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THE DECLINE NORMAL WATER LEVEL OF LAKE TOBA FOR INTEGRATED REGIONAL WATER MANAGEMENT NORTH SUMATERA

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ABSTRACT

The needs of raw water in Medan increases every year in line with the population growth, whereas the quality of hygienic water in the river is insufficient. Therefore, it needs another alternative source to meet the standard quality with low cost. One of the potential sources is Lake Toba. To meet the needs until 2032, North Sumatera Provincial Government intends to use Lake Toba, but it is feared that the decline of normal water level will disrupt the cruise ship, especially when anchored at the port. The Government plans a water supply system in Integrated Water Management (IWRM) to be used collectively to be efficient in construction and operation. This study aims to determine the effect of the use of Lake Toba as a regional water supply and impact on normal water levels. In this paper, the normal water levels were analyzed by inflow and outflow, not based on elevations above sea level. The method of analysis is water balance analysis done in two parts, analysis of water debit requirement (output) and analysis of water supply (input) in hydrological analysis. Comparison of the water balance is a consideration for conclusions. The results showed that the required debit was 82.37 m^3/sec. (output discharge) while the supply of rainfall as reliable discharge was 121.79 m^3/sec. In addition, the supply of rivers around Lake Toba contributed 87.3 m^3/sec, resulting in total discharge to 209.09 m^3/sec. It can be illustrated that the output discharge is less than the input discharge, so it can be concluded that Lake Toba can be used as a source of raw water and does not affect the normal water level.

Keywords: hydrological analysis, normal water level, regional water supply system.

INTRODUCTION

The need for raw water of North Sumatera increases every year, especially in Medan, while the condition of raw water supply is getting worse due to pollution in the river. The problems faced by Medan today are that the field that keeps the water demand increases along with the increase of population, the result has not been able to meet the water needs of the community both in quantity and quality, the impact of regional development is the provision of the community's raw water needs (Aspan *et al*., 2015)

The Government of North Sumatra intends to apply Integrated Water Management (IRWM) to serve Medan City, Tebing Tinggi City, Pematang Siantar City, Simalungun Regency, Deli Serdang Regency and Serdang Bedagai Regency, but for Simalungun Regency, Deli Serdang and Serdang Bedagai Districts do not serve All areas cover only sub-districts which are only bypassed by pipelines. (Department of Spatial Planning and Settlement of North Sumatra Province, 2012)

The government needs another alternative source that meets the quality standard of water and can be produced at low cost. One of the potential sources is Lake Toba which is located very far from the city of Medan about 175 km. To meet the needs until 2032, the North Sumatera Provincial Government intends to use Lake Toba, but it is feared that the decline of water level will disrupt the cruise ship, especially when anchored at the port, because from 1984 to 1987 there was a drastic drop in water levels in Lake Toba that use water for power generation was released from the lake at a higher rate than net inflows into the lake (Acreman et al., 1993). In addition, Lake Toba is far from the city of Medan, the estimated cost of infrastructure will be expensive.

In 2014, the population in Medan was 2,191,140 people, in Tebing Tinggi 154,804 people, Pematang Siantar 245,104 people, Simalungun 844,033 people, Deli Serdang 1,984,598 and Serdang Bedagai 606,367 people. By 2015, the population in Medan increased to 2,210,624 people, Tebing Tinggi 156,815 people, Pematang Siantar 247,411 people, Simalungun 849,405 people, Deli Serdang 2,029,308 and Serdang Bedagai 608,691 people (BPS Provinsi Sumatera Utara, 2016).

The Government plans a water supply system in Integrated Water Management (IWRM) to be used collectively to be efficient in construction and operation. Integrated Area Water Management will serve the area along the pipe crossings. The service area is divided into two channels, namely, Medan-Deli Serdang channel 1 and Tebing Tinggi-Pematang Siantar- Simalungun-Serdang-Bedagai channel 2.

This study aims to determine the effect of the use of Lake Toba as a regional water supply and impact on normal water levels. In this study, normal water levels were analyzed by inflow and outflow, not based on elevations above sea level. If the outflow is greater than the release of the inlow, it will decline the normal water level.

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METHODOLOGY

The research method used in this research was water balance analysis done in two parts that is analysis of demand of water (output) and analysis of water supply (input) through hydrological analysis. Comparison of water balance was a consideration for conclusion.

The analysis of discharge water demand (output)

The analysis of water demand (output) is based on a number of populations forcasting up to 2032. Population forcasting used geometric method (Directorate General of Human Settlements, 2007):

$$P_n = P_o(1+r)^n \quad (1)$$

Where "Pn" is the total of population in the year to "n", while "Po" is the number of the base year population and "r" is the average population growth and also "n" is the number of years.

The water need is determined based on the population, the level of service and the standard of water use which consists of three categories: domestic demand, non-domestic needs, and water loss. Population growth and population existing are shown in Table-1.

Table-1. Population growth and population existing.

District	2014	2015	Population growth (%)
Medan	2,191,140	2,210,624	0.009
Tebing Tinggi	154,804	156,815	0.013
Pematang Siantar	245,104	247,411	0.009
Simalungun	844,033	849,405	0.006
Deli Serdang	1,984,598	2,029,308	0.023
Serdang Bedagai	606,367	608,691	0.004

Domestic water needs uses Connection House (CH) and Public Hydrant (PH) ratio 80:20, and this will increase to 90:10 where 1 CH serves 5 people and 1 PH serves 100 people. Table-2 shows the average needs of household drinking water.

Table-2. The average of household water consumption.

Region	Total population	Water consumption (Liters/people/day)
City	>1.000.000	240
Metropolitan	500.000 - 1.000.000	190
Big City	100.000 - 500.000	150
Medium city	10.000 - 100.000	110
Town Village	3.000 - 10.000	90

Non-domestic needs, urban survey categories I, II, and III were determined by municipalities related to city master plans. For cities, category IV non-households required 20% of household needs, while the category of city V was 10% of household needs. Based on the criteria of integrated water supply system planning, the losses due to the piping system were 20%, in accordance with the provisions of drinking water standards and services for a maximum daily factor of 1.15 and a maximum hours factor of 1.75 based on estimates water needs was tailored to the treatment system and the level planned service level (Directorate General of Human Settlements, 2007).

The analysis of water supply (input) through the hydrological analysis

Water availability is determined by Hydrological Analysis using rainfall data in watersheds and lake discharge to river. The rainfall data used in the hydrological analysis is the monthly rainfall area Situnggaling, Sitinjo (Dairi around), Tanjung Gorbus, Pangururan (around Samosir), Dolok Bun, Laguboti (Toba Samosir around) and Lumban Julu around. The rainfall data used in this research is 15 years from 1993 to 2007.

Analysis of rainfall data can be done by various methods, such as the Average Algebra Method, Isohyet Method, and Thiessen Method (Sosrodarsono and Takeda, 1997). In this paper the maximum daily rainfall data is approached with the Average Algebra Method using the equation:

$$R = \frac{1}{n}(R_1 + R_2 + ...+ R_n) \quad (2)$$

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Where “R” is the rainfall area, “n” is the number of points or the observation post and “R_1, R_2, ... R_n “ is rainfall at each point of observation.

The rainfall data test

Average rainfall is based on rainfall data of 4 stations and for this analysis the minimum water needs is calculated. If rainfall has been met, the minimum water needs is met. Rainfall data for each data consistency is tested by Rescaled Adjusted Partial Sum (RAPS) method. Test data consistency with cumulative deviation test (Buishand, 1982). For test data is determined as follows:

$$S_K* = \sum_{i=1}^{k}(Y_i - \overline{Y}) \quad (3)$$

$$D_y{}^2 = \frac{(S_K*)^2}{n} \quad (4)$$

$$D_y = \frac{\sum D_y{}^2}{n} \quad (5)$$

$$S_K** = \frac{S_K*}{D_y} \quad (6)$$

Statistical value Q and R are:

$$Q = Maks\left|S_K**\right| \; untuk \; 0 \le k \le n \quad (7)$$

$$R = Maks\left|S_K**\right| - Min\left|S_K**\right| \quad (8)$$

Based on the above statistical values can be determined the value of $Q/n^{(0.5)}$ and $R/n^{(0.5)}$, the results are compared with the value of $Q/n^{(0.5)}$ and $R/N^{(0.5)}$ required (value Table-3). The value is smaller than the consistent data.

Table-3. Table Values for $Q/n^{(0,5)}$ and $R/n^{(0,5)}$.

n	$Q/n^{0,5}$			$R/n^{0,5}$		
	90%	95%	99%	90%	95%	99%
10	1,05	1,14	1,29	1,21	1,28	1,38
20	1,10	1,22	1,42	1,34	1,43	1,60
30	1,12	1,24	1,48	1,40	1,50	1,70
40	1,14	1,27	1,52	1,44	1,55	1,78
100	1,17	1,29	1,55	1,50	1,62	1,85
200	1,22	1,36	1,63	1,62	1,75	2,00

The determination of the goodness of fit test of the frequency distribution of the sample data from the probability distribution function is expected to reflect the frequency distribution of the required test parameters. For measurement, parameters can be performed by Chi-square test or Kolmogorov-Smirnov test (Massey Jr, 2005). This research used Kolmogorov-Smirnov test which is often called non parametric test because the test did not use specific distribution function. Of these two opportunity scores determined the largest difference between observational possibilities and theoretical opportunities:

$$D = maksimum\left[P(Q_{maks}) - P'(Q_{maks})\right] \quad (9)$$

From Table-4, the critical value of Kolmogorov-Smirnov is determined "Perform". If the "Dmax" is smaller than the "Do" distribution to determine which is acceptable, if the value "Dmax" is greater than "Perform", the distribution is unacceptable.

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Table-4. Critical value “Do” of Kolmogorov-Smirnov test.

N	α			
	0,20	**0,10**	**0,05**	**0,01**
5	0,45	0,51	0,56	0,67
10	0,32	0,37	0,41	0,49
15	0,27	0,30	0,34	0,40
20	0,23	0,26	0,29	0,36
25	0,21	0,24	0,27	0,32
30	0,19	0,22	0,24	0,29
35	0,18	0,20	0,23	0,27
40	0,17	0,19	0,21	0,25
45	0,16	0,18	0,20	0,24
50	0,15	0,17	0,19	0,23
n>50	$1,07/n^{0,5}$	$1,22/n^{0,5}$	$1,36/n^{0,5}$	$1,63/n^{0,5}$

Dependable flow

Dependable discharge can be calculated based on dependable rainfall (effective rainfall). Dependable flow is the minimum flow for probability of meeting with probability 80% (Chow *et al.*, 1988).

Rainfall data are sorted from largest to smallest and then given a number as "m". The probability is calculated by the formula P=m/(1+n) where "n" is the number of data. Values have seen an 80% probability of the sequence number 'm". If the value is not exactly 80% probability is the number "m" then do interpolation to get an 80% probability

Water availability

Water availability determined based on rainfall data is then calculated as the rainfall intensity. The calculation of the rainfall intensity with Mononobe equation (Wesli, 2008) as follows:

$$I_T = \frac{R_{24T}}{24}\left(\frac{24}{T_c}\right)^{2/3} \quad (10)$$

Time-concentration (Tc) by Kirpich:

$$T_c = 0.00013\frac{L^{0.77}}{S^{0.385}} \quad (11)$$

Where "I" is rainfall intensity (mm/hours), “R_{24}“is maximum rainfall in 24 hours (mm) and “Tc” is the duration of rainfall.

Runoff coefficient is the ratio of the rainfall as runoff. The coefficient of runoff ranges from 0 to 1 and depending on the soil type, vegetation type, characteristics of land use and construction surfaces such as paved roads, roofs of buildings and others that cause rain could not directly onto the surface of the ground so it cannot infiltrate and will produce nearly 100% runoff *(Chow et al.*, 1988):

Runoff coefficient regions:

$$C_{kawasan} = \frac{(C_i * A_i) + (C_{i+1} * A_{i+1}) + ... + C_{i+n} * A_{i+n})}{A_{kawasan}} \quad (12)$$

The discharge calculated by rational methods (Chow *et al.*, 1988):

$$Q = 0,278.C.I.A \quad (13)$$

Where ”Q” is discharged (m^3/sec), ”C” is Runoff coefficient, ”I” is rainfall intensity (mm/hours) and “A“ is Catchment area (km^2).

Land use in the catchment area of Lake Toba is required to determine the runoff coefficient. Land use is shown in Table-5.

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Table-5. Land use the Lake Toba.

Land	Land area (Ai)	%	Land	Land area (Ai)	%
Brushwood	390.6	10.46	Open land	21.27	0.57
Lake	1,126.97	30.17	Housing residents	31.64	0.85
Forest	765.06	20.48	Grass	289.60	7.75
Field	266.89	7.15	Grass grove	39.26	1.05
Thicket fields	477.84	12.79	Paddy Field	188.03	5.03
Meadow	137.42	3.68	River	0.20	0.01

Input discharge will be compared with the output discharge that would be a consideration in for research conclusions.

RESULTS

The forecasting of district residents in North Sumatra was determined based on the total number that exists with population growth with equation (1). The results of district water needs of each region and its development are shown in Table-6.

Table-6. The district water needs forecasts and the discharge of each region.

Region	Water needs (liters/day)		Development needs (liters/day)	Discharge need (m^3/sec)
	2015	2032		
Medan	530,549,760	616,718,439	86,168,679	23.94
Tebing Tinggi	23,522,250	29,293,487	5,771,237	1.6
Pematang Siantar	37,111,650	43,518,765	6,407,115	1.78
Simalungun	127,410,750	141,921,318	14,510,568	4.03
Deli Serdang	385,568,520	563,097,600	177,529,080	49.31
Serdang Bedagai	91,303,650	97,438,507	6,134,857	1.7
Total	1,195,468,595	1,491,990,148	296,521,536	82.37

Integrated Regional Water Management (IWRM) was planned in two systems, namely system 1 (Medan-Deli Serdang) with discharge 11.874.594 liter / second and system 2 (Simalungun-Tebing Tinggi-Pematang Siantar-Serdang Bedagai) with discharge 2,254,642 liter/second, as shown in Table-7.

Table-7. Water development needs System 1 and System 2.

System	Region	Discharge need (m^3/sec)	Total
1	Medan	23.94	73.25
	Deli Serdang	49.31	
2	Tebing Tinggi	1.60	9.12
	Pematang Siantar	1.78	
	Simalungun	4.03	
	Serdang Bedagai	1.70	

The daily average rainfall based on the use of rainfall station data used minimum data, the results as shown in Table-8.

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Table-8. Rainfall monthly Minimum.

Tahun	Situng galing	Sitinjo	Tj. Gorbus	Pangur uran	Dolok Sang gul	Lagub oti	Lum ban Julu	Average
1993	37	89	26	42	10	52	100	50,86
1994	25	14	10	23	6	19	13	15,71
1995	125	44	23	61	21	63	74	58,71
1996	42	67	9	32	22	42	72	40,86
1997	49	45	10	82	38	38	61	46,14
1998	35	37	26	36	16	53	36	34,14
1999	40	21	39	0	56	28	17	28,71
2000	25	72	65	7	46	15	29	37,00
2001	33	0	55	23	26	24	81	34,57
2002	37	27	15	27	195	43	156	71,43
2003	53	33	21	110	155	115	30	73,86
2004	8	30	19	6	125	97	49	47,71
2005	56	49	5	66	42	37	117	53,14
2006	28	47	52	6	78	65	19	42,14
2007	121	99	74	83	202	83	202	123,43

Before rainfall data were used, the consistency was tested. The method used in this test was the RAPS (Rescaled Adjusted Partial Sum) method. Measures consistency used rainfall station data, then it was determined using equations (2) to (8). Analysis of minimum monthly rainfall consistency data Table-9 that a significant level (confidence level) of 90% indicates the critical value of $Q/n^{(0,5)}$ and $R/n^{(0,5)}$. Data from all rain stations were smaller than the value (Table-9) so that the rainfall data were consistent and usable.

Table-9. Calculation rainfall consistency data test from all stations.

Rainfall data	$Q/n^{0,5}$	Results	$R/n^{0,5}$	Results
Situnggaling	0,475 < 1,075	Consistent	0,467 < 1,275	Consistent
Sitinjo	0,332 < 1,075	Consistent	0,332 < 1,275	Consistent
Tj Gorbus	0,271 < 1,075	Consistent	0,246 < 1,275	Consistent
Pangururan	0,262 < 1,075	Consistent	0,252 < 1,275	Consistent
Dolok Sanggul	0,815 < 1,075	Consistent	0,761 < 1,275	Consistent
Laguboti	0,389 < 1,075	Consistent	0,387 < 1,275	Consistent
Lumban Julu	0,808 < 1,075	Consistent	0,798 < 1,275	Consistent

The distribution of Goodness fittest used Kolmogorov-Smirnov test, the distribution test results were shown in Table-10.

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Table-10. Calculate Smirnov-Kolmogorov distribution test.

M	Rainfall (R)	P = m/(n+1)	T	P' = 1/T	D = l P-P' l
1	123,43	0,06	27,673	0,036	0,026
2	73,86	0,13	4,424	0,226	0,101
3	71,43	0,19	4,072	0,246	0,058
4	59,71	0,25	2,780	0,360	0,110
5	53,14	0,31	2,282	0,438	0,126
6	50,86	0,38	2,139	0,468	0,093
7	47,71	0,44	1,961	0,510	0,072
8	46,14	0,50	1,881	0,532	0,032
9	42,14	0,56	1,701	0,588	0,026
10	40,86	0,63	1,649	0,606	0,019
11	37,00	0,69	1,511	0,662	0,026
12	34,57	0,75	1,436	0,697	0,053
13	34,14	0,81	1,423	0,703	0,110
14	28,71	0,88	1,287	0,777	0,098
15	15,71	0,94	1,090	0,918	0,020

Table-10 presents that the value of Dmax "m" is line 5 (highlight) Dmax value is 0.126. Table-4 shows that n = 15 with a confidence level α = 5%, the value obtained from Do=0.34. Here it can be seen that "Dmax <Do", then the distribution of data can be accepted.

The dependable discharge was determined based on reliable rainfall (effective rainfall). Dependable flow is the minimum flow for probability of meeting with probability 80% (Chow *et al*., 1988).

Table-11. Dependable flow with a probability 80%.

Years	Rainfall	Rainfall from largest to smallest	Serial number (m)	Probability P=m/(n+1) (%)
1993	50,86	123.43	1	6.25
1994	15,71	73.86	2	12.5
1995	58,71	71.43	3	18.75
1996	40,86	58,71	4	25
1997	46,14	53.14	5	31.25
1998	34,14	50.86	6	37.5
1999	28,71	47.71	7	43.75
2000	37,00	46.14	8	50
2001	34,57	42.14	9	56.25
2002	71,43	40.86	10	62.5
2003	73,86	37.00	11	68.75
2004	47,71	34.57	12	75
2005	53,14	34.14	13	81.25
2006	42,14	28.71	14	87.5
2007	123,43	15.71	15	93.75

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Rainfall data were sorted from the largest to the smallest and numbered as "m". The probability was given by the formula P = m / (1 + n) where "n" is the amount of data. The probability value of 80% was between "m" 12 and 13 (highlight). The probability of "m" 12 is 75% with rainfall of 34.57 mm and the probability of "m" 13 was 81.25% with rainfall of 34.14 mm. 80% probability by interpolating rainfall result was 34, 38 mm.

Probability 80% of rainfall was used to determine 80% discharge as annual discharge. The intensity of rainfall was determined based on the probability of 80% rainfall (0.997 mm) in concentration time (Tc = 1.482 hours), rainfall intensity was 0.23 mm / hour.

Land use in Lake Toba is to determine the runoff coefficient. The area of Lake Toba is 3, 374, 79 ha. Furthermore, the regional runoff coefficient was 0.51 as shown in Table-12.

Table-12. Region runoff coefficient (C).

Land	**Land area** (Ai) **Ha**	**Runoff coefficient** (Ci)	C_i*A_i
Brushwood	390.60	0.55	214.83
Lake	1,126.97	0.90	1,014.27
Forest	765.06	0.20	153.01
Field	266.89	0.40	106.76
Thicket fields	477.84	0.50	238.92
Meadow	137.42	0.30	41.23
Open land	21.27	0.50	10.63
Housing residents	31.64	0.55	17.40
Grass	289.60	0.21	60.82
Grass grove	39.26	0.40	15.70
Paddy Field	188.03	0.15	28.20
River	0.20062	0.60	0.12
Total	3,734.79		1,901.90
Region runoff coefficient C		0.51	

Dependable discharge 80% is determined by the Mononobe rational method in equation (12) where the determination is based on the coefficient of runoff, rainfall intensity, and service area. The Dependable discharge 80%result is 121.79 m^3/sec.

In addition, the water source of Lake Toba also some waterfalls that enter the river that contributes as input (Napitupulu, 2010). Various waterfalls and rivers as shown in Table-13.

Table-13. Source of discharge contribution from the Rivers.

Waterfall	Rivers	Average discharge (m^3/det)
Sipulak	Aek Siharar	5.00
Peadungdung	Aek Peadungdung	2.00
Pollung	Aek Sibuluan	4.00
Tahurjati	Sei Sopang	2.00
Simandame	Aek Sisira	6.00
Namo Sarangan	Aek Sisira	3.00
Sibokkik	Aek Rambe	4.00
Simursa	Sei Simursa	2.00
Simursa II	Sei Simursa II	1.50
Sibabo	Aek Simonggo	10.00
Simolap	Sei Baringin	3.00
Sipang	Aek Sipang	0.80
Ompu Sarme	Aek Pungga	2.00
Raja Panopa	Aek Pungga	3.00
Ompu Lagang	Aek Mahumba	3.00
Nadumonggor	Aek Sibuluan	2.50
Sipultak Hoda	Aek Silintong Gota-gota	2.00
Janji	Binanga Janji	1.50
Manonga Tao	Aek Silang	10.00
Parpahuan	Aek Silang	10.00
Sibundong II	Aek Sibundong	5.00
Sibundong III	Aek Sibundong	5.00
Total		87.30

DISCUSSIONS

The population in 2015 was 6,102,254 people, the largest in Medan was 2, 210, 624 people and the lowest was Tebing Tinggi with 156, 815 people. By 2032, population forecasting in the service area is estimated to be 7, 616, 511 people with the addition of 1, 514, 257 people, so that the demand for raw water by population increases from 1, 195, 468, 595 liters/day (2015) to 1, 491, 990, 144 liters/day (2032) with increase of 24.80%

Service area was divided into two systems, namely system 1 (Medan-Deli Serdang) and system 2 (Simalungun-Tebing Tinggi-Pematang Siantar-Bedagai Serdang). The raw water needs for both systems were 73.25 m3 / sec (system1) and 9 m3 / sec (system 2). This illustrated that the system needs (Medan-Deli Serdang) was very high as shown in Table-7.

According to consistency data test with Rescaled Adjusted Partial Sum (RAPS) method by a significant level (confidence level) 90% indicates that the rainfall data is consistent and can be accepted as well as Goodness fittest by Kolmogorov Smirnov also acceptable therefore rainfall data can be used to calculate supply water.

Rain intensity probability 80% is 0.23 mm/hour; runoff coefficient region is 0.51 so that input discharge probability 80% within Rational Mononobe 121.79 m3/sec. Comparison of the water balance is a consideration in the conclusions. The results suggest that the discharges required 82.37 m^3/sec (output discharge) while the supply of rainfall 121.79 m^3/sec. In addition, the supply of the rivers around that contributed 87.3 m^3/sec so that input discharges total 209.09 m^3/sec.

The IWRM approach strive to find the delicate balance between water for livelihoods and water for maintaining the resource base, and to ensure coordination of all sector uses so that impacts from one particular use is taken into account when looking at other uses (UCC Water, 2015), in plan of Integrated Regional Water Management (IWRM) North Sumatera, which will use Lake Toba as a water source, it is necessary to consider a decline normal water levels, therefore can be illustrated that the output discharge is smaller than the input discharge and it can be concluded that the water of Lake Toba can be used and not affecting the normal water level.

CONCLUSIONS

The results showed that required debit was 82.37 m^3/sec (output discharge), while the supply of rainfall was 121.79 m^3/sec. In addition, the supply of rivers around Lake Toba contributed 87.3 m^3/sec, resulting in total discharge to 209.09 m^3/sec. therefore can be illustrated that the output discharge is smaller than the input discharge and it can be concluded that the water of Lake Toba can be used and not affecting the normal water level. To safeguard forests as groundwater buffers, it is advisable to expand forest areas through reforestation and increase productive forest areas.

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