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ORIGINAL ARTICLE

Assessment of Spatiotemporal Variation of Water Quality of Lake Tana, Ethiopia

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ABSTRACT

Lakes are freshwater resources that contribute significantly to the maintenance of local ecosystems and ecological functions and services, including water supply, irrigation, hydroelectric production, aquaculture, and extreme flood and drought management. These services are declining, especially in developing countries such as Ethiopia, due to rapid population growth and human activities that have accelerated land degradation. Recently, Lake Tana shows signs of water hyacinth and is now found in the Fogera and Dembia floodplains. The lake resources are being abused, leading to resource degradation and ecosystem disruption. Studies of the physicochemical parameters of Lake Tana are limited to the banks of the lake and this study was conducted to investigate selected physicochemical water quality parameters of Lake Tana not limited to the banks of the lake. Four field trips were made in 2018 to measure transparency or Secchi Disc Depth (SDD), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Temperature (T0), and to collect water samples at 20 sampling locations for Suspended Sediment Concentration (SSC) and turbidity analysis. The result was analyzed spatiotemporally, statistically and graphically using R Statistical software and ArcGIS. Accordingly mean values of SSC of 205.7, 190.8, 377.4, 422.7 mg/l, turbidity of 20.1, 41.2, 90.8, 72.1 NTU, SDD of 0.78, 0.56, 0.40, 0.31 m, TDS of 93.6, 94.8, 90.8, 88.3 ppm, T0 of 24.3, 24.3, 23.5, 22.7 0C, and EC of 143.3, 143.9, 135.9, 131.4 µmhos/cm were found for May, June, July and August 2018 respectively. The analysis revealed that the sediment concentration had a higher spatiotemporal variation along the inlets of tributary rivers and in the centre of the lake Temperature and total dissolved solids results also showed that it is appropriate for water hyacinth development and expansion over the lake surface. By treating the nutrient-rich sediment with optimal management techniques such as soil and water conservation, minimizing recession agriculture near the lake, and enhancing wetland management, it may be possible to change the physicochemical water quality and the dynamics of water hyacinth expansion.

Keywords: Water Quality, Water Hyacinth, Lake Tana, Spatiotemporal, Ethiopia

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1. Introduction

Water is essential for humans, animals, and plants, and without it, there would be no life on Earth. Humans need water not only for drinking, but also for various purposes such as bathing, washing, cooking, manufacturing, agriculture, and leisure activities (Tibebe et al., 2019; Wondim, 2016). However, freshwater lakes all around the world are under pressure, and especially pollution, sedimentation, and eutrophication are major environmental problems (Moges et al., 2016; Wondim et al., 2016). Lakes are freshwater resources that contribute significantly to the maintenance of local environmental and ecological functions and services, including water supply, irrigation, hydropower generation, fishery production, extreme flood and drought management (Gezie et al., 2018; Kebedew et al., 2020b; Tibebe et al., 2019; Wondim, 2016). Land degradation and water quality in the past were not impacted by anthropogenic activities due to the low population density (Alemu et al., 2017). These services are declining, particularly in developing countries like Ethiopia, due to rapid population growth and human activities that have accelerated land degradation (Ayele et al., 2017; Kebedew et al., 2020b; Setegn et al., 2009; Tamiru, 2021; Wondim, 2016; Yezbie & Dessie, 2019). However, the physical and chemical properties of lakes in their natural environment are influenced by several factors, including the effects of topography, geology, rainfall-runoff processes, and climatic variability (Mustapha & Abdu, 2012; Tibebe et al., 2019; Yezbie & Dessie, 2019).

In addition, agricultural runoff which contains pesticides, fertilizers, and organic manure is an important input source into the watershed of freshwater bodies, contributing to the physicochemical characteristics and eutrophication (Dersseh et al., 2019; Ewnetu et al., 2014; Kebedew et al., 2020a; Moges et al., 2017; Moges et al., 2016; Setegn et al., 2009; Tamiru, 2021; Tibebe et al., 2019) and water quality is monitored using physicochemical parameters and biological organisms (Hone & Beneberu, 2020; Wondim, 2016; Wondim & Mosa, 2015). Currently, lakes, especially Lake Tana (Ethiopia, East Africa), population growth, improved living standards, intensive agricultural practices, industrial development, and expansion of water hyacinth contribute to excessive water withdrawal while increasing the level of nutrient and sediment loading in the remaining natural freshwater systems (Alemu et al., 2017; Asmare, 2017; Dersseh et al., 2019; Setegn et al., 2009; Tewabe, 2015; Wondim & Mosa, 2015). Today, Lake Tana shows signs of water hyacinth infestation with the potential susceptible area for water hyacinth growth and expansion covering an area of 30,728.4 ha varying year from year and currently found in the flood plains of Fogera and Dembia, which have the largest area of intensive agriculture, and industry around the lake (Alemu et al., 2017; Dersseh et al., 2019; Dersseh et al., 2020; Enyew et al., 2020; Moges et al., 2016; Tewabe, 2015; Worqlul et al., 2020) and the release of untreated wastewater to the lake ecosystem contributes to its deterioration (Dersseh et al., 2019; Gezie et al., 2018; Hone & Beneberu, 2020; Wondim & Mosa, 2015; Yezbie & Dessie, 2019). Likewise, in the 12 lakes of the Ethiopian Rift Valley, water hyacinth infestation has been observed (Asmare, 2017; Firehun et al., 2014). The weed has severely disrupted ecological and socioeconomic functions such as the aquatic food chain, nutrient cycling, agricultural activities, tourism, transportation, cultural and religious practices, and public health issues (Enyew et al., 2020). This brought about major changes in the physicochemical structure and dynamics of the lakes, which often showed a clear change from clear water to turbid condition (Dersseh et al., 2019; Womber et al., 2021).

Water pollution and water hyacinth coverage are now major ecological challenges for Lake Tana (Alemu et al., 2017; Asmare, 2017; Dersseh et al., 2019; Enyew et al., 2020; Gezie et al., 2018;

Moges et al., 2016; Tewabe, 2015; Vijverberg et al., 2009; Wondim & Mosa, 2015). The Lake Tana basins with diverse ecosystems (lakes, wetlands, and rivers) support the world's unique and endemic fish species which are economically important to the surrounding community (Gezie et al., 2018; Kebedew et al., 2020b; Moges et al., 2016; Tewabe, 2015; Worqlul et al., 2020). The lake resources are being abused, leading to resource degradation and ecosystem disruption. To develop an integrated approach to managing lake water quality, it is important to fully understand this spatial and temporal variation, as well as the fate and dynamics of these physicochemical parameters in the lake.

Several reports have been made on external loads of nutrient and water quality status of Lake Tana (Alemu et al., 2017; Ewnetu et al., 2014; Tibebe et al., 2019; Yezbie & Dessie, 2019), ecological condition and the coverage of water hyacinth (Asmare, 2017; Dersseh et al., 2019; Dersseh et al., 2020; Enyew et al., 2020; Tewabe, 2015; Worqlul et al., 2020), and algal bloom and trophic status of the lake (Moges et al., 2017; Tibebe et al., 2019). However, all these reports have shown deterioration in the water quality of the lake with time which could be associated with non-point sources, sediment, and nutrient inflow, and high erosion rate from the watershed especially from the agricultural sector (Alemu et al., 2017; Moges et al., 2017; Moges et al., 2016). Dersseh et al. (2019) reported that water hyacinth has a strong impact on the physicochemical components of the water of the invaded ecosystem. Temperature, total dissolved solids, nitrogen, and phosphorus are known water quality parameters affecting the growth and expansion of water hyacinth.

This study was conducted to investigate the selected physicochemical water quality of Lake Tana spatially not limited to the banks of the lake. Studies of the physicochemical parameters of Lake Tana are limited (Wondim et al., 2016; Yezbie & Dessie, 2019; Tibebe et al., 2019) to the banks of the lake. Therefore, there is a need to conduct in-depth research to provide possible solutions to these problems and thus, to improve understanding of the spatial and temporal variation of physicochemical and nutrient concentrations in the lake ecosystem to suggest appropriate measures for sustainable management of the lake. The main purpose of this study is to investigate the selected potential physicochemical parameters in the Lake Tana ecosystem. Specifically, this study aimed to investigate how temperature and total dissolved solids affect the growth and expansion of water hyacinth over Lake Tana.

2. Materials and Methods

2.1 Study Area

Lake Tana is located at 12° 01′35″N latitude and 037° 18′12″ E longitude (Moges et al., 2017) or located in the northwest of the Ethiopian highlands at an altitude of 1786 m above sea level (Alemayehu et al., 2010; Alemu et al., 2017; Dersseh et al., 2020; Tibebe et al., 2019) (Figure 1). The lake is the source of the Blue Nile, the largest lake in Ethiopia and the third largest lake in the Nile Basin which accounts for 50% of the freshwater resource of the country (Dersseh et al., 2020; Moges et al., 2017; Stave et al., 2017; Vijverberg et al., 2009; Wondie et al., 2012). The lake is found in a wide depression of the Ethiopian basaltic plateau and is bordered by flood plains that are often flooded during the rainy season. The flood plains bounding the lake are the Fogera flood plain in the east (mainly by Gumara and Rib rivers), the Dembia flood plain in the north (from Megech river), and the Kunzila flood plain in the southwest (mainly associated with Gilgel Abay, Kelti, and Koga river), while it is bordered by steep rocks in the west and northwest (Tewabe, 2015; Vijverberg et al., 2009).

It is a shallow lake with a mean depth of 9 m and a maximum depth of 15 m (Alemayehu et al., 2010). The lake is approximately 84 km long and 66 km wide (Dersseh et al., 2020; Kaba et al., 2014). The lake has an average temperature of 22°C (Moges et al., 2017) and a mean annual rainfall of 1355.74 mm (Tibebe et al., 2019). Lake Tana is fed by numerous seasonal rivers and four permanent rivers such as the Gilgel Abay, Rib, Megech, and Gumara rivers (Alemu et al., 2017; Kebedew et al., 2020b; Poppe et al., 2013; Vijverberg et al., 2009; Zimale et al., 2018). The estimated mean annual flow to Lake Tana from Gilgel Abay, Gumara, Rib, and Megech is 1810, 930, 430, and 189 million m^3 respectively. The mean annual inflow to the lake is estimated to be 158 m^3/s (Alemayehu et al., 2010). The lake's surface area ranges from 3000 to 3600 km^2 (Danbara, 2014), depending on the season and rainfall. The lake level has been regulated for hydropower production since 1995 with the construction of the Chara-Chara control weir (Alemu et al., 2017; McCartney et al., 2010). These controls flow to the Blue Nile Falls and a hydropower station (Abate et al., 2015).

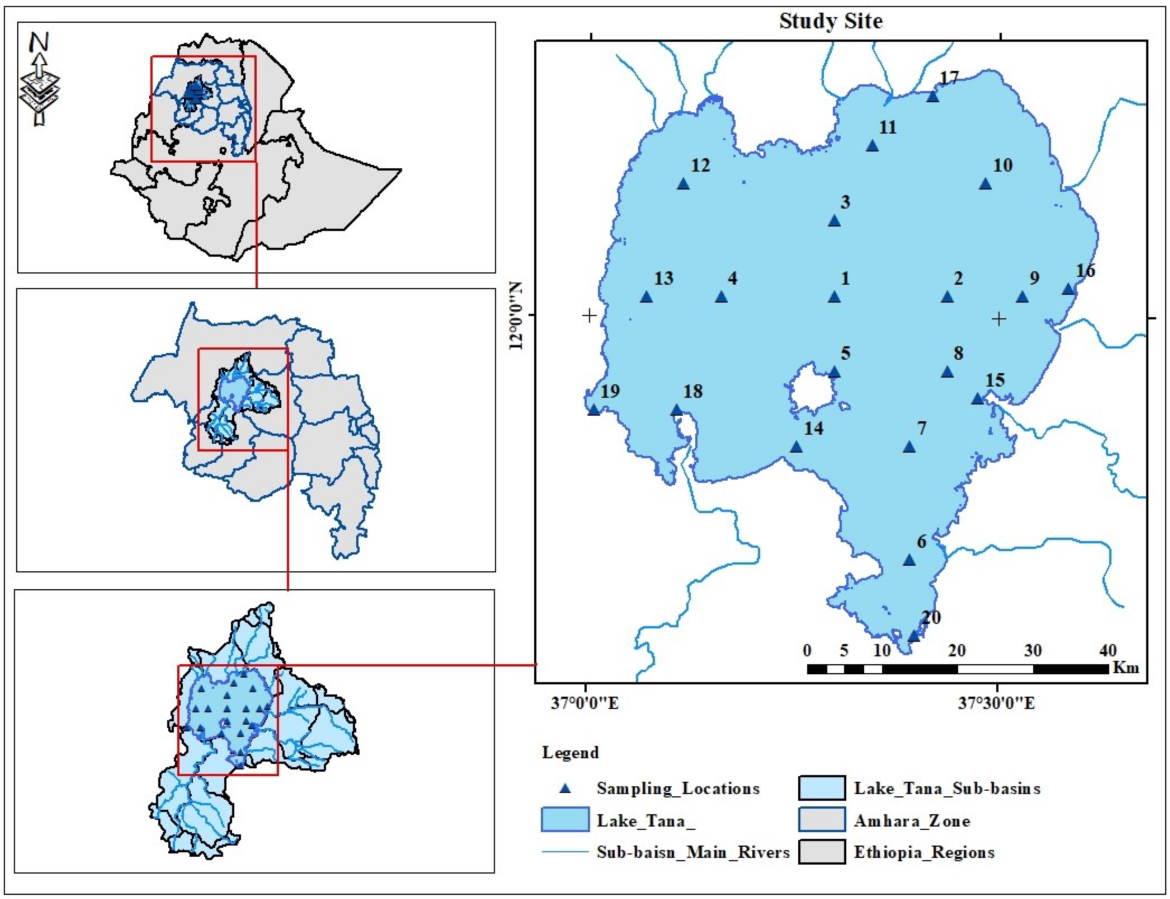


Figure 1: Major contributing rivers and location map of Lake Tana Basin.

2.2 Dataset and Water Sampling

Four field trips were made in 2018 from May 11 to 13, June 8 to 10, July 15 to 17, and August 12 to 14 to measure transparency or Secchi disc depth (SDD), electrical conductivity (EC), total dissolved solids. (TDS), water temperature (T^0) and water sampling at 20 monitoring points on the lake at a depth of 0.2m using a Van Dorn water sampler (Kaba et al., 2014; Moges et al., 2017) in both pre-rainy and rainy seasons for suspended sediment concentration (SSC) and turbidity. Sampling dates were spread over these months to capture the variation of physicochemical parameters of water quality. For each sampling point, GPS coordinates were obtained at a defined location of the lake to enable the collection of water quality data at the same location at different times. The points were chosen to represent the spatial-temporal distribution of the physicochemical parameters as the main tributaries (i.e. the Gilgel Abay, Gumara, Rib, and Megech rivers) enter the lake. The sampling points are shown in Figure 1.

SDD, TDS, EC, and Temperature Measurements

Transparency or SDD was observed using a 20 cm diameter circular disc marked with black and white to determine the depth to which visibility remained clear. The disc was submerged using a gaged rope and depths where the disk could no longer be seen from the surface with the naked eye were marked and recorded (Beeton, 1958; Dersseh et al., 2019; Moges et al., 2017; Walker, 1982). Electrical conductivity (EC), total dissolved solids (TDS), and water temperature (T^0) were measured *in-situ* using the YSI 556 multi-probe system (Yezbie & Dessie, 2019).

SSC and Turbidity Measurement

The determination of SSC was performed by filtering 1 liter of sampled water using Whatman filter paper 320 mm in diameter and drying it in an oven for 24 h at 105 °C and subtracting the weight of the dried filter and sediment to the filter weight divided by the volume of sample water (Dagnew et al., 2016). Turbidity was determined using a Hach 2100 N turbidimeter after calibration using a 0.1 to 7500 NTU formazin standard solution provided with the kit (Kaba et al., 2014).

2.3 Methods of Data Analysis

The results from field measurement and laboratory analysis were analyzed by using R Statistical and ArcGIS Desktop Software. R Statistical Software was used for descriptive statistics, ANOVA, correlation, and graphical visualization, and ArcGIS Desktop was used for spatial analysis of sampling stations. The temporal variation and spatial distributions of physicochemical water quality parameters were interpolated over the Lake Tana boundary and mapped based on the coordinate points of the sampling areas.

Statistical Analysis

Descriptive statistics were used to quantitatively describe or summarize the measured water quality information. A one-way ANOVA was applied to compare means and test for the significance of each water quality parameter. The method assesses the temporal variation of water quality parameters among sampling campaigns. This test is used for the reason the samples are related because they are the same water quality parameters tested each time (Hone & Beneberu, 2020; Tibebe et al., 2019). Pearson correlation matrix analysis techniques were used for studying and investigating the strength of the relationship between two quantitative variables (water quality parameters).

Geo-statistical Methods in Water Quality Analysis

The spatiotemporal variability of the water quality data was predicted by the ordinary Kriging interpolation method, with a spherical semivariogram model using the spatial analyst tool in ArcGIS. Using these interpolated values, raster layers for each parameter were developed, which shows the spatial variability of the water quality parameters. Interpolation is the process by which a surface is created through the input of data collected at several sample points. There are several forms of interpolation such as Basic Kriging, Spline, and Inverse Distance Weighted (IDW).

However, Kriging is based on statistical models that include the statistical relationship among the measured points and best predictor among all unbiased predictors even compared with spline and IDW (Dersseh et al., 2019).

3 Results and Discussion

3.1 Suspended Sediment Concentration (SSC)

The mean value of the measured SSC from the surface of Lake Tana was found as 205.71 *mg/l*, 190.84 *mg/l*, 377.38 *mg/l,* and 422.71 *mg/l* in May, June, July, and August respectively. The spatiotemporal concentration of suspended sediment measured from the collected water samples ranged between 113.1 to 375.9 *mg/l*, 107.6 to 375.2 *mg/l*, 108.2 to 1661.3 *mg/l* and 104.0 to 1519.2 *mg/l* for May, June, July, and August respectively (Table 1). The maximum SSC of 1661.3 *mg/l* during July and 1519.2 *mg/l* during August was observed at the Gumara and Gilgel Abay river inlet mouth to Lake Tana, respectively (Figures 2 and 5). This could be due to the lake's shallow depth and re-suspension of sediments could also occur with the movement of lake water and higher sediment load inflow from non-point sources in the intensively cultivated agricultural watershed (Moges et al., 2017). A good positive relationship was found between *in-situ* observed SSC and turbidity, a negative relationship with SDD, and a weak negative relationship with TDS, EC, and T^{0}, and their relationships have been shown in Figures 3 and 4. The results also indicate that the SSC varies insignificantly temporally among the sampling months within a 95% confidence interval. Temporally, ANOVA analysis of SSC (p = 0.058) showed that statistically there is no significant variation between the observed sampling campaigns (Table 2).

Table 1. Temporal summary statistics of measured water quality parameters.

Descriptive Statistics	**SSC (mg/l)**				**Turbidity (NTU)**			
	May	*June*	*July*	*August*	*May*	*June*	*July*	*August*
Mean	205.7	190.8	377.4	422.7	20.1	41.2	90.8	72.1
Median	181.7	154.1	169.9	228.6	14.6	20.0	49.9	54.9
SD	89.4	92.2	470.5	435.8	15.2	45.0	125.3	57.5
Minimum	113.1	107.6	108.2	104.0	7.30	12.7	14.2	16.8
Maximum	375.9	375.2	1661.3	1519.2	68.6	178	558	253
	SDD (m)				**TDS (ppm)**			
Mean	0.78	0.56	0.40	0.31	93.6	94.8	90.8	88.3
Median	0.815	0.62	0.27	0.26	94.3	95.1	90.6	87.9
SD	0.29	0.27	0.22	0.18	3.16	1.64	3.28	6.27
Minimum	0.28	0.06	0.13	0.09	83.5	90.7	83.5	72.9
Maximum	1.5	0.87	0.84	0.75	96.7	97.5	95.2	99.4
	T^0 (^{0}C)				**EC (µmhos/cm)**			
Mean	24.33	24.3	23.5	22.7	143.3	143.9	135.9	131.4
Median	24.25	24.3	23.5	23.0	143.4	144.5	136.7	130.9
SD	0.78	0.99	1.07	0.78	3.50	3.07	7.00	11.14
Minimum	22.9	22.9	21.7	21.5	136.9	138.2	122.5	105.6
Maximum	25.8	26.1	25.0	23.9	148.7	148.8	145.9	155.5
Count	20	20	20	20	20	20	20	20

3.2 Turbidity

For the sampled months, spatiotemporal turbidity had a minimum and maximum value ranging between 7.3 to 68.6 *NTU*, 12.7 to 178 *NTU*, 14.2 to 558 *NTU,* and 14.8 to 253 *NTU* in May, June, July, and August respectively. The sampled months also had an average value of 20.1 *NTU*, 41.23 *NTU*, 90.8 *NTU,* and 72 *NTU*, respectively. The maximum turbidity value of 558 *NTU* was observed in July near the Ribb river inlet mouth to Lake Tana and the minimum of 7.3 *NTU* in May at the center (Table 1). Unlike this study, higher turbidity (989 NTU) was observed during August in Lake Tana as reported by Wondim (2016). The higher observed turbidity was in May (Rib and Megech), June (Rib and Gilgel Abay), July (Rib and Megech), and August (Rib) river inlet to Lake Tana respectively (Figures 2 and 6). The values observed in July, during the rainy season were higher compared to those observed in May and August falling within the dry period (Figure 2). The higher turbidity result in that particular location might be due to the mixing zone of tributary rivers (Ewnetu et al., 2014). The high turbidity in July and August may be due to runoff from catchment areas, soil erosion, sediment load coming from non-point sources, and poor agriculture around the lake (Moges et al., 2017; Wondim, 2016). The result of turbidity was found strongly related negatively with *in-situ* observed SDD and weakly related negatively with TDS, EC, and T^0 (Figures 3 and 4). The results also indicate that the turbidity varies significantly temporally among the sampling months within a 95% confidence interval. Temporally, the ANOVA analysis of turbidity (p = 0.0147) showed statistically significant variations among the sampled months (Table 2). Similar results of ANOVA analysis of turbidity varying significantly between sampling months were also reported by Moges et al. (2017).

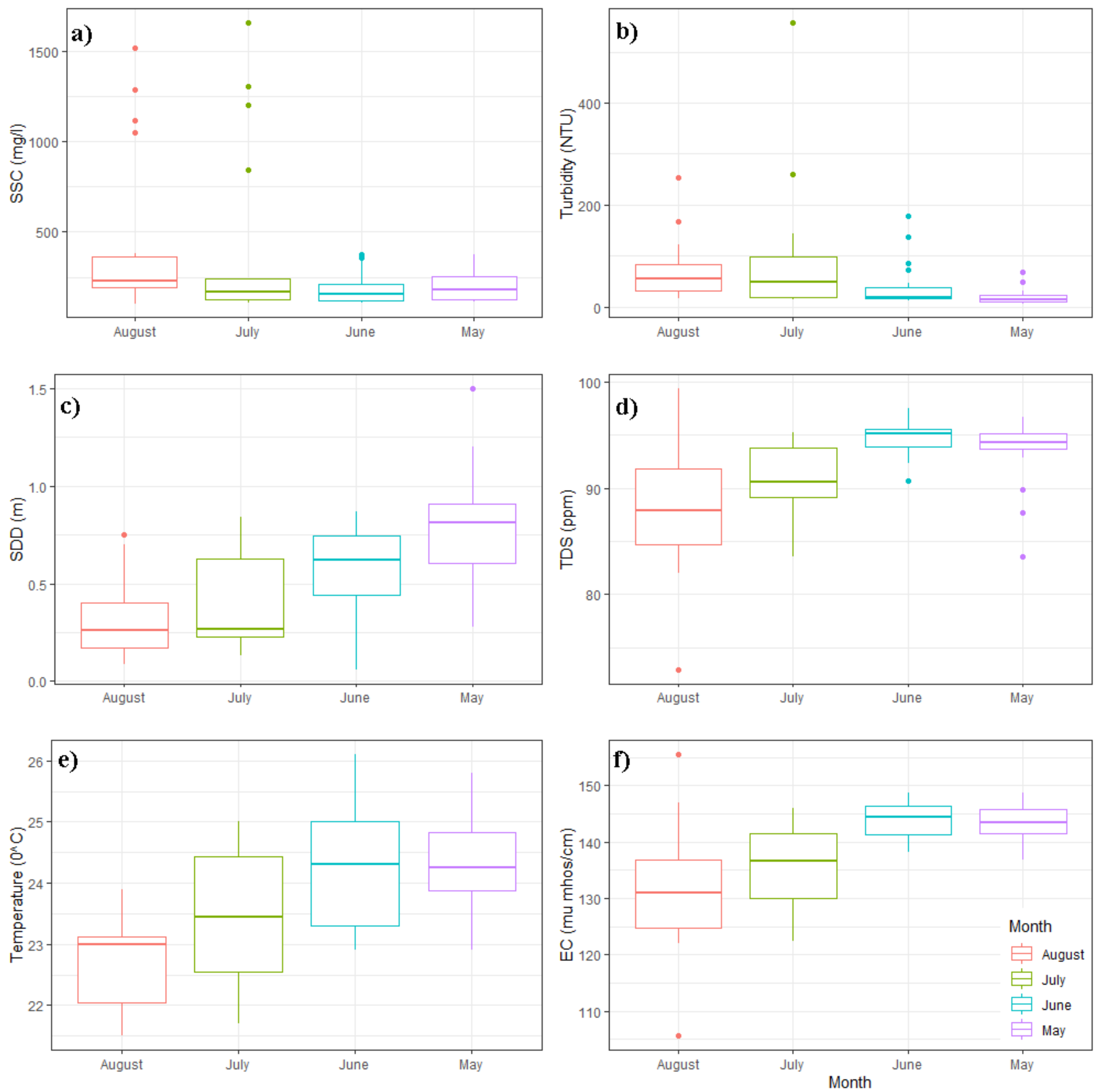


Figure 2. Distribution of sampled water quality parameters a)SSC, b) turbidity, c) SDD, d) TDS, e) Temperature (T^0), and f) EC over the surface of Lake Tana.

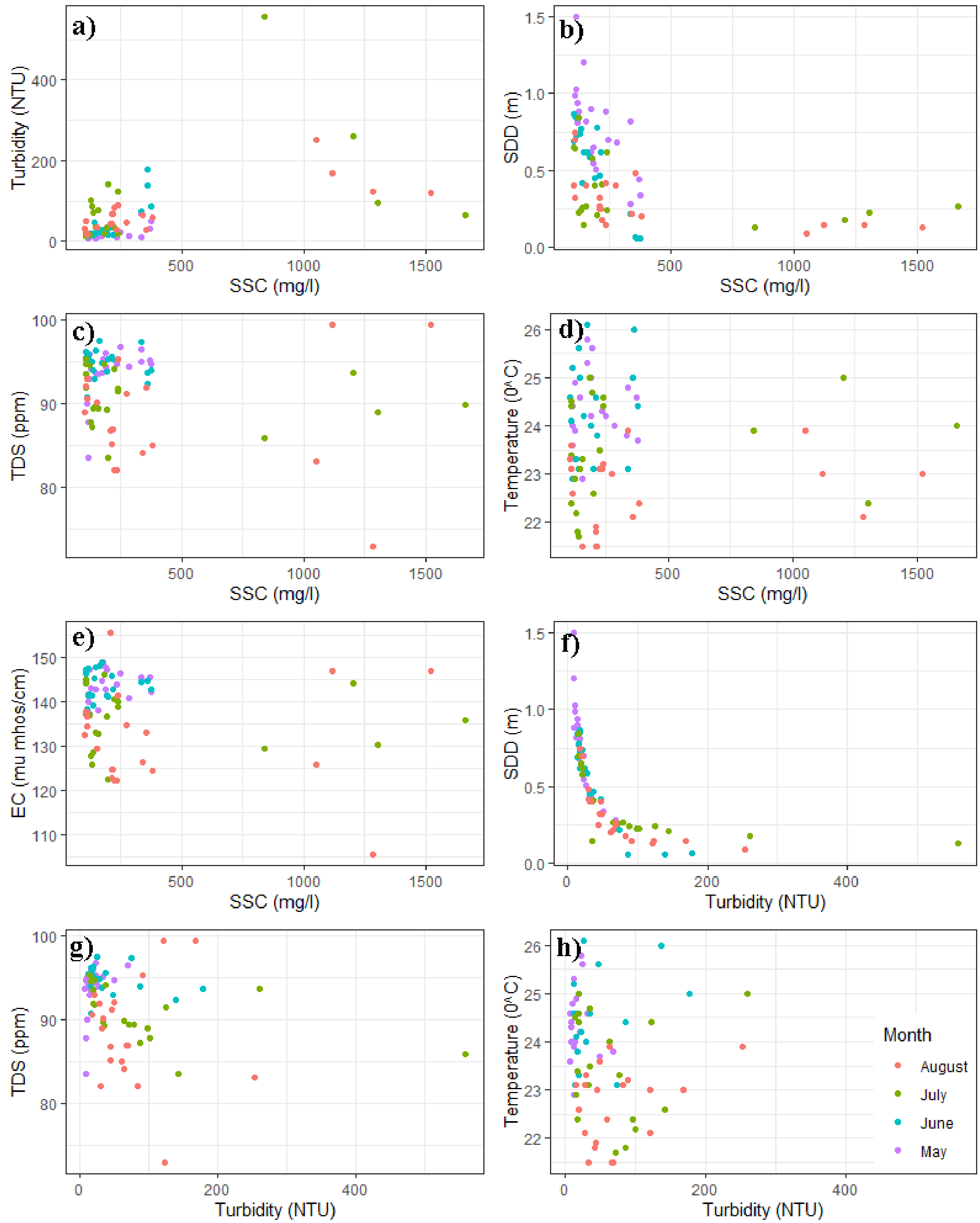
Table 2. Temporal one-way analysis of variance of water quality parameters over Lake Tana.

ANOVA of SSC (mg/l)					
Source of Variation	**DF**	**Sum Sq**	**Mean Sq**	**F-value**	**Pr(>F)**
Between Groups	3	836988	278996	2.608	0.0577
Within Groups	76	8129490	106967		
ANOVA of Turbidity (NTU)					
Between Groups	3	59541	19838	3.731	0.0147
Within Groups	76	404082	5317		

ANOVA of SDD (m)					
Between Groups	3	2.517	0.8389	14.02	2.30E-07
Within Groups	76	4.546	0.0598		
ANOVA of TDS (ppm)					
Between Groups	3	505.2	168.4	10.72	5.89E-06
Within Groups	76	1193.2	15.7		
ANOVA of EC (µmhos/cm)					
Between Groups	3	2202	733.9	15.08	8.59E-08
Within Groups	76	3698	48.7		
ANOVA of Water Temperature (0C)					
Between Groups	3	36.70	12.23	14.62	1.31E-07
Within Groups	76	63.59	0.837		

3.3 Secchi Disc Depth (SDD)

The spatiotemporal SDD had a minimum and maximum value ranging between 0.28 to 1.50 *m*, 0.06 to 0.87 *m*, 0.13 to 0.84 *m,* and 0.09 to 0.75 *m* for the sampled months, respectively. The spatiotemporal SDD also had an average value of 0.77 *m*, 0.56 *m*, 0.39 *m,* and 0.31 *m*, respectively (Table 1). The maximum SDD values of 1.2 *m* and 1.50 *m* were observed in May at the center and Rema (local name) on Lake Tana (Figure 2 and 7), this could be due to low sediment inflow from non-point sources from upstream of the watersheds (Moges et al., 2017). The values observed in June and August, during the rainy season were lower compared to those observed in the other months indicating that the lake water was turbid (Figure 7). Similar results were reported by Moges et al. (2017), that the water quality parameter observed in May and December falling to the dry season were lower than values observed in August during the rainy season. The result of SDD was found to be in a good negative relationship with *in-situ* observed SSC and turbidity, and a weak positive relationship with TDS, EC, and T^0 (Figures 3 and 4).


a)
Turbidity (NTU)
SSC (mg/l)
b)
SDD (m)
SSC (mg/l)
c)
TDS (ppm)
SSC (mg/l)
d)
Temperature (0^C)
SSC (mg/l)
e)
EC (mu mhos/cm)
SSC (mg/l)
f)
SDD (m)
Turbidity (NTU)
g)
TDS (ppm)
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h)
Temperature (0^C)
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Month
August
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May

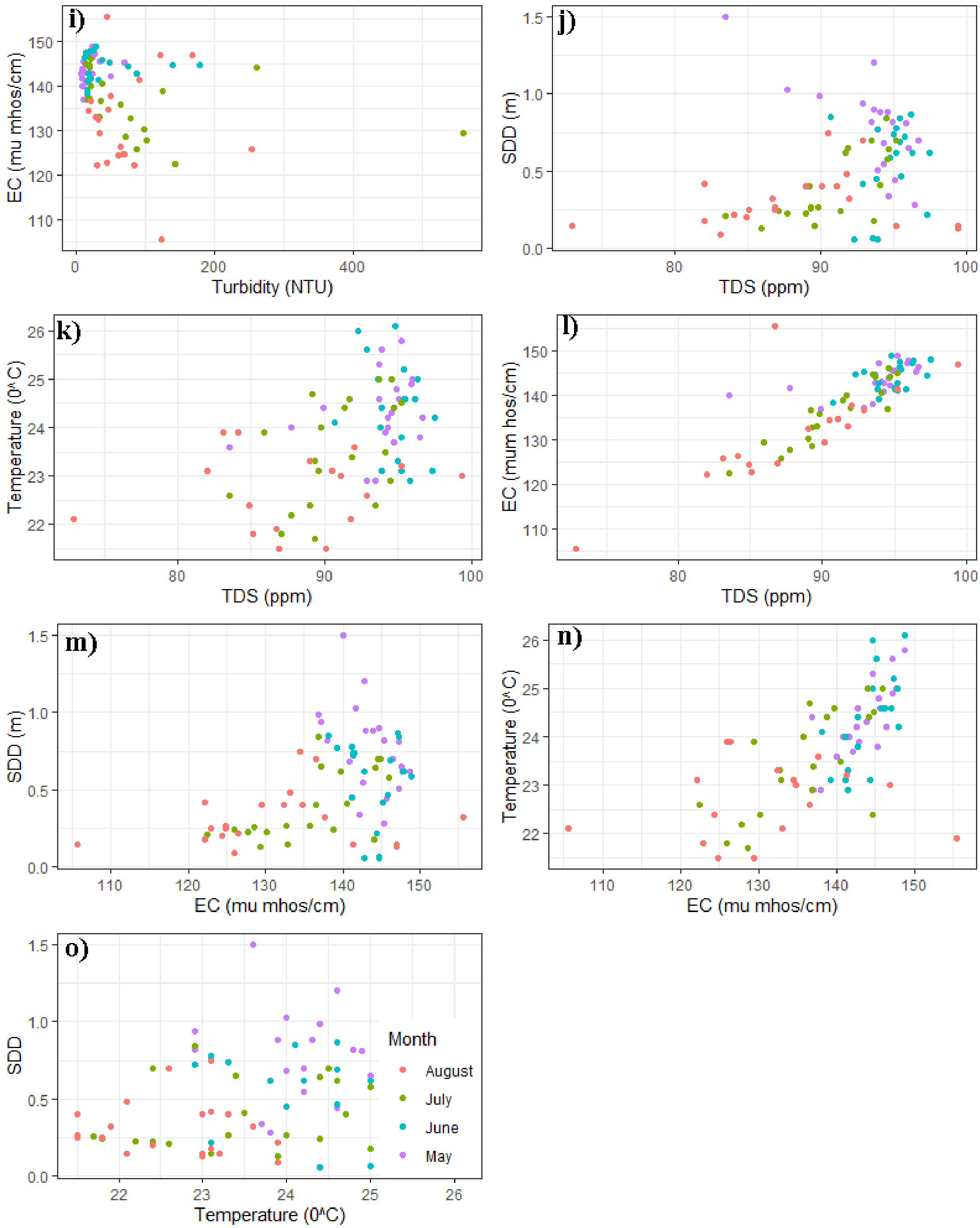

Figure 3 Relation of sampled water quality parameters a) Turbidity vs SSC, b) SDD vs Turbidity, c) TDS vs SSC, d) Temperature vs SSC, e) EC vs SSC , and f) SDD vs Turbidity ,g) TDS vs Turbidity, h)Temperature vs Turbidity,i)Ec vs Turbidity , j) SDD vs TDS, k)

Temperature vs TDS l) Ec vs TDS, m) SDD vs EC, and n) Temperature vs EC O) SDD vs Temperature over the surface of Lake Tana….

The result also indicates that the SDD varies significantly temporally among the samplings within a 95% confidence interval. Temporally, the ANOVA analysis of SDD (p = 2.3E-07) showed statistically significant variations between the sampled campaigns (Table 2). Similar results of ANOVA analysis of Secchi disc depth varying significantly between sampling months were also reported by Moges et al. (2017). The shallowest SDD was found during the wet season and the deepest during the dry season and similar results were also reported by Tibebe et al. (2019). The declining trend in SDD reading is one of the indications which suggest the increasing trend in turbidity of the lake, which can be mainly attributed to catchment degradation and sedimentation (Womber et al., 2021).

Figure 4. Correlation matrix between water quality parameters over Lake Tana.

3.4 Total Dissolved Solids (TDS)

The mean value of the spatiotemporally measured TDS from the surface of Lake Tana was found as 93.56 *ppm,* 94.79 *ppm,* 90.79 *ppm,* and 88.3 *ppm* in May, June, July, and August respectively. The spatiotemporally measured TDS from the lake surface ranged between 83.5 to 96.7 *ppm*, 90.7 to 97.5 *ppm*, 83.5 to 95.2 *ppm* and 72.9 to 99.4 *ppm* in May, June, July, and August respectively (Table 1). The maximum TDS of 99.4 *ppm* during August was observed at the Rib and Gilgel Abay river inlet mouth to Lake Tana, respectively (Figures 2 and 8). Similarly higher TDS values during August were also reported by Dersseh et al. (2019). The high value of TDS observed in the northeast during August also indicates that it is suitable for the growth of water hyacinth (Dersseh et al., 2019). This could be due to the increased effect of effluent from the surrounding highly agricultural areas on Lake Tana (Moges et al., 2017; Tibebe et al., 2019). A strong positive relationship was found between *in-situ* observed TDS and EC, and weak negative relationship between SSC and turbidity, and a weak positive relationship between SDD and T^0 (Figures 3 and 4). The result also indicates that the TDS varies significantly temporally among the samplings within a 95% confidence interval. Temporally, ANOVA analysis of TDS (p = 5.89E-06) showed that statistically there is a significant variation between the observed sampling campaigns (Table 2).

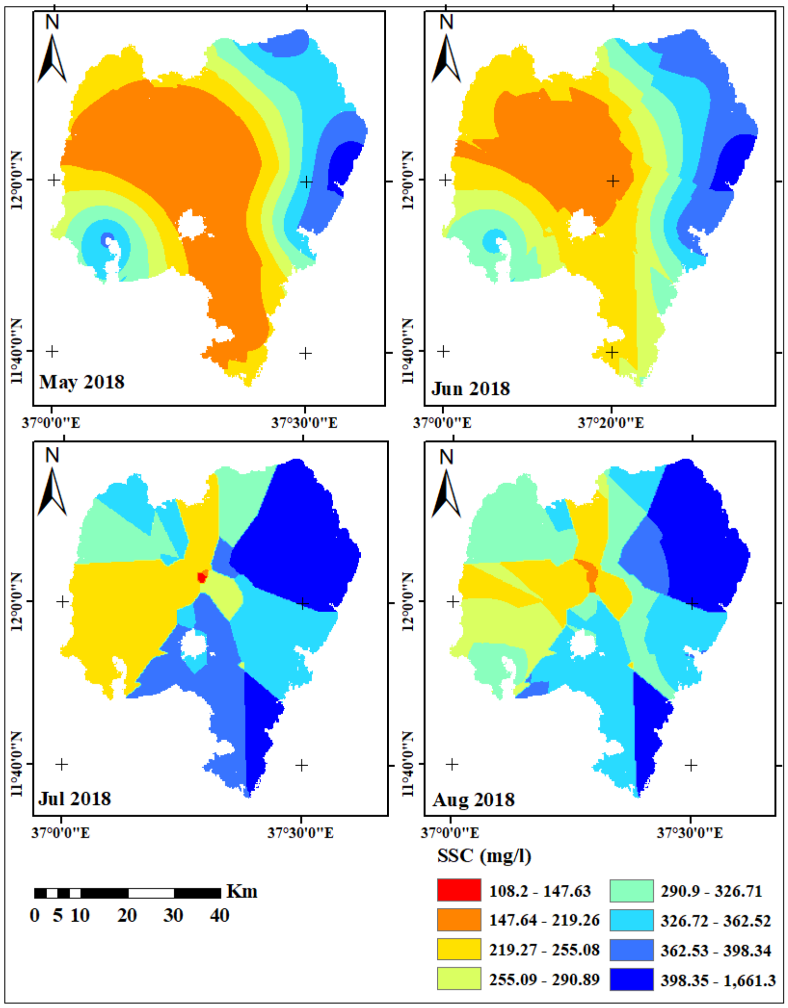

Figure 5. Spatiotemporal distribution of SSC (mg/l) over the surface of Lake Tana.

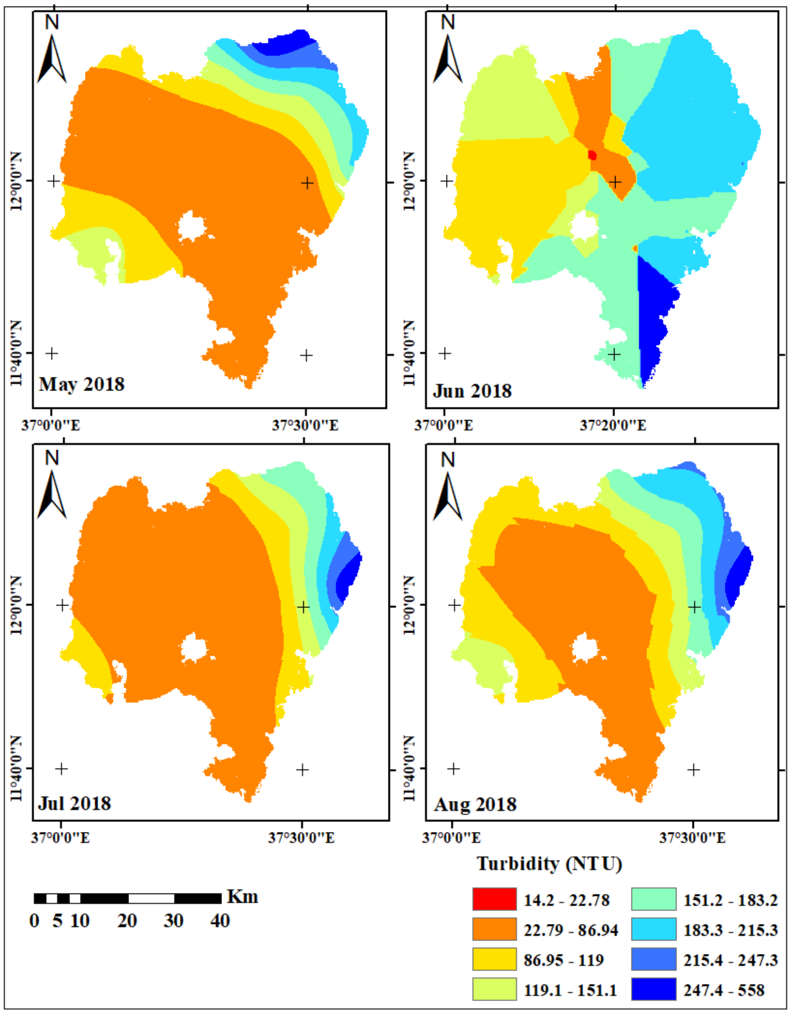

Figure 6. Spatiotemporal distribution of Turbidity (NTU) over the surface of Lake Tana.

3.5 Electrical Conductivity (EC)

The spatiotemporally measured EC from the lake surface ranged between 136.9 to 148.7 *µmhos/cm*, 138.2 to 148.8 *µmhos/cm*, 122.5 to 145.9 *µmhos/cm* and 105.6 to 155.5 *µmhos/cm* in May, June, July, and August respectively. The mean value of the spatiotemporally measured EC from the surface of Lake Tana was found as 143.3 *µmhos/cm,* 143.9 *µmhos/cm,* 135.9 *µmhos/cm* and 131.4 *µmhos/cm* in May, June, July, and August respectively (Table 1). The maximum EC of 155.5 *µmhos/cm* during August was observed at the Gumara river inlet mouth to Lake Tana (Figures 2 and 9). A strong positive relationship was found between *in-situ* observed EC and TDS, water temperature, and a weak negative relationship with SSC and turbidity (Figures 3 and 4). The result also indicates that the EC varies significantly temporally among the samplings within a 95% confidence interval. Temporally, ANOVA analysis of EC (p = 8.59E-08) showed that statistically there is a significant variation between the observed sampling campaigns (Table 2).

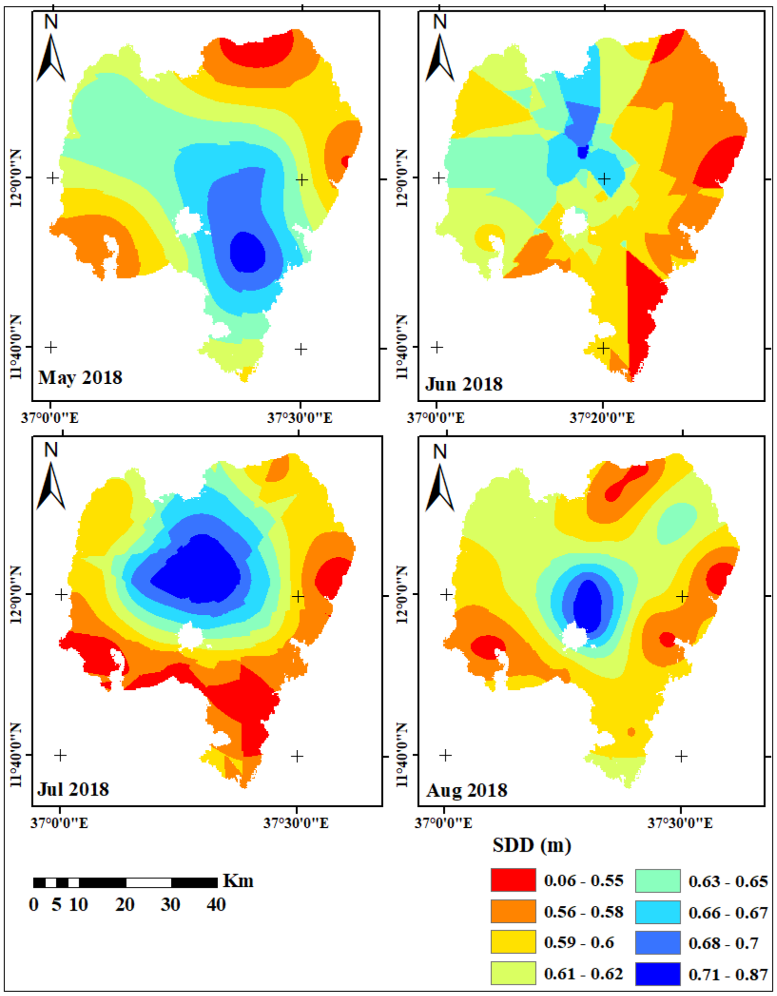

Figure 7. Spatiotemporal distribution of SDD (m) over the surface of Lake Tana.

3.6 Water Temperature (T^0)

The mean value of the spatiotemporally measured water temperature from the surface of Lake Tana was found as 24.3 ^{0}C, 24.3 ^{0}C, 23.5 ^{0}C, and 22.7 ^{0}C in May, June, July, and August respectively. The spatiotemporally measured water temperature from the lake surface ranged between 22.9 to 25.8 ^{0}C, 22.9 to 26.1 ^{0}C, 21.7 to 25.0 ^{0}C, and 21.5 to 23.9 ^{0}C in May, June, July, and August, respectively (Table 1). The maximum temperature of 26.1 ^{0}C during June was observed at the Gilgel Abay river inlet mouth to Lake Tana (Figures 2 and 10). The main reason for this result may be influenced by the increase in ambient temperature in one-day measurement (Ewnetu et al., 2014). A strong positive relationship was found between *in-situ* observed temperature and EC, and weak negative relationship with SSC and turbidity, and a weak positive relationship with TDS and SDD (Figures 3 and 4). The result also indicates that the temperature varies significantly temporally among the samplings within a 95% confidence interval. Temporally, ANOVA analysis of T^0 (p = 1.31E-07) showed that statistically there is a significant variation between the observed sampling campaigns (Table 2). The spatial temperature variation could be explained by the altitudinal difference between tributaries rivers that flow into the lake and the sampling locations in the lake (Wondim, 2016). The temperature observed in this study is suitable for the growth of water hyacinth, the area suitable for infestation was found to be larger in August than in the other months as reported by Dersseh et al. (2019). Moreover, Lake Tana has narrow seasonal fluctuations in water temperature as the lake is a shallow tropical lake (Yezbie & Dessie, 2019).

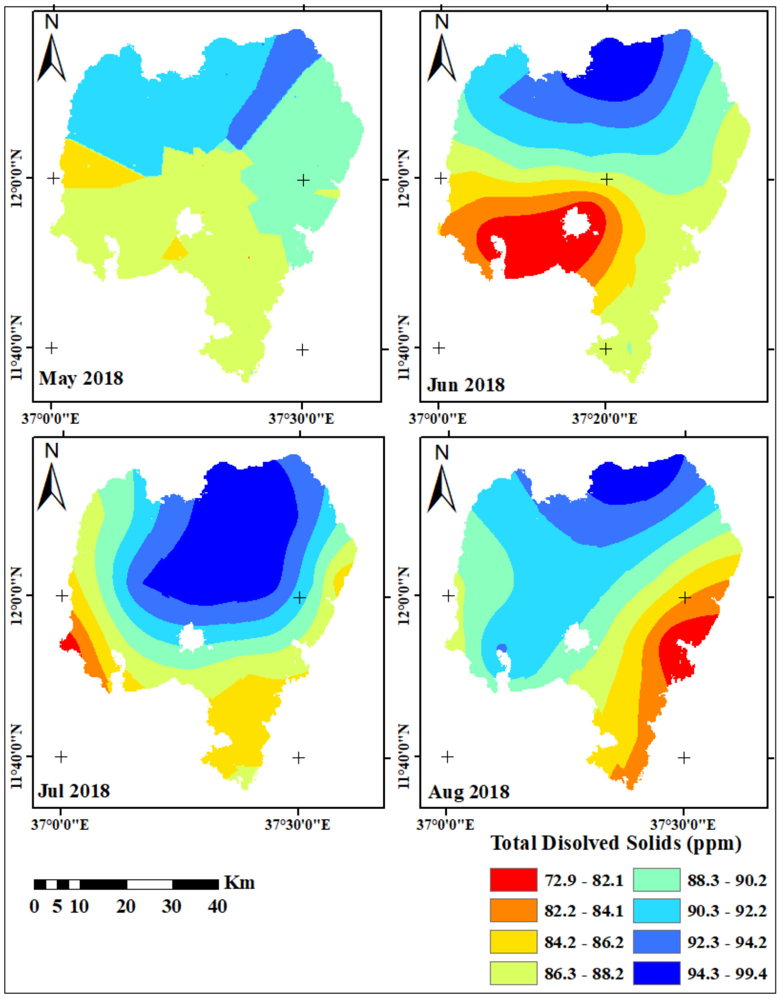

Figure 8. Spatiotemporal distribution of TDS (ppm) over the surface of Lake Tana.

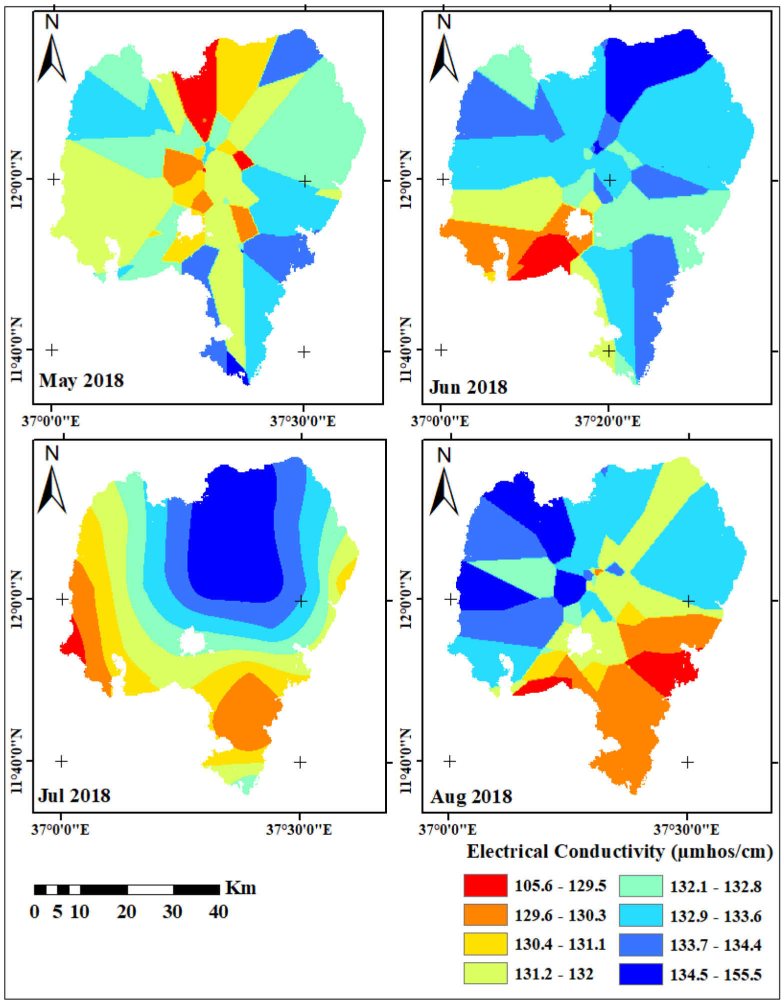

Figure 9. Spatiotemporal distribution of EC (µmhos/cm) over the surface of Lake Tana.

In this study, six water quality parameters were considered in the analysis for the investigation of Lake Tana's water quality status. The spatiotemporal distribution of selected parameters has been interpolated and presented (Figure 5-10). There were spatiotemporal variations in the water quality indicators in the lake ecosystem during the study period. Higher SSC, turbidity, SDD, TDS, EC, and T^0 were recorded in sampling sites of the major feeding rivers in rainy seasons. The deterioration of water quality is explained by changes in physicochemical water quality parameters (Tibebe et al., 2019). It has been witnessed that the physicochemical water quality parameters change considerably as the trophic status of the water body changes. In most eutrophic lakes, the physicochemical water quality parameters deviate from the normal surface water quality standards (Ayele & Atlabachew, 2021).

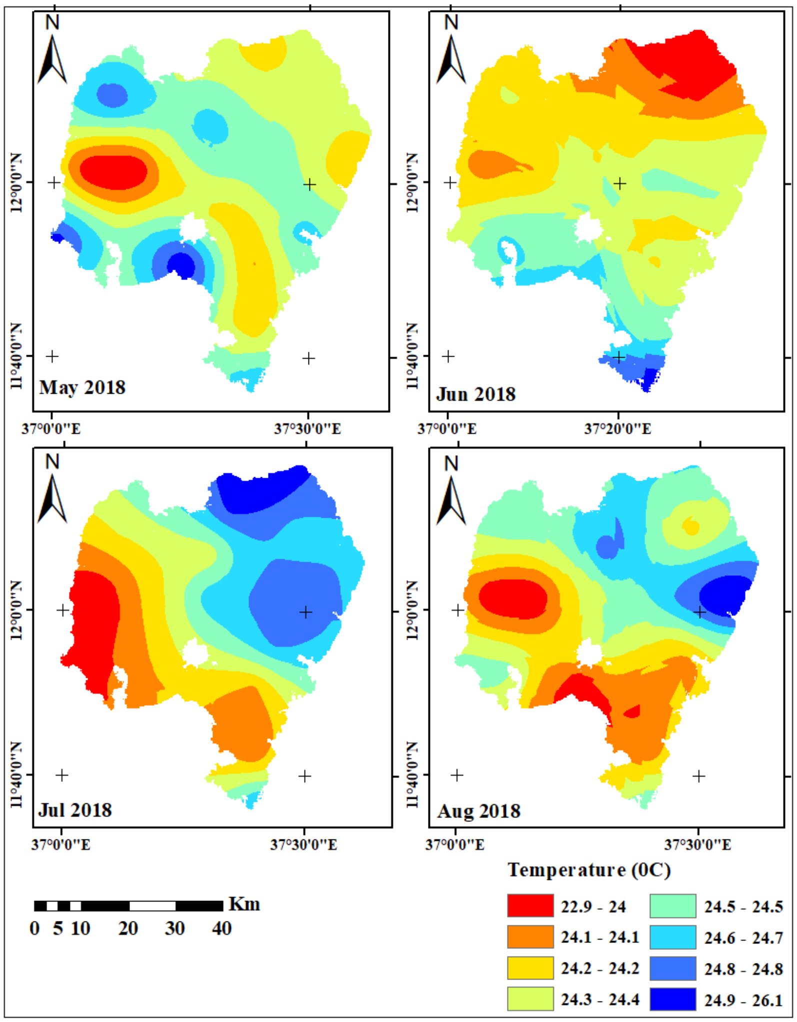

Figure 10. Spatiotemporal distribution of water temperature (^{0}C) over the surface of Lake Tana.

Spatial and temporal water quality variation can be driven by both anthropogenic and natural factors within the lake basins and could also be affected by soil erosion from the upland contributing watershed through surface water inputs (Womber et al., 2021). The spatiotemporal distribution of SSC and turbidity from river mouths to the lake appears higher during the rainy season and lower during the dry season (Figures 5 and 6). Before the start of the rainy season, discharging rivers to Lake Tana (Gilgel Abay River in the southwest, Gumara and Rib River in the east, and Megech and Arno-Garno River in the northeast) was relatively free of suspended sediment and clean (Womber et al., 2021). The spatiotemporal distribution of SDD was higher at the center and river mouth of the lake and higher TDS was observed at the center during July and the northern part of the river mouth to the lake during the study period (Figures 7 and 8). Higher spatiotemporal distribution of EC was observed mostly at the river mouth to the lake and the center during July and minimum EC concentration was observed at Gumara river mouth during August (Figure 9). The spatiotemporal distribution of T^0 was higher at the west and southwest side of the lake during May and June, east and northeast side of the lake during July and August, and minimum T^0 was observed at the west side of the lake (Figure 10).

4 Conclusion and Recommendation

Lake Tana, which has a higher surface area and complex ecosystem lake in the East African region and the largest freshwater lake in Ethiopia and Nile Basin, nowadays is exposed to dynamic land use/cover shifts across time and is also vulnerable to water pollution and water hyacinth invasion. This study conducted water quality of Lake Tana not limited to the banks of the lake. Spatiotemporally the selected water quality parameters (SSC, Turbidity, SSD, TDS, $T^{0,}$ and EC) has statistically significant variation and were related positively and negatively to each other. Higher distribution of suspended sediment concentration was observed around major tributary river inlets to Lake Tana such as Gilgel Abay, Gumara, Rib, and Megech Rivers. In addition, a higher concentration of turbidity was observed at the center of the lake due to the progressive delta effect in the lake. The result of temperature and total dissolved solids also indicated that it is suitable for the growth and expansion of water hyacinth over the lake surface. The physicochemical water quality and water hyacinth expansion dynamics could be altered by treating the nutrient-rich sediment with best management practices such as soil and water conservation, reducing recession agriculture adjacent to the lake, and wetland management.

Conflict of Interest

The authors declare no conflict of interest

Authors Contribution

All authors contributed to the study conception and design, material preparation, data collection and analysis were performed by Zelalem R. Womber, Fasikaw A. Zimale, Mastewal L. Assefa, and Dessalegn W. Ayalew. The first draft of the manuscript was written by Zelalem R. Womber and all the other authors commented on previous version of the manuscript and it was edited by Zelalem R. Womber and Fasikaw A. Zimale. All authors read and approved the final manuscript.

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