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ORIGINAL ARITICLE

The Impact of Anthropogenic Activities on Water Quality of Lake Tana (Northwestern Ethiopia). Analysis by Using Physicochemical parameters.

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Abstract

Lake Tana is the largest fresh water lake in Ethiopia affected by anthropogenic activities. This study was designed to assess human impacts on water quality of Lake Tana using some physicochemical parameters. The study was taken in five study areas and 11 sampling sites. The sites were selected based on the impact levels to compare with the reference site as a control based on the international standard selection criteria, APHA (American Public Health Association). The analytical results parameters selected in the study area indicated were Temperature (To) (21.93OC), pH (7.310), EC (electrical conductivity) (157.0µS/cm), BOD5 (biological oxygen demand) (22.30mg/l), COD (chemical oxygen demand) (311.2mg/l), TSS (total suspended solids) (0.5mg/l) and TDS (total dissolved solids) (78.6mg/l). The values of the analyzed parameters showed significant variation among the wet and dry seasons than among different locations ($P<0.05$). Strong positive correlations are observed between Temperature with EC and BOD5, EC with BOD, COD and TDS, BOD with COD and TDS at the $p<0.01$. Therefore, the lake water was very poor and unfit for drinking due to human induced pollution and it requires treatment before use.

Keywords**:** *Physicochemical parameters; Pollution; TDS; BOD; COD; Human induced pollution.*

Introduction

Lake Tana is the largest fresh water lake in Ethiopia that has domestic use value (drinking, washing etc.), agricultural value, home to biodiversity, recreational value and is a source of livelihood. But all these values are affected by anthropogenic activities (Eshete, 2003). The Lake is the main recipient of most urban wastes as well as agricultural and industrial pollutants. The sources of the Lake stress are agricultural activities, urbanization, and industrial activities that emanate pollution due to pesticides and fertilizers, waste water, water diversion for drainage and irrigation. In addition to this, climate change affected Lake Tana. Thus, the current socio-economic development of the upstream and downstream riparian inhabitants is degrading the water quality of Lake Tana (Stave *et al.*, 2017).

Lake Tana's average water temperature varies within the range of 21oc to 26oc and dissolved O2 concentration ranges form 5-7 mg/l to 6.9 mg/l. The water is almost alkaline, with bicarbonate levels ranging from 48 to 75 mg/l and a pH range level is 7.3 to 8.1. But there is a fear that after constant death and deposition of riparian plants, the case may lead to the accumulation of organic debris and the subsequent ecological degradation of the lake through acidification. According to Wondie (2015) the physicochemical characteristics of Lake Tana is TDS (PPT) 0.42, TSS (mg/l) 34, pH 9.0 and EC (µS/Cm) 1200. The Lake temperature is (oC) 20–24, Electrical conductivity (µS/cm) 220, PH 8.1 and

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TDS (mg/L) 150 (Kebede *et al.*, 2005).These literatures indicated that the impact on the lake is increasing with time. Hence, the current human impact will be studied by analyzing the water quality measurements comparing impacted sites with reference sites.

The quality of the lake water is also being increasingly affected by pollution from point and non-point sources in the region. Solid waste and effluent discharges from the domestic, commercial and industrial quarters of Bahir Dar and the surrounding urban and rural areas pass untreated into the lake. Already, with the growth of urban centers in the watershed of Lake Tana, the amount of domestic, municipal and industrial waste discharged to the lake is increasing. At present the gulf area of the lake appears to have high levels of silt and waste materials most of which originate from activities in the cities and towns. The use of agrochemicals, to promote agricultural productivity and pesticides to control pests are washed to the lake by runoff. The disposal of waste into the lake has implication for the fish population and for the sustainability of the livelihood of local communities (Tesfaye, 1998). The chemicals (agrochemicals and urban and industrial waste pollutants) affect the water quality parameters. The water quality parameters affect the biotic integrity of the lake. Assessment of water quality parameters is an ideal indication serving as a pertinent measure for water quality monitoring (Barbour et al., 2002). The lake's ecosystem monitoring can be assessed by comparison of the reference site with the impacted sites that are affected by anthropogenic factors which can provide scientific evidence of tangible effects of human activities on the lake water quality. Consequently, the lake is expected to be degraded by anthropogenic activities. Algal blooming and decline in biodiversity is observed in some parts of the lake (Eshete, 2003).

Anthropogenic activities are sources of pressure on natural ecosystem specially the aquatic ecosystem. Rapid population growth, agricultural activities, mining, urbanization and industrial activities have been degrading the environment and pollution has reached to a burning issue. All these activities are causes for the increasing of organic matter, silt, nutrients and other wastes in water resources resulting in the alteration of the ecological functioning of aquatic ecosystems (Steve *et al.*, 2015).

In the catchment areas of Lake Tana, human activities have been much more intense than many years before. Thus, it is possible to conclude that human interference in the lake basin would affect water quality of Lake Tana (Habiba, 2010). Of the many cities and towns found in the catchment areas of Lake Tana, the fast-growing cities that are affecting the lake are Bahir Dar, Gondar and Debre Tabor. The growing population and industrialization of these cities can have potentially serious consequences on the lake. It is possible that domestic and industrial wastes find ways into the lake (Stave et al., 2017). The waste discharged from these urban centers and agricultural areas are expected to have contribution to the decrease in the water quality and the increase in the concentrations of ions (Wondie, 2015). These ions determine the physicochemical characteristics of the water known by water quality that has a relation with biodiversity. To justify the expected outcome of the anthropogenic activities surrounding Lake Tana, the water quality of the lake has to be studied (Stave *et al.*, 2017).

Lack of integrated water resource management, ecologically oriented scientific research and wise resource utilization of the lake are unforeseen impacts. The lake water quality affected by human activities need to be properly identified, targeted and proper mitigation measures should be put in place. This study on some physicochemical properties of Lake Tana water is fundamental for the understanding of the ecological status and water quality of the Lake Tana water resource management system. Therefore, the aim of this research is to examine the human impacts on water quality of Lake Tana using some physico-chemical parameters.

Materials and Methods

The study area

Lake Tana is located between the coordinates of 37 0 00’-370 20`East Longitude and 110 37`-12000’North Latitude with an average altitude of 1784.5m a.s.l (Eshete, 2003). It is found in the north-western highlands of Ethiopia, Amhara region (Misganaw and Getu, 2016). Lake Tana is found in the Lake Tana sub basin with an area of 16,500 km2 (Wondie, 2015). It is the largest fresh water Lake in Ethiopia accounting 50% of the total inland water of the country with surface area of 3200 km2 and a shoreline of 385 km (Eshete, 2003). The border are Zegie Gorgora , Delgi , Kunzila town and Bahir Dar city. The maximum length of Lake Tana from north to south is 78 kms and the maximum width from east to west of the lake is 67 kms (Eshete, 2003). Its maximum depth is 14 m with an average depth of 8 m (Misganaw and Getu, 2016; Eshete, 2003). There are 37 islands in the lake with ancient churches and monasteries that form the cradle of the Ethiopian Orthodox Church and tourist attraction sites; and some are home to colonies of birds (Misganaw and Getu, 2016). It is also endowed with Dry Evergreen Montane Forest, Fauna Diversity, Mammals, Birds, Fish, Reptiles, Amphibians, Invertebrates and many other creatures. Many of the species are endemic to Ethiopia (Eshete, 2003).

Lake Tana forms the headwaters of the Blue Nile, which contributes more than 80% of the water of the Nile River flowing to Sudan, Egypt and the Mediterranean Sea (Stave et al., 2017). The lake is fed by more than 60 small seasonal tributaries and seven big perennial rivers. The big rivers are Gumara, Ribb, Megech, Gilgel Abbay, Gelda, Arno-Garno and Dirma that supply 95% of the lake’s inflow (Eshete, 2003). Recently, the perennial rivers are becoming seasonal due to upstream water pumping for irrigation activities and catchment degradation (Stave et al., 2017). The Lake is also experiencing changes in the environmental balance (the water level, the biodiversity and the water quality); mostly by the persistence of waste discharge, unsustainable production and consumption systems in the watershed and also due to climate change (Wondie, 2015).

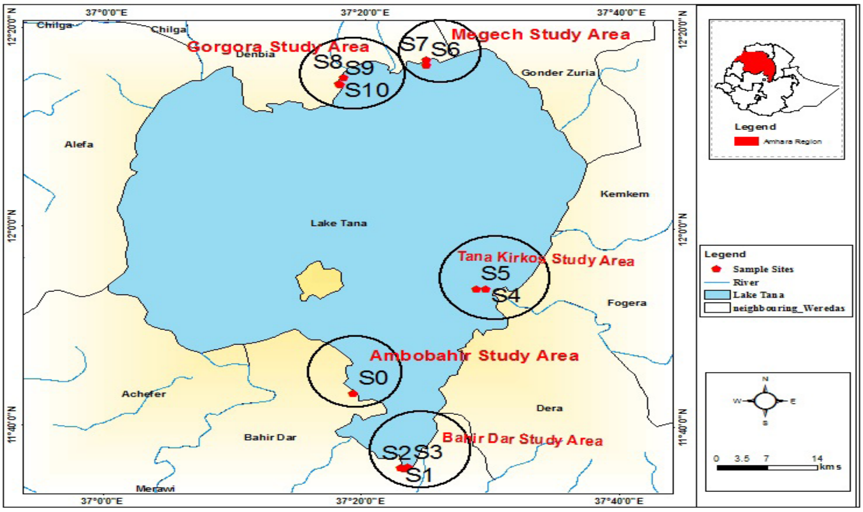

Figure 2.1: Location map of the study area and sampling sites (Source: The researcher Coordinate Data)

Sampling areas and sites

Sampling was conducted in five study areas. Primarily two urban areas, Bahir Dar city and Gorgora town in which Bahir Dar city was expected to have high impact and Gorgora town with minimal impact. The other category was two agricultural areas, Megech area that has high impact and Tana Kirkos area that has minimal impact as per the criteria of APHA. Lastly, Ambobahir was a reference site which likely to have less impact and used for comparison of impacted areas with less impacted areas which are selected based on the criteria indicated in section 2.3. Each study area has sampling sites. The Bahir Dar study area sampling sites were adjacent to Kuriftu (S_1), Tana Transport (S_2) and Tana Hotel (S_3) while Gorgora sampling sites locations were adjacent to Gorgora hotel (S_{10}), Gorgora Transport (S_9) and Debresina (S_8). In addition, the Tana Kirkos study area sampling sites were adjacent to Tana kirkos (S_4) and Gumara (S_5) while Megech study area sampling sites were Megech Inlet (S_7) and Megech East (S_6).

The Ambobahir study area was a reference site that has one sampling site named by Ambobahir (S0). The sampling site locations from S_0 to S_{10} are given in their geographic locations using GPS receiver as shown in Figure 2.1. All sampling sites were selected with expected impact categories into areas expected to be less polluted, moderately polluted and highly polluted; the criteria in the selection of sites were with consideration of pollution load (organic and inorganic load) of the lake. The other forms of categories were influenced by urban and agricultural activities, as per the study of Ehetie (2003). Sampling sites were selected based on the relative significances of anthropogenic activities on Lake Tana along shorelines. Therefore, Bahir Dar study area, Gorgora study area, Tana Kirkos study area and Ambobahir study area with their respective sites were selected. Reference site was fixed at Ambobahir study area.

Reference Conditions

To address the levels of impact to any part of Lake Tana, understanding the inherent biological variability's and natural condition of the lake is necessary and it is accomplished using a reference approach as used by Hughes (1995), which is based on minimal human impact. The objective of the reference is to collect and summarize data from least disturbed site as a framework in order to compare and develop appropriate criteria for the impacted sites (Barbour *et al.*, 2002; APHA, 2005).

The reference condition refers to the range of quantifiable ecological elements that are water chemistry, habitat and biology to be found in minimally disturbed environmental condition. Finding a reference site in the lake is a difficult task, because no part of the lake is entirely without human disturbance due to the water movement characteristics. Therefore, the reference site has been selected based on minimally or least influenced attributes or parameters (Gregory *et al.*, 1991).

Selection of Reference Area

According to Barbour et al., (1999), a reference site for any location must meet 11 criteria:

1. pH > 6 if black water, then pH<6 and DOC>8 mg/l
2. DO > 0.000004 mg/l
3. Nitrate < 300 mg/l
4. Urban land use < 20% catchment area
5. Forest land use > 25% catchment area

vi. Remoteness rating: optimal or suboptimal
vii. Aesthetics rating: optimal or suboptimal
viii. In stream habitat rating: optimal or suboptimal
ix. Riparian buffer width >15 m
x. No channelization
xi. No point source discharge

However, as there is a problem getting a reference site that fulfils all the above criteria from number one to eleven, the reference of this study was identified based on the following four criteria as used by Jennifer et al. (2003):

i. Same water body type, size and chemical characteristics as treated sites,
ii. Within the same watershed as the treated sites,
iii. Minimal impacts within the last few years, and
iv. Limited anthropogenic inputs.

Sampling and analysis

Sample collection

Samples were taken at regular intervals seasonally in wet and dry seasons at Lake Tana across five study areas having 11 sampling sites to determine seasonal variations in different sites following the protocols used for water sample analysis (APHA, 2005) for one year (June 2014 to May 2015) based on water sampling technique. The wet seasons represented from June to December of 2014 (a combination of summer and autumn seasons, expected to have less variation in rain fall pattern) and the dry season from January to may 2015 (a combination of winter and spring seasons).

One liter capacity polyethylene bottles, which were cleaned and washed with deionised water and then rinsed with sample water, were used for collection of samples. Thus, water samples were collected in polyethylene bottles from each site (two replicate samples were collected per site per sampling date with the water sampler at different depth intervals and homogenized before being sub sampled for laboratory analyses) to test the water quality. The water samples were collected seasonally in selected sampling zones 10cm below the surface of the lake water based on the procedure used by Das and Acharya (2003). The samples were brought to Dashen brewery and Bahir Dar university water analysis laboratories within 48 hours and analyzed. Standard methods for examination of water and waste water procedure APHA (2005) were employed.

Laboratory analyses

Chemical oxygen demand (COD) and biological oxygen demand (BOD_5) as chemical variables; and temperature, pH, TSS, TDS and electrical conductivity as physical variables were selected and measured following water quality assessment protocols (APHA, 2005). Water temperature (0C) was measured by using glass thermometer, pH was measured using pH meter and electrical conductivity was measured using conductivity meter (Table 2.1).

TSS, TDS and COD were analyzed using spectrophotometer (HACH DR/2010, USA) and BOD_5 was determined using Jenway Model 6305 UV/Vis Spectrophotometer (Mohamed *et al.*, 2009; APHA, 2005).

Data Analysis

Basic statistical measurement was done and results were expressed as mean ± SE using SPSS version 23 (SPSS, 2016). One-way ANOVA was used to study the significant mean differences among sites and LSD (least significant difference) test was subsequently applied where significant values ($P < 0.05$) were obtained to detect the specific point of difference among variables. Correlation among some physicochemical variables ($n = 7$) was also conducted to the extent and magnitude of relationships in sample parameters among different sampling points. Graphs were used to show differences in physicochemical parameters among the reference and impacted sites as well as the wet and dry seasons.

Results and Discussion

In this study, the mean results for the 7 physicochemical parameters among 11 sampling sites, and wet and dry seasons were given in Table 3.1 and Table 3.2 respectively. EC, COD and BOD5 showed significant differences among different sample locations while others did not. On the other hand, all parameters showed significant differences among the wet and the dry seasons. These reflected that most physicochemical variables modified by habitat disturbances showed a short-term pollution effect with impaired sites (Steve *et al.*, 2015). Pond and McMurray (2002) reported that electrical conductivity, pH and organic load (which can be expressed in the form of COD and BOD_5) in degraded habitat were significant factors to compare reference and impaired sites in aquatic environment. In this study, EC, COD and BOD_5 showed habitat degradation in impaired sites when compared with the reference site.

Table 3.1: Some Physicochemical parameters of 11 sites in wet and dry season of Lake Tana water

	Ambobahir		Bahir Dar Study area (S.A)						Tana Kirkos S.A				Megech S.A				Gorgora S. A					
Parameter	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
	S_0	S_0	S_1	S_1	S_2	S_2	S_3	S_3	S_4	S_4	S_5	S_5	S_6	S_6	S_7	S_7	S_8	S_8	S_9	S_9	S_{10}	S_{10}
Temp (Oc)	20	23	23.5	24.6	23.7	24.9	22	24.5	21.3	23.4	22.4	24.3	22.1	23.7	23.2	24.9	20	23.2	20.8	23.8	22.2	24.5
PH	6.99	7.35	7.09	7.35	6.93	7.76	7.23	8.4	6.93	7.13	7.2	7.31	7.74	7.84	7.71	7.9	7.7	7.89	7.31	7.84	7.58	7.94
EC (µS/cm)	78	89	180	252	196	234	146.2	219	131.4	155.6	133	149.8	214	282	242	393	123.9	137.9	143.2	151	139.4	172.3
BOD5 (mg/l)	4	13	50	92	33.3	48	12	26	20	37	36	26	8	61	29	114	25	16	8	76	20	67
COD (mg/l)	44	41	520	562	270	502	325	480	102	156	72	138	310	490	456	680	645	39	281	274	344	231
TSS (mg/l)	0.105	0.025	1.143	0.167	0.195	0.202	0.159	0.161	0.13	0.12	0.54	0.44	1.225	0.514	0.115	0.113	0.265	0.116	0.235	0.122	0.945	0.434
TDS (mg/l)	74	39	68.4	73.6	69	72.2	66.7	66	73	72.6	73.3	69.5	116.9	252	119	234	67.4	70.7	69.7	120.2	67.1	113.5

The environmental processes such as physical, chemical and biological interactions at ecosystem scale affect the Lake ecosystem including algae and invertebrates which are food for fish and other aquatic organisms. Therefore, it is logical to examine the physical, chemical and contaminants as potentially influencing the Lake Tana ecosystem.

Table 3.2. Some physicochemical parameters value (Mean± SE, n= 7) of the eleven study sites.

	Season		
n=Parameter	**Wet Mean ± SE**	**Dry Mean ± SE**	**Mean ± SE**
Temp (°C)	21.9 ± 0.4	24.1 ± 0.2	23.0 ± 0.3
pH	7.3 ± 0.1	7.7 ± 0.1	7.5 ± 0.1
EC (µS/cm)	157.0 ± 14.0	203.2 ± 25.6	180.1 ± 15.1
BOD5 (mg/l)	22.3 ± 4.3	52.4 ± 9.9	37.3 ± 6.2
COD (mg/l)	311.2 ± 55.0	321.7 ± 67.0	316.5 ± 43.1
TSS (mg/l)	0.5± 0.1	0.2 ± 0.1	0.3 ± 0.1
TDS (mg/l)	78.5 ± 5.9	107.6 ± 21.3	93.1 ± 11.2

The frequencies of some physicochemical parameters are represented in Figures 3.1 – 3.7 and the correlations coefficient matrix between each two pairs of parameters was estimated to conclude the relationships between some physicochemical parameters value (Table 3.3). It is summarized as follows:

Table 3.3: Correlation coefficient matrix between selected parameters of Lake Tana water

	Temp	**pH**	**EC**	**BOD5**	**COD**	**TSS**
Temp	1					
pH	.417	1	.			
EC	.625**	.451*	1			
BOD5	.670**	.296	.718**	1		
COD	.264	.422	.715**	.539**	1	
TSS	-.056	-.004	.033	-.098	.141	1
TDS	.309	.412	.751**	.601**	.433*	.063

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Parameters that have strong Positive correlations at the 0.01 level (2-tailed) are: Temperature with EC and BOD$_5$, EC with BOD$_5$, COD and TDS, BOD$_5$ with COD and TDS. While Parameters that have strong positive correlations at the 0.05 level (2-tailed) are: pH with EC and COD with TDS.

According to Mohamed *et al.* (2009), the EC value indicated the total amount of ionizable salts in the water. TDS are due to the presence of the inorganic salts, organic matter and others dissolved in water. Therefore, EC and TDS are correlated (Wondie, 2015).

Temperature (°C)

The temperature showed no significant mean variation ($P < 0.05$) between the reference site and impacted sites (Table 3.3). But there was significant variation of temperature between the wet season and the dry season Appendix 1. However, the lowest value was recorded in the reference site (S_0) and the highest value was recorded in Megech inlet (S_7) sampling site of the lake (Figure 3.1).

The highest temperature was recorded during winter season (dry season) and lowest during summer season (wet season) which is a normal feature in fresh water surface bodies (Wondie, 2015). The climate of the tropical region is one rainy season in the months between June and September. The air temperature shows small seasonal changes 21°C with an annual average temperature. The seasonal distribution of rainfall is due to the northward and southward movement of the intertropical convergence zone of wind (ITCZ). During summer seasons (June to September) the moist air masses are driven from the Atlantic and Indian Oceans. But during the rest of the year the ITCZ shifts southwards and dry conditions continue in the region between the months of October and May. Generally, the southern part of Lake Tana or the Bahir Dar study area is wetter than the western and the northern parts (Kebedea *et al.*, 2005). Temperature determines the chemical and biological activities of the aquatic system. Water temperature in Lake Tana water ranged between 20- 24 and 23-25 °C during wet and dry seasons, respectively (Figure 3.1). The lowest 20°C is at the reference site in wet season and the highest temperature 25°C at the sampling site Megech inlet where there is a loss of riparian vegetation cover and all discharges of Gondar town and the surrounding area is flowing towards river Megech. The higher temperature in dry season was probably due to the increased load of suspended solids, soil particles and decomposed organic matter in the lake; because they absorb more heat. And also the surface water temperature is influenced by the intensity of solar radiation, evaporation and fresh water influx (Wondie, 2015). Temperature affects distribution and survival of aquatic organisms. This is because temperature influences the amount of dissolved oxygen that is available to aquatic organisms and also the metabolic rate because increasing in temperature decreases the DO (APHA, 2005; Vincy et al., 2012). Temperature plays also an important role in the physical and chemical characteristics of the Lake Tana environment; it has a pronounced effect on the rate of CO2 fixation by phytoplankton (primary productivity). In addition, temperature is responsible for the decomposition of organic matter and nutrient recycling by the bacterial activities. Hence, it may affect the food chain of aquatic organisms (APHA, 2005; Mohamed *et al.*, 2009).

According to FDREEPA and UNIDO (2003) standard, the temperatures of inland (Surface waters) generally range from 5 - 30 °C for the protection of the aquatic species. Therefore the water temperature range of 20-25 °C at the sampling sites of Lake Tana was within this range. But the variation of temperature among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas Table 3.1.

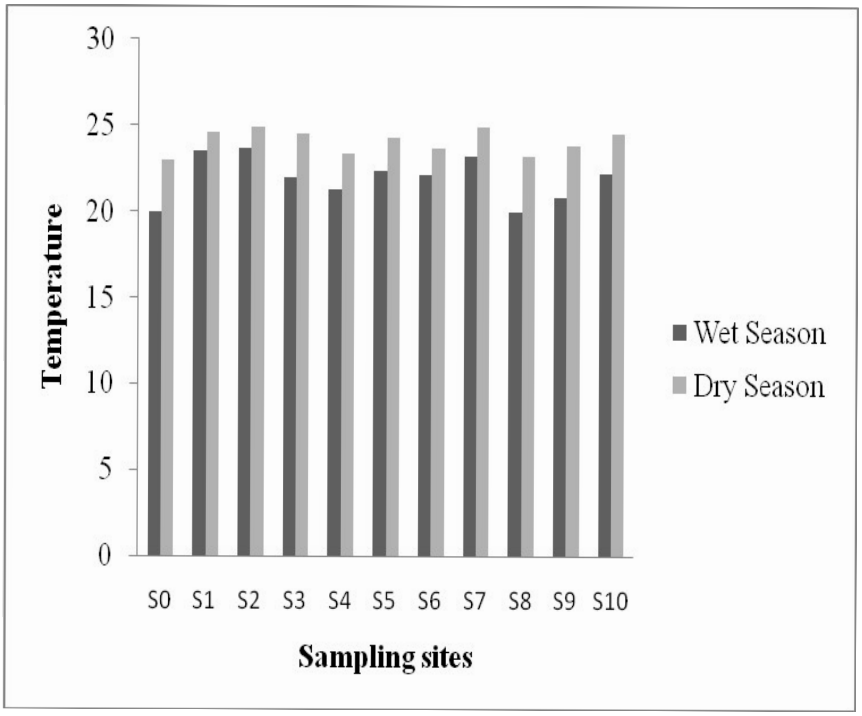

Figure 3.1: Water temperature (°C) in Lake Tana Water

pH (Power of Hydrogen)

In this study the pH difference between the reference and impacted sites was not significant ($P < 0.05$). But there was significant difference in pH value between the wet season and the dry season. pH showed neutrality in the reference site (S_0) and impacted sites S_1, S_2, S_4, S_5 and to S_6 (Figure 3.2). Moderate alkalinity peaks were recorded in S_3, S_6, S_7, S_8, S_9 and S_{10} from pH value 7.8 to 8.4 in the dry season. The reference site pH value was recorded as 7.0 in the wet season and 7.4 in the dry season while impacted sites S_2 6.9 at wet season is increasing to S3 8.4. The maximum pH value was 8.4 recorded at S_3 in the dry season as compared with the minimum value 6.9 at S_2 during the wet season. Both the maximum and the minimum records were at Bahir Dar study area in the southern part of Lake Tana (Figure 3.2) where there are high human activities. But in all sites the wet season pH value was less than the dry season Table 3.1. Rainwater, which has a slightly acidic pH, as well as dilution effect, could be responsible for the decreased pH values in the wet season (Ghana EPA, 2002). Increased pH appears to be associated with increased use of alkaline detergents in residential areas and alkaline material from wastewater in industrial areas, pesticides and fertilizers from agricultural activities (FDREEPA and UNIDO, 2003).

Generally, temporal fluctuations in pH could be attributed to factors like removal of carbon dioxide by the process of photosynthesis through bicarbonate degradation and low primary productivity; besides decomposition of organic matter. The recorded high pH values during dry season might be due to the influence of light penetration and high biological activity as a result of organisms' respiration in the water bodies (Wondie, 2015). pH is an important parameter in water quality assessment because it influences the biological and chemical processes in the water bodies. It is also important in all processes associated with water supply and treatment (Wondie, 2015). It is also a good environmental factor and considered as an index for suitability of the aquatic environment to life (FDREEPA and UNIDO, 2003). The pH of water is very important because it affects the solubility, availability and utilization of nutrients by aquatic organisms (Osman and Kloas, 2010).

Natural fresh waters have a pH range between 6.0 and 8.0 suitable for aquatic organisms (Osman and Kloas, 2010). The largest varieties of aquatic animals prefer a range of 6.5 to 8.0 pH. A pH standard for surface water pollutants with regard to protection of aquatic species is 6.0 to 9.0 (FDREEPA and UNIDO, 2003). When pH is not in this range, diversity within the water body may decrease due to physiological stress and result in reduced reproduction. Extremes in pH can produce conditions that are toxic to aquatic life, alterations in the ionic and osmotic balance of individual organisms that could change in community structure (FDREEPA and UNIDO, 2003). Lethal effects of pH on aquatic organisms occur below 4.5 and above 9.5 (WHO, 2006).

In general, it can be concluded that the pH value of Lake Tana water lies within the permissible range of standards indicated in Table 3.4 suitable to human, livestock consumption and fisheries (Ghana EPA, 2002). But the difference in pH among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas (Table 3.1).

Table 3.4: pH standards of surface water as cited by Osman and Kloas (2010)

pH values	Reference
7.0 – 8.0	WHO (2006)
6.5 – 8.5	Law 25 (1967)
6.5– 9.0	CCME (2007)
6.5 – 8.5	WHO (2008)
6.5 – 8.5	USEPA (2008)
6.5 – 9.5	EU (1998)
6.5 – 8.5	Iranian (1997)
6.5 – 8.5	Australian (1996)
6.5 – 9.2	Indian (2005)
7.0 – 8.5	New Zealand (2008)
6.0 – 9.0	FDREEPA and UNIDO (2003)

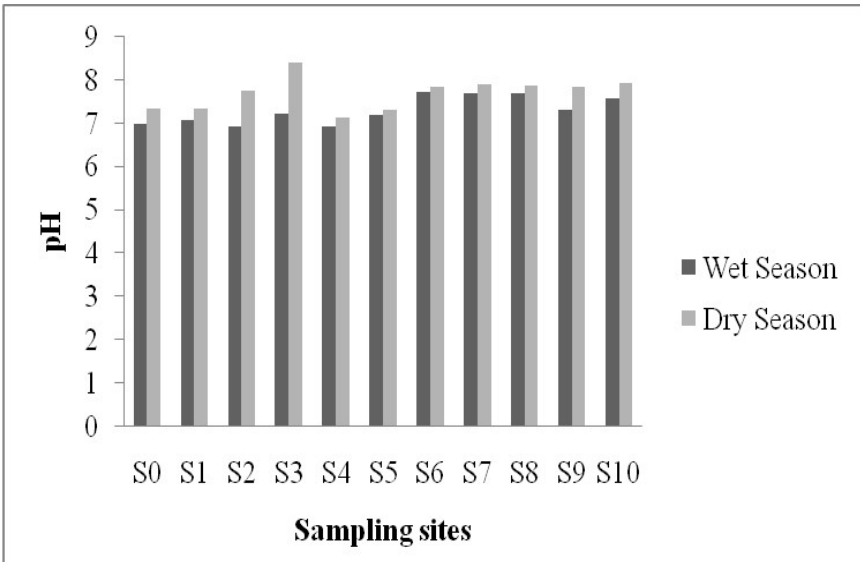

Figure 3.2: Hydrogen ion concentration (pH) in Lake Tana.

EC (Electrical Conductivity)

Electrical conductivity (EC) showed significant difference between the reference and impacted sites as well as between the wet season and the dry season ($P < 0.05$) (Figure 3.3). Highly significant differences in conductivity were observed between Megech study area sites and the rest of the study area sampling sites ($P < 0.05$). Electrical conductivity values in Lake water varied between 78-242 and 89-393 µS/cm during wet season and dry season respectively (Table 3.1). The lowest mean value was recorded in the reference site (Eastern part of Lake Tana) in the wet season and the highest mean value was in S_7 (Northern part of Lake Tana) in the dry season where every effluent of Gondar town and upstream agricultural wastes were discharged to Megech and reached at the study area with stipend run off (Table 3.1, Table 3.2 and Figure 3.3).

EC is a useful indicator of the mineralization in a water sample. EC of the water is the sum of ionic conductance of the ionic constituents. It depends on the dissolved nutrients of the water samples. The EC is an indication of the total amount of ionizable salts in solution (Wondie, 2015). As Wondie, (2015) stated that any rise in the electrical conductivity of water indicates pollution.

EC is a numerical expression of an aqueous solution to carry electric current. This ability depends on the presence of ions, their concentration, mobility, valence, relative concentrations and temperature of a solution. High value of EC in dry season could be due to inflow of high quantum of domestic sewage and increased concentration of salts (ions and cations) that is discharged domestic sewage and organic matter in to the lake; while low values might be due to higher temperature and stabilization of water due to sedimentation. It is generally known that organic loading from domestic and industrial wastes, fertilizers and pesticides increase the lake water ionic concentrations and subsequently conductivity (Osman and Kloas, 2010).

Wet season conductivity was lower than dry season conductivity at all sites (Figure 3.3). Because evaporation of water from the surface of a lake concentrates the dissolved solids in the remaining water and so it has a higher EC. High electrical conductivity which is an indicator of saline conditions (Fatoki and Awofolu, 2003). On the other hand, the large amounts of water received during the wet season contribute to dilution effects and a subsequent lowering of EC.

According to Fatoki and Awofolu (2003), health effects in human beings for consuming water with high EC may include disturbances of salt and water balance, adverse effect on certain mycocardic patients and individuals with high blood pressure.

A standard for priority of surface water pollutants with regard to protection of aquatic species, EC is 1000 mg/l at 20oC (FDREEPA and UNIDO, 2003). The World Health Organization (WHO) limit for EC for drinking and potable water is 700 µS/cm (WHO, 2006). Based on this limit, the Lake Tana water is suitable for domestic use in relation to electrical conductivity recorded in this study. EC was below the permissible limit imposed by the Romanian legislation which is 2500 µS/cm (Osman and Kloas, 2010).

Generally, EC is below the standard limits indicated in Table 3.5. But the variation of pH among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas (Table 3.1).

Table 3.5: EC standards of surface water as cited by Osman and Kloas (2010)

EC (µS/cm)	Reference
1000	SON (2007)
2500	EU (1998)
700	WHO (2003)
2500	RL (2002)
1000	FDREEPA and UNIDO (2003)

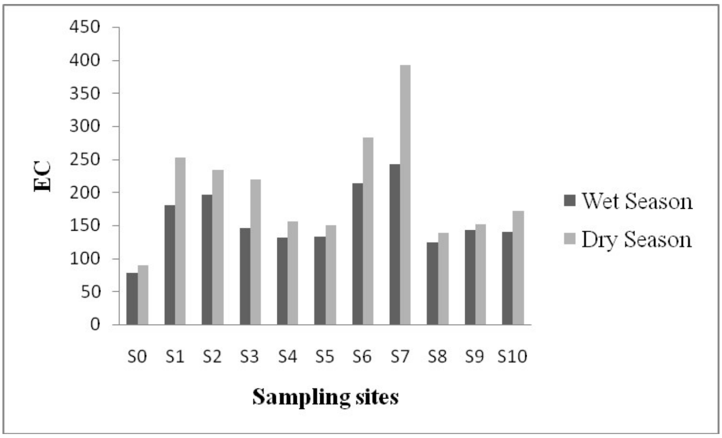

Figure 3.3: Electrical conductivity (EC, µS/cm) in Lake Tana.

BOD_5 (Biological Oxygen Demand)

BOD_5 (Biological Oxygen Demand) represents the amount of oxygen that microbes need to stabilize biologically oxidizable matter in five days. It is found to be more sensitive test for organic pollution (WHO, 2006). There were no significant differences in BOD_5 ($p<0.05$) between the reference site and impacted sites. But there was significant difference between the wet season and the dry season. BOD5 ranges between 4.0-50.0 and 13-114 mg/l in the wet season and dry season respectively (Figure 3.4 and Table 3.2). The highest BOD5 (12.2 mg/l.) was observed at S_7 in the dry season and lowest was in the reference site (4 mg/l) in the wet season (Table 3.1).

Large quantities of organic matter can reduce the chemical and biological quality of surface water. It also resulted in impacted biodiversity of aquatic communities and microbiological contamination that can affect the quality of water. Sources of organic matter are discharges from domestic activities, industrial effluents and agricultural runoff that can affect the water quality. Organic pollution leads to higher rates of metabolic processes that demand oxygen which could result in the lack of oxygen (anaerobic conditions) in the lake water. It indicates that aerobic aquatic organisms' amount of oxygen consumption in the process of metabolizing all the organic matter available in the lake water. High BOD_5 is low levels of dissolved oxygen in polluted water resulting in aquatic organisms becoming stressed and in extreme cases suffocating and dying (WHO, 2006). Therefore, Megech study area sampling sites are more suffocated when compared with others that it is affected by human activities in the upstream, Gondar city and its surroundings.

S_7 is with high BOD5 (114 mg/l). A high oxygen demand indicates the potential for developing DO sag as the microbiota oxidizes the organic matter in the water (FDREEPA and UNIDO, 2003). In all sampling sites the dry season is with high BOD_5 compared with the wet season. This might be because organic matter decomposition is appropriate with the dry season that would influence by temperature.

Generally, the BOD_5 levels recorded in the sampling points except the reference site in the wet season were higher than the EU guidelines of 3.0 to 6.0 mg/1 (BOD5) for the protection of fisheries and aquatic life and for domestic water supply (EU, 1998) as cited by (FDREEPA and UNIDO, 2003) and 5 mg/1 standard limit of WHO and Ethiopian EPA to the protection of aquatic species (FDREEPA and UNIDO, 2003). According to Indian standards, desirable limit of BOD5 is 4.0 mg/1 and permissible limit is 6.0 mg/1. Biological oxygen demand below 3 mg/1 or less is required for the best use in India (Igbinosa et al., 2012). Lake Tana water is used for domestic, recreational and agricultural activities with no treatment especially in the surrounding rural areas. Hence, the BOD5 levels were beyond the indicated permissible limits in most of the sampling sites.

Temperature and pH are limiting factors for the survival of bacteria in the environment for the decomposition process of organic matter that determine BOD_5 which is indicated in all the sampling sites except in the reference site. In the dry season the reference site BOD_5 is 13 mg/1 that might be due to leaf debris decomposition of the riparian vegetation that is highly vegetated. A high oxygen demand indicates the potential for developing DO sag (oxygen depletion) as the micro biota oxidizes the organic matter in the water (Igbinosa *et al.*, 2012).

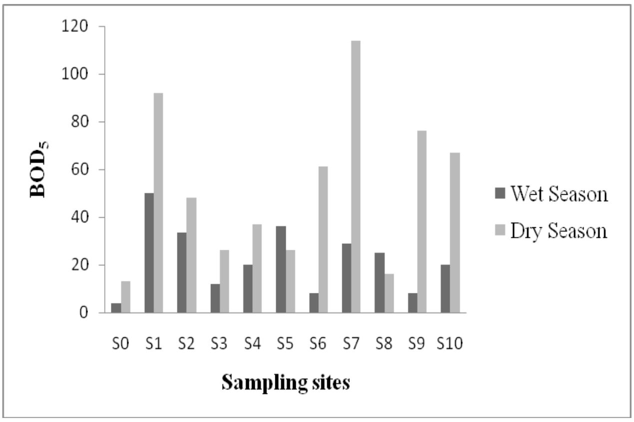

Figure 3.4: Biological Oxygen Demand BOD_5 (mg/l) in Lake Tana.

COD (Chemical Oxygen Demand)

There were significant differences in COD ($p<0.05$) between the reference site and impacted sites as well as the wet season and the dry season (Figure 3.5 and Table 3.2). Within the reference site S0 the COD is less compared with the impacted sites. S0 is 44 mg/l and the impacted sites range from 72 mg/l (S_5) to 456 mg/l (S_7) and S0 is 41 mg/l and the impacted sites range from 39 mg/l (S_8) to 680 mg/l (S_7) in the wet and dry seasons respectively (Table 3.1).

The high COD values observed in this study indicated that both organic and inorganic contaminants from municipal and industrial sources are entering into the water system. This is undesirable when continuously untreated effluent discharged to the water and negatively impacted the quality of the lake water that leads to harm the aquatic life (Igbinosa et al., 2012).

BOD_5 and COD are indices of organic pollution. Since nearly all organic compounds are oxidized in the COD test, COD results are always higher than BOD_5. This was confirmed in this study with all the sampling sites (WHO, 2006).

The increasing trend in COD concentration is found in all the sampling sites except the reference site (44 and 41 mg/l) and impacted sites S_4 (102 and 156 mg/l) and S_5 (72 mg/l and 138 mg/l) in the wet and dry seasons respectively (Table 3.1) when compared to the WHO standard value (200 mg/l) and Ethiopian EPA 150 mg/l (to the protection of aquatic species) which is an indication of pollution from domestic, agricultural and industrial sources (FDREEPA and UNIDO, 2003).

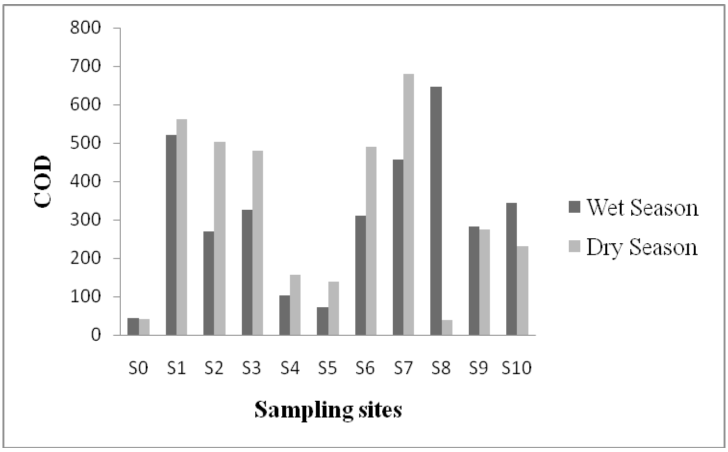

Figure 3.5: Variation in Chemical Oxygen Demand COD (mg/l) of Lake Tana

TSS (Total Suspended Solids)

There were no significant differences in TSS ($p<0.05$) between the reference site and impacted sites. TSS values ranged in the reference site S_0 (0.105 mg/l) and impacted sites S_7 (0.115 mg/l) to S_6 (1.225 mg/l) in the wet season and S0 (0.025 mg/l); S7 (0.113 mg/l) to S_6 (0.514 mg/l) in the dry season (Figure 3.6, Table 3.1 and Table 3.2). Total Suspended Solids (TSS) is known as non-filterable residue, solids (minerals and organic material) that remain trapped on a 1.2 µm filter. TSS elevated concentrations reduce water clarity which can inhibit the ability of aquatic organisms to find food, degrade habitats, clog fish gills, decrease photosynthetic activity, cause an increase in water temperatures, limit the ecological function of aquatic habitats, reduce light penetration, decrease in primary production and reduce food availability for aquatic organisms. Suspended solids could enter Lake Tana through runoff from industrial, urban and agricultural areas (FDREEPA and UNIDO, 2003).

The TSS value in all sampling sites and seasons of Lake Tana was below the WHO and Ethiopian EPA maximum permissible limit of 20 mg/l and 25 mg/l for drinking water respectively. In addition, the levels of TSS in the entire sample points were below the WHO, USEPA and Ethiopian EPA guidelines of 50 mg/l for the protection of fisheries and aquatic life (FDREEPA and UNIDO, 2003). But the difference in TSS among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas (Table 3.1).

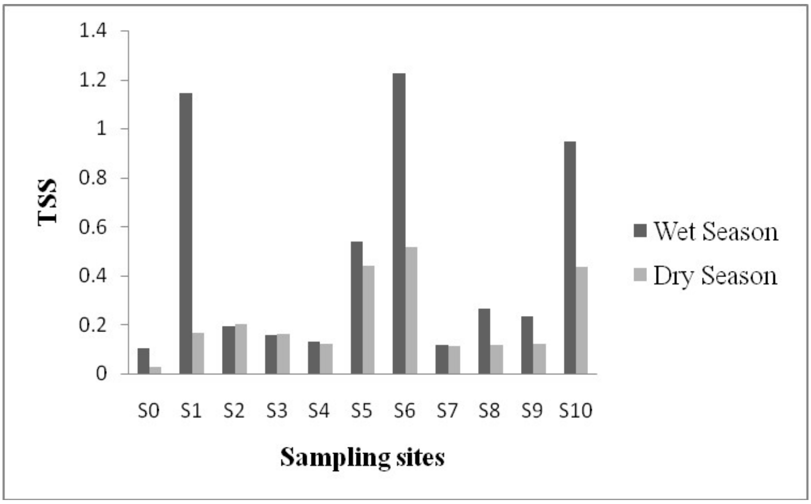

Figure 3.6: Variation in Total Suspended Solids TSS (mg/l) of Lake Tana

TDS (Total Dissolved Solids)

There were no significant differences in TDS ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between wet and dry seasons. TDS values ranged from 66.7 to 119.0 mg/l at impacted sites (S_3 and S_7) respectively in the wet season and 39.0 to 252.0 mg/l at the reference site (S_0) and impacted site (S_6) respectively in the dry season (Figure 3.7). The average TDS value for the two seasons was 93.1 mg/l. The wet season mean value was 78.6 mg/l which is lower than the dry season mean value 107.6 mg/l (Table 3.1). The highest concentration of dissolved solid was 252.0 mg/ 1 measured at S_6 during the dry season while the lowest value was 39 mg/l at S0 during the dry season. The data showed a wide variation in dissolved solids content along the whole of Lake Tana during dry season (Figure 3.7 and Table 3.1).

Variations in TDS may be due to the inflow of domestic and industrial effluent discharges, animal and agriculture wastes which are examples of the types of sources that may contribute to increased TDS concentrations in the sampling sites. Evaporation also leads to an increase in the total salts (FDREEPA and UNIDO, 2003).

Water is a solvent to large number of salts that again influences the physicochemical properties of the water and in turn has an indirect effect on aquatic life forms. Mohamed *et al.* (2009) observed that large amount of dissolved solids result in high osmotic pressure in the aquatic organisms. On the other way, the presence of excess TDS may cause gastrointestinal irritation (Mohamed *et al.*, 2009). It also affects the physiology of aquatic organisms, adaptations of individual species, community structure and microbial and ecological processes (rates of metabolism and nutrient cycling). TDS has synergistic effect with high water temperature that can affect the total community composition and function in the water bodies (FDREEPA and UNIDO, 2003).

The total dissolved solids fluctuated in all sites of Lake Tana in the wet season as well as the dry season was in the tolerance limits indicated in Table 3.6. WHO has 500 mg/1 as maximum tolerance limit for TDS to domestic water supply and the TDS levels recorded in the entire sample points were below the WHO guideline of 1000 mg/l for the protection of fisheries and aquatic life (WHO, 2006). Ethiopian standard to TDS limit is 30 mg/l to the protection of aquatic species (FDREEPA and UNIDO, 2003). Hence the TDS range in Lake Tana water is indicating that Lake Tana has good water quality for drinking, fisheries and irrigation (Mohamed et al., 2009). Even though the TDS values of Lake Tana were below the desirable limit, it was affected by the human activities, because there is variation in TDS among the study areas and sampling sites and the wet and the dry seasons (Table 3.1).

Table 3.6: TDS standards of Surface water as cited by Mohamed et al. (2009)

TDS (mg/l)	Reference
600	WHO (2008)
500	USEPA (2008)
500	Iranian (1997)
500	Australian (1996)
1500	Indian (2005)
100	New Zealand (2008)

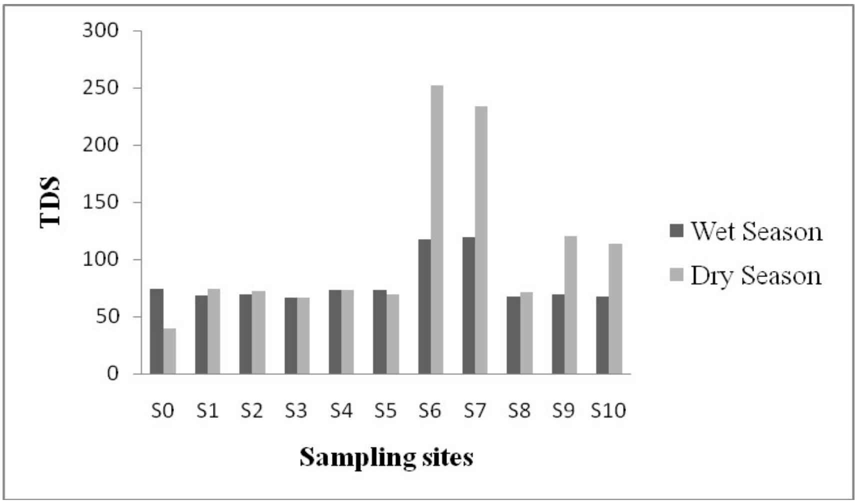

Figure 3.7: Total dissolved solids content TDS (mg/ 1) in Lake Tana.

Conclusion

This study has revealed that there was an undesirable impact on some physicochemical characteristics of Lake Tana due to the discharge of untreated waste entering into the Lake from the watershed municipalities, industries and agricultural activities. This poses domestic use value (drinking, washing etc.), agricultural value, home to biodiversity, recreational value and the source of livelihood.

This study has highlighted the various physicochemical parameters of Lake Tana and seasonal variations in some water quality parameters. The lake was found to be polluted and suffered from waste discharge. The survival of the lake has become impossible mainly due to rapid population growth and anthropogenic destruction. The Lake faces increasing threats from anthropogenic activities. The increasing levels of pollutants in Lake Tana was as a result of agricultural, industrial, urban and domestic waste and it is an issue of concern on water quality, human health and quality of aquatic environment. The presence of pollutants was expressed in terms of pH, BOD_5, COD, TSS and TDS prevailing physicochemical characteristics as indicators of Lake Tana pollution.

The Physicochemical values of Lake Tana indicated that the water was very poor and unfit for drinking and the water requires proper water treatment before use. Hence, the BOD_5 and COD levels are beyond the WHO and Ethiopian EPA standard permissible limits in some of the sampling sites. There is physicochemical characteristics variation between the wet and dry seasons that indicated water quality impairment.

Therefore, continued monitoring of water quality and stricter management measures of Lake Tana are needed to conserve this beautiful natural repositories of flora and fauna. Indigenous technologies should be adopted to make the water fit for societal use.

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References

APHA (2005). Standard methods for the examination of water and wastewater, 21st ed. American Public Health Association, Washington, D.C. 2005, 55.

Barbour M.T., Gerritsen J., Snyder B.D., Stribling J.B. (1999). Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroin vertebrates and fish, 2nd ed. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington D.C.

Barbour, M. T., Gerritsen, J., Snyder, B. D., & Stribling, J. B. (1999). Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish (Vol. 339). Washington, DC: US Environmental Protection Agency, Office of Water.

Barbour M. T., Chris F., Jeroen G., Blaine D. S. (2002). *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish.* Second Edition. James B. Stribling 401 M Street, NW Washington, DC.

Das, J., & Acharya, B. C. (2003). Hydrology and assessment of lotic water quality in Cuttack city, India. *Water, Air, and Soil Pollution*, 150(1-4), 163-175.

Eshete D., (2003). *Ecology and potential for fishery of the small barbs (Cyprinidae, Teleostei) of Lake Tana*, Ethiopia.

Fatoki, O. S., & Awofolu, R. (2003). Levels of Cd, Hg and Zn in some surface waters from the Eastern Cape Province, South Africa. *Water SA*, 29(4), 375-380.

FDREEPA and UNIDO, Federal Democratic Republic of Ethiopia EPA and UN Industrial Development Organization (2003). Guideline ambient environment standards for Ethiopia. Ecologically sustainable industrial development (ESID). Addis Ababa, Ethiopia.

Ghana EPA, Environmental Protection Agency, Ghana (2002). Specific effluent quality guidelines for discharge in to natural water bodies (maximum permissible levels).

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). *An ecosystem perspective of riparian zones. BioScience*, 41(8), 540-551.

Hughes R.M. (1995). Defining acceptable biological status by comparing with reference conditions. in Davis, W. S., & Simon, T. P. (Eds.). (1995). *Biological assessment and criteria: tools for water resource planning and decision making.* CRC Press. Boca Raton, Florida.

Igbinosa, E. O., Uyi, O. O., Odjadjare, E. E., Ajuzie, C. U., Orhue, P. O., & Adewole, E. M. (2012). Assessment of physicochemical qualities, heavy metal concentrations and bacterial pathogens in Shanomi Creek in the Niger Delta, Nigeria. *African Journal of Environmental Science and Technology*, 6(11), 419-424.

Jennifer, L. W., James, W. P., & Frank, E. M. (2003). Florida Marine Research Institute, Florida Fish and Wildlife. *Conservation Commission, St. Petersburg, Florida, USA. Institute of Ecology, University of Georgia, Athens, Georgia, USA.*

Kebede, S., Travi, Y., Alemayehu, T., & Marc, V. (2006). Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia. *Journal of hydrology*, 316(1-4), 233-247.

Misganaw, K., & Getu, A. (2016). Marketing and livelihood contribution of fishermen in Lake Tana, North Western part of Ethiopia. *Fisheries and Aquaculture Journal*, 7(3), 1-6.

Toufeek, M. A., & Korium, M. A. (2009). Physicochemical characteristics of water quality in Lake Nasser water. *Global Journal of Environmental Research*, 3(3), 141-148.

Osman A.G.M, Kloas W. (2010). Water quality and heavy metal monitoring in water, sediments and tissues of the African Catfish Clarias gariepinus (Burchell, 1822) from the River Nile, Egypt. *Journal of Environmental Protection*, Vol. 1.

Pond, G. J., & McMurray, S. E. (2002). A macroinvertebrate bioassessment index for headwater streams in the eastern coalfield region, Kentucky. *Kentucky Department for Environmental Protection, Division of Water, Frankfort, KY [available on internet at http://water. ky. gov/Documents/QA/Surface% 20 Water% 20SOPs/Historic% 20SOPs/EKyMBI. pdf].*

SPSS (2016). SPSS for Windows. SPSS Inc., Chicago.

Stave, K., Goshu, G., & Aynalem, S. (2017). Social and Ecological System Dynamics. Springer Verlag.

Steve O. N., Phillip O. R., Alfred A. (2015). The impact of water quality on species diversity and richness of macroinvertebrates in small water bodies in Lake Victoria Basin, Kenya.Vol. 6(1). DOI: 10.5897/JENE2013.0403. ISSN 2006-9847 © Academic Journals http://www.academicjournals.org/JENE

Tesfaye W. (1998). Biology and Management of Fish Stocks in Bahir Dar Gulf Lake Tana, Ethiopia. Wageingen University, Netherlands.

Vincy, M. V., Rajan, B., & Pradeep Kumar, A. P. (2012). Water quality assessment of a tropical wetland ecosystem with special reference to Backwater Tourism, Kerala, South India. *International Research Journal of Environment Sciences*, 1(5), 62-68.

WHO (2006).Guidelines for drinking - water Quality First Addendum to Third Edition. Volume 1 Recommendations Geneva, Switzerland.

Wondie Z. A. (2015). Comparative study on composition and abundance of major planktons and physico-chemical characteristics among two ponds and Lake Tana, Ethiopia. Journal of Coastal Life Medicine; 3(11): journal homepage: www. jclmm.com