo, 2012 IJTEK J. Technol. Sci. 23 87–91.
[17] Mueller JST, B Grabowski, SK Brewer and T A Worthington, 2017 J.Fish Wildl. Manag. 8
Wang CW, Li S, Chen D, Li D, Wang and J Liu, 2018 Sci. Total Environ. 618 1125–1138.

Permatasari P, AY Setiawan, RN Khairiah and H Effendi, 2017 J. Phys. Conf. Ser. 547 7.

Ujianti RM, DS Anggoro, AN Bambang and F Purwanti, 2018 J. Phys. Conf. Ser. 1025 8.

Rodríguez-Romero AJ, AE Rico-Sánchez, E Mendoza-Martínez A, Gómez-Ruiz JE, Sedeño-Diazand, E López-López, 2018 Water (Switzerland) 10 16.

Razak A, 2018 IOP Conf. Ser. Mater. Sci. Eng. 335 6.

Sunaryani A et al., 2018 IOP Conf. Ser. Earth Environ. Sci. 126 52–58.

Sonneveld BF, Thoto D, Houessou and L van Wesenbeeck, 2019 Int. J. Commons. 13 1–28.

Antomi YD, M Hartono, M Suparmoko and R H Koestoer, 2016 OIDA Int. J. Sustain. Dev. 9 51–62.

Bogdá AA, Walęga T, Kowalik and A Cupak, 2019 Water 11 23.

Khairul A, Kamarudin M et al., 2018 Int. J. Eng. Technol. 7 67–74.

Parwati E and A D Purwanto, 2017 Int.J. Remote Sens. Earth Sci. 14 61–70.

Samawi M, FS Werorilangi, and M B Selamat, 2019 IOP Conf. Ser. Earth Environ. Sci. 253 7.

Wang CS, Chen D, Li D, Wang W Liu and J Yang, 2017 Geosci. Model Dev. 10 4347–4365.

Toban E, WN Sunarta and NIM Trigunasih, E-Jurnal Agroekoteknologi Trop. (Journal Trop Agroecotechnology) 394–404.

Nugroho J, TZ Zylshal and D Kushardono, 2018 Int. J. Remote Sens. Earth Sci. 15 71–80.

Paimin S, Sidik Cepat Degredasi Sub Drh Aliran Sungai (DAS) Bogor Putlitbang Hutan Dan Konser Alun.

Wiyayanto N, 2014 Biodiversitas, J. Biol. Divers. 12 52–58.

Bahaya BM, Al-Quraishiand, C Gruden, 2019 Environ. Prog. Sustain. Energy. 8.

Dhannahisvara A, JH Harjo, P Wicaksono, and FS Nugroho, 2019 Geoplanning J. Geomatics Plan 5 177–188.

Guimaraes T T et al., 2019 Sustainability 11 13.

Balai Pemantapan Kawasan Hutan Region I Medan, 2017 Medan.

Sihaloho HP, H Saragi and R Simbolon, 2018 IOP Conf. Ser. Earth Environ. Sci. 205 9.

Hamdani, Harahap R and H Humaizi, 2018 IOP Conf. Ser. Earth. Environ. Sci. 126 8.

Wijopriono WK, Purnomo E, S Kartamihardja and Z Fahmi, 2017 Indones. Fish Res. J. 16 7.

Balai Pengelolaan Daerah Aliran Sungai dan Hutan Lindung (BPDAS-HL) Asahan Barumun, 2017 Medan.

Harianja DM, RS Damanik and R Restu, 2018 J. Geogr. 10 176–183.

Ukpaka CP and O Thankgod, 2016 AEIJST 4 10.

Setyowati RDN, 2016 J. Ilmu-Ilmu Tek. 12 7–15.