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Water Quality Status of Lake Tana, Ethiopia

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Abstract
The purpose of this study was to assess the physico-chemical water quality status of Lake Tana at 25 sampling sites from August 2011 to July 2012.A total of 150 water samples from 25 sites on Lake Tana were collected in the period August 2011 to July 2012. Water samples were collected from Lake Tana using acid–washed polyethylene bottles for chemical analysis(nutrients).In-situ measurements of physical properties were determined using Multi-Maji parameter by dipping the probe about 3-5cm below the water surface. Lake Tana water is slightly alkaline of acceptable pH range (*p*H range 6.98 to 9.97).The temperature varies between 16.4^{o}c to 31.3 ^{o}c. Lake Tana has high turbidity (ranges5.1 to 989 NTU) with high seasonal variation. The electrical Conductivity (EC) value ranges between60 µS/cm to 1000µS/cm. It has low TDS (20 to500mg/l).The alkalinity value varies between21 to 3630mg/l. The total hardness value ranges between 65 mg/l to 5300 mg/l. The nitrate value ranges between 0.003 mg/l to 4.7 mg/l. The nitrite value ranges between not detectable to 3.4 mg/l-N 0 to 3.25mg/l. The ammonia value varies between0 to 6.6mg/l. The phosphate value varies between 1.55 to 15.8mg/l. Trends for the Lake Tana water quality monitoring sites and overall trends for the period between 2011 and 2012 time period, there were generally a mixture of both increasing and decreasing trends for all analyses. There were increasing overall trends for electrical conductivity, ammonia, total alkalinity and total hardness and decreasing overall trends for PH, temperature, turbidity, total dissolved solid, nitrate and nitrite. No trend or stable overall trends for phosphate.
Keywords: Lake Tana, physico-chemical properties, water quality, spatial variations, and trends

1. Introduction

Water is essential to human being, animals, and plants and without water life on earth would not exist. Humans need water not only for drinking but also for various other purposes like bathing, washing, cooking, industrial, agricultural, and recreational activities (Mulugeta, 2012; Yirga et al., 2015. Therefore, adequate supply of potable water is necessary for proper health care and significant socio-economic development. However, water resources all around the world are under pressure. The rapid industrialization, growing urbanization and increasing use of chemicals in agriculture constitutes some of the important factors responsible for various forms of pollution of water bodies (Tripathi and Pandey, 1990)

This raises the need to address the problem of water pollution with the view of monitoring the situation and formulating possible mitigating measures. Monitoring the water quality is used to assess the usability of that water for a particular purpose, whether for human consumption, agricultural production, industry or the needs of the environment. During the last decades, there has been an increasing demand for monitoring water quality of many rivers by regular measurements of various water quality variables (Vassilis et.al., 2001).The Physico-chemical characteristics of water are important parameters as they may directly or indirectly affect its quality and consequently its suitability for the distribution and production of fish and other aquatic animals (Moses, 1983; Ezekiel, 2011).

In Ethiopia, some studies have been conducted regarding surface water pollution due to human induced impacts. In South Ethiopia, the physico-chemical characteristics of the Rift valley lakes have been studied systematically and in much detail (Elizabeth et al., 1994; Zinabu et al., 2002).This in contrast with the North Ethiopian water bodies where information on physico-chemical and microbial water quality contamination is generally scanty (Wood and Talling 1988; Elizabeth et al, 1992; Berhanu et al, 2002).Goraw et al.(2010) conducted a pilot study on anthropogenic faecal pollution impact in Bahir Dar Gulf of Lake Tana, Northern Ethiopia. Their interest was mainly on the faecal pollution impact in Bahir Dar Gulf of Lake Tana. They didn't include physico-chemical parameters and the data generated from their work could be considered spatially and temporally limited. Recently, Tana Sub Basin Organization (TaSBO) already established water quality monitoring stations at Lake Tana within the framework of Tana-Beles integrated water resource development project (TBIWRDP). In the year 2011, annual report on Lake Tana water quality baseline monitoring was produced by TaSBO. The Lake Tana water quality baseline monitoring report result revealed that the physico-chemical as well as biological characteristics of the major tributary rivers of Lake Tana, river mouths and lake shore areas were significantly different from open (pelagic) station of the Lake(TaSBO,2011).

The present study is the continuation of the Lake Tana baseline water quality monitoring. Thus it was seek to answer the following research questions:(a) Is there a significant variations in different water quality parameters within littoral, pelagic(open) and river mouth stations of lake Tana?, (b) Is there a significant variations in different water quality parameters between the dry and wet season of Lake Tana?, (c)Is all physico-chemical properties of this study indicate increasing trend?,(d) Is all the water quality samples of Lake Tana compliance with different fisheries and aquatic life standards?, and (e) Which of the physico-chemical water quality parameters of Lake Tana is/are identified as the main water quality concern of Lake Tana?. To answer these questions, this study intends to provide comprehensive information about physico-chemical water quality status and trends of Lake Tana.

The overall objective of this study was to determine the water quality status of the Lake Tana. The specific objectives of the study were to: (a) study the physico-chemical characteristics of the Lake Tana water quality; (b) reveal spatial and temporal changes and trends on Lake Tana and its major tributaries; (c) determine compliance with different fisheries and aquatic life standards and (d) propose recommendations for the efficient management of the Lake ecosystem. The physico-chemical water quality assessment of Lake Tana water quality will be discussed in detail in this paper.

2. Methods and Materials

2.1 Study Area

This study was carried out from August 2011- July 2012 in Lake Tana. It is the largest freshwater lake of Ethiopia. Lake Tana is located at latitude 12º00'N, and longitude 37º15'E on the basaltic Plateau of the North Western highlands of Ethiopia. Its surface area ranges from about 3,050km^2 in the dry season to 3,600 km^{2}at the close of the rainy season, with a perimeter length ranging from 3,000,000 to 3,187,730 m depending on season and rainfall. The lake is about 68 km wide and 73 km long with a previously recorded maximum depth of 14m and average depth of 8.8m(Busulwa,2009).The Basin of Lake Tana is located between 10°56` to 12°45`N latitude and 36°44`- 38°14`E longitude. It is one of the sub-basin of Abay River Basin, has a drainage area of 15054km^2.The Lake Tana covers (20%) while the terrestrial part covers (80%) of the total sub-basin.

Lake Tana is fed by over 60 rivers and streams draining from the watershed and form complicated hydrologic networks. The major rivers that drain to Lake Tana are Gilgel Abay, Gumera, Ribb, Gelda, Megech and Dirma rivers. Gilgel Abay meaning "small Abay/Nile" is located at southwestern part of Lake Tana while Gumera and Rib Rivers are situated on eastern shore of Lake Tana and they are the Largest Rivers next to Gilgel Abay. Megech and Dirma River are located at the northern part of Lake Tana.

Tana sub-basin has been designated as one of five growth corridors in Ethiopia. Within this framework, an increasing number of ad-hoc investments has been taking place or is being planned around Lake Tana: the construction of dams for hydropower generation, small and large-scale irrigation schemes, other investments in agriculture, agro-industry, micro-enterprises, hotels and tourism around Lake Tana, and a floriculture site of 700 ha for export. Currently those investment activities affect the water quality of Lake Tana.

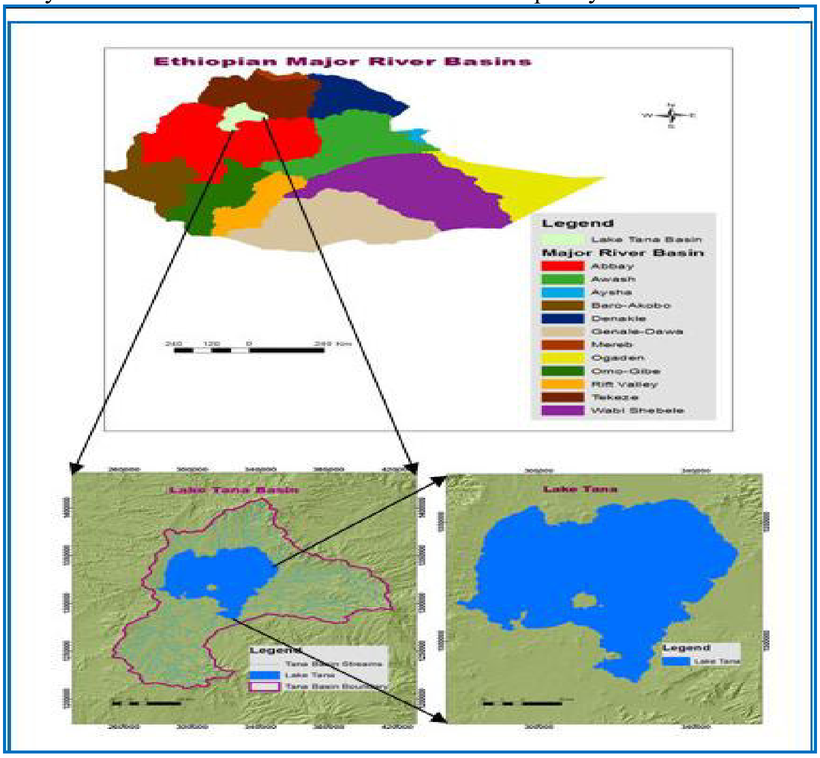

Figure 1.Location Map of the study area (taken from Yirga et al., 2015)

2.2 Sampling Site

Water samples from the littoral, pelagic (open), river mouth and major tributary Rivers of Lake Tana were collected. Littoral parts are mainly the shore areas or the periphery of the lake that are highly affected by anthropogenic sources of pollution while pelagic parts are the open (the interior parts of the Lake) that are relatively less affected by anthropogenic sources of pollution. The river mouths are the places where the major perennial rivers joined with Lake Tana. Sampling stations at major tributaries of Lake Tana account anthropogenic sources of pollution from the Lake Tana Sub-basin that contributes for the Lake water pollution. 25 sampling stations (12 sites from littoral station both in the southern and northern part of the lake, 5 sites from open water, 3 sites from river mouth stations and5 sites from the major tributary Rivers of Lake Tana) were chosen based on baseline monitoring objectives, parts of the Lake where highly affected by anthropogenic impacts and parts of the Lake where relatively less affected by anthropogenic impacts.

Table 1.Water Quality Sampling Stations of Lake Tana

No.	Sampling Site Name	Sampling Site Code	Category of Sampling Sites	Coordinates	
				East	North
1	Zegie-01	LI01	Littoral	0316933	1293100
2	Zegie-02	LI02	Littoral	0316434	1292853
3	Delgie-01	LI03	Littoral	0288430	1348474
4	Delgie-02	LIO4	Littoral	0287602	1347306
5	Gorgora-01	LIO5	Littoral	0315435	1353634
6	Gorgora-02	LIO6	Littoral	0315312	1353905
7	Kunzeila-01	LIO7	Littoral	0285982	1314649
8	Kunzeila-02	LIO8	Littoral	0283637	1314477
9	Bahirdar Mango Park	LIO9	Littoral	0324202	1282558
10	Bahirdar Fishery Research	LI10	Littoral	0323162	1283960
11	Bahirdar Alema	LI11	Littoral	0324466	1282557
12	Bahirdar Tana Hotel	LI12	Littoral	0324917	1283093
13	Zegie open	PE01	pelagic	0320898	1294729
14	Near Dik	PE02	pelagic	0324917	1284803
15	Angara	PE03	pelagic	0315300	1350099
16	Sekelet	PE04	pelagic	0308117	1309378
17	Deqe Estifanos	PE05	pelagic	0316549	1315958
18	Rib River Mouth	RMO1	River Mouth	0346738	1331328
19	Gumara River Mouth	RMO2	River Mouth	0335167	1316327
20	Abay River Mouth	RMO3	River Mouth	0293925	1314066
21	Ribb River	MTR01	Major Tributary River	0359658	1326162
22	Gumara River	MTR02	Major Tributary River	0351293	1309078
23	Megech River	MTR03	Major Tributary River	0331322	1380956
24	Dirmma River	MTR04	Major Tributary River	0318056	1374398
25	Abay River	MTR05	Major Tributary River	0294705	1313687

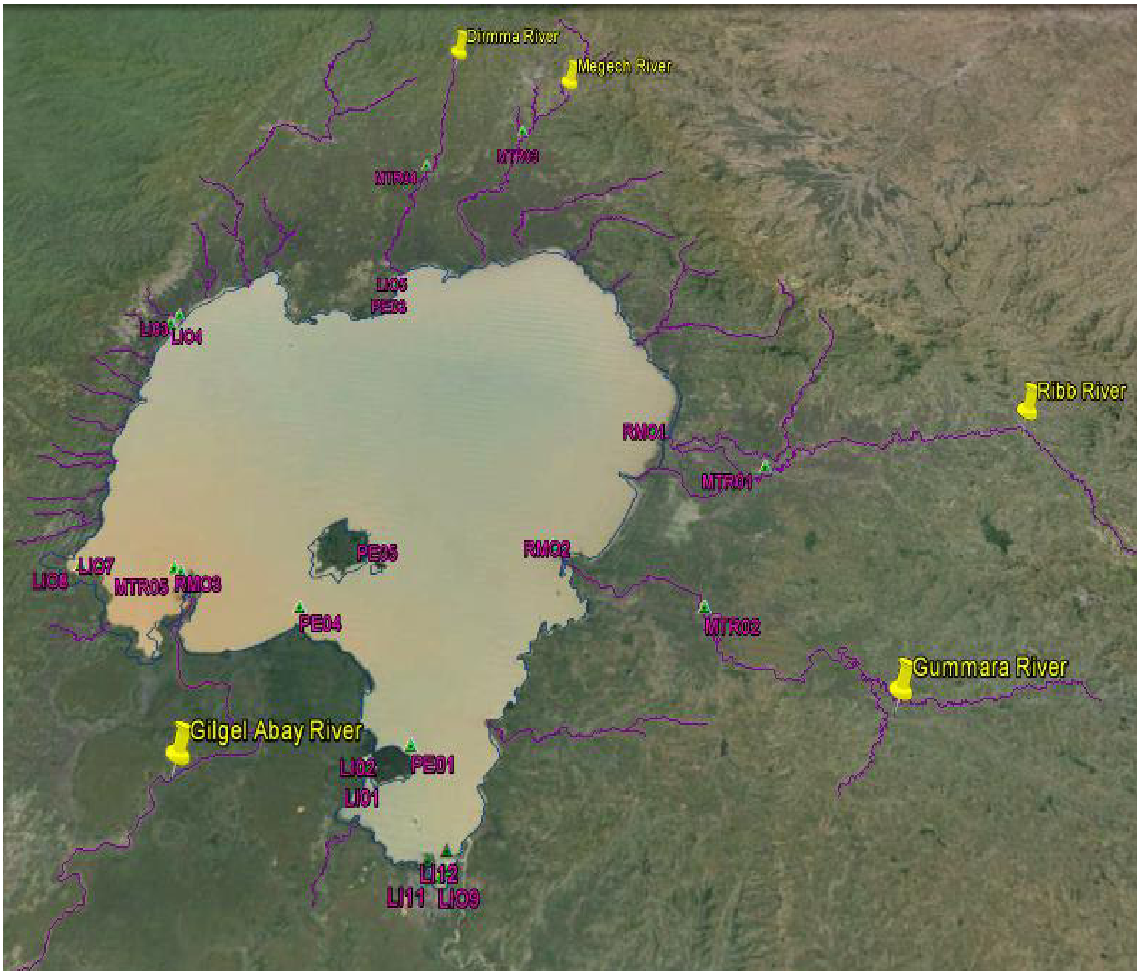

Figure 2.Location Map of Water Quality Sampling Stations (Sampling Site Code) in Lake Tana

2.3 Sampling and Laboratory Analysis

A total of 150 water samples from 25 sites on Lake Tana (Figure.2) were collected in the period August 2011 to July 2012. Water samples were collected from Lake Tana using acid–washed polyethylene bottles for chemical analysis(nutrients) based on standard procedures (APHA, 1992).The sample bottles were immediately kept in an ice cooled box and transported to the laboratory where they were analyzed within six hours from the time of collecting the first sample with a mobile water analysis kit (Wagtech international, Palintest transmittance display photometer 5000, Palintest Ltd., UK).In-situ measurements of physical properties were determined using Multi-Maji parameter by dipping the probe about 3-5cm below the water surface. A total of 11 physicochemical parameters including pH, temperature, turbidity, electrical conductivity (EC), total dissolved solid (TDS), total alkalinity (TA), total hardness (TA), nitrate, nitrite, ammonia and phosphate were analyzed in this study.

2.4 Data Analysis

Data analysis is one of the most important aspects of the report, because it is the principal mechanism by which raw data are transferred into usable information to reach conclusions. Statistical analysis was done with Microsoft Excel (2013) and IBM SPSS Statistics 20. Using Microsoft Excel (2013), differences among the littoral, pelagic (open), river mouths and major tributaries of Lake Tana water quality were tested using maximum value, minimum value, mean and standard deviation of the pooled data for the whole sites.

Data analysis was performed with SPSS(analysis of variance) to assess or check the presence of significant variations of the selected physico-chemical parameters of Lake Tana water quality among the categories of the sampling sites of Lake Tana i.e., littoral, pelagic(open),river mouth and major tributaries of Lake Tana. Furthermore, data analysis was performed with SPSS to analysis the correlation between the variables of the physico-chemical parameters of Lake Tana sediments.

To understand the spatial variability of physico-chemical characteristics of the Lake water quality, different water quality maps were produced using ARC GIS 10.1 Software. These maps clearly indicate the spatial variation of physiochemical characteristics as point data in the form of concentration circles. The value was reclassified into a number of concentration circles by taking into account the standards developed for each physico-chemical parameters using ARC GIS10.1 Software, symbology, quantities (graduated symbols).

The trend assessment was carried out for two years using the Time Trends Software (http;//www.niwa.co.nz/our-science/freshwater/tools/analysis).The Man-Kendall test was used to evaluate the trends of physico-chemical parameters at various Lake Tana water quality monitoring sites; river mouths, lake open part, shore areas and river stretches. Sample data collected between the periods August 2011 to July 2012 were used for this trend analysis. The Man-Kendall trend test a non-parametric test for identifying trends in time series data. The test compares the relative magnitude of the sample data rather than the data values themselves (Gibert, 1987). In this Time Trends Software, the Man-Kendall test includes the computation of: Man-Kendall Statistics(S), variance (VAR(S)), normalized test statistic (Z), probability associated with Man-Kendall Statistics(S),median annual sen slope(SSE),relative sen slope estimate(RSSE) and Median RSSE. The overall median RSSE value is an indication of the overall trends of the water quality of Lake Tana. A positive median RSSE indicates an increasing trend, while a negative median RSSE indicates a decreasing trend.

3. Results and Discussions

3.1 Physico-chemical Water Quality of Lake Tana

3.1.1 Physical Water Quality of Lake Tana

Table 2.Average, Maximum and Minimum Values for Various Physical Parameters of Lake Tana Water

	Site Code	***PH***			***Temperature***(ºc)			***Turbidity***(NTU)			***Conductivity***(mS/cm)			***Total Dissolved Solid***(mg/l)		
		Av	Ma	Mi	Av	Ma	Mi	Av	Ma	Mi	Av	Ma	Mi	Av	Ma	Mi
1	LI01	8.2	8.4	7.8	*24.9*	*28*	*22*	*34*	*63*	*18*	*126*	*169*	*21.5*	*74*	*109*	*22*
2	LI02	*8.0*	*8.3*	*7.5*	*23.4*	*26*	*21*	*36*	*58*	*19*	*120*	*180*	*21.2*	*68*	*118*	*21*
3	LI03	*8.1*	*8.5*	*8.0*	*21.7*	*25*	*17*	*103*	*259*	*21*	*118*	*168*	*21.1*	*64*	*109*	*21*
4	LIO4	*8.0*	*8.5*	*7.7*	*21.8*	*31*	*17*	*166*	*603*	*20*	*121*	*167*	*20*	*66*	*108*	*20*
5	LIO5	*8.3*	*8.6*	*7.9*	*22.6*	*25*	*20*	*47*	*101*	*24*	*117*	*170*	*23.6*	*64*	*110*	*24*
6	LIO6	*8.4*	*9.0*	*7.8*	*23.8*	*25*	*22*	*47*	*104*	*24*	*114*	*170*	*24.3*	*66*	*110*	*24*
7	LIO7	*8.2*	*8.4*	*7.9*	*22.8*	*24*	*20*	*96*	*260*	*19*	*141*	*170*	*110*	*77*	*110*	*60*
8	LIO8	*8.1*	*8.4*	*7.7*	*23.0*	*26*	*20*	*122*	*312*	*33*	*146*	*191*	*120*	*79*	*124*	*60*
9	LIO9	*8.0*	*8.4*	*7.6*	*23.7*	*26*	*22*	*27*	*39*	*16*	*127*	*177*	*23*	*66*	*115*	*23*
10	LI10	*8.0*	*8.2*	*7.9*	*23.7*	*26*	*22*	*33*	*87*	*13*	*120*	*179*	*22.2*	*65*	*116*	*22*
11	LI11	*7.9*	*8.4*	*7.1*	*23.5*	*26*	*22*	*27*	*43*	*14*	*122*	*178*	*21.6*	*66*	*115*	*22*
12	LI12	*8.0*	*8.4*	*7.8*	*23.7*	*26*	*23*	*26*	*40*	*14*	*122*	*179*	*23.7*	*65*	*116*	*24*
13	PE01	*8.3*	*8.9*	*8.1*	*23.2*	*25*	*21*	*37*	*76*	*12*	*141*	*176*	*120*	*77*	*114*	*60*
14	PE02	*8.3*	*8.6*	*8.0*	*23.2*	*25*	*21*	*39*	*72*	*14*	*145*	*175*	*120*	*77*	*113*	*60*
15	PE03	*8.3*	*8.6*	*8.1*	*23.2*	*25*	*21*	*40*	*102*	*20*	*114*	*168*	*24.2*	*64*	*109*	*24*
16	PE04	*8.3*	*8.6*	*8.1*	*23.0*	*25*	*21*	*49*	*74*	*21*	*145*	*174*	*120*	*81*	*113*	*60*
17	PE05	*8.2*	*8.5*	*7.7*	*22.6*	*24*	*21*	*24*	*35*	*15*	*119*	*160*	*22.5*	*63*	*102*	*23*
18	RMO1	*8.2*	*9.3*	*7.4*	*22.7*	*26*	*17*	*265*	*686*	*49*	*161*	*240*	*104*	*85*	*120*	*50*
19	RMO2	*8.0*	*8.5*	*7.1*	*22.1*	*24*	*19*	*83*	*134*	*16*	*118*	*164*	*52*	*63*	*107*	*33*
20	RMO3	*8.5*	*10.0*	*7.6*	*25.0*	*31*	*20*	*294*	*729*	*14*	*151*	*311*	*60*	*85*	*202*	*20*
21	MTR01	*7.8*	*8.3*	*7.0*	*23.4*	*28*	*20*	*269*	*783*	*6*	*360*	*1000*	*56*	*188*	*500*	*36*
22	MTR02	*8.2*	*8.4*	*8.0*	*23.5*	*28*	*20*	*295*	*822*	*43*	*154*	*280*	*35*	*82*	*141*	*22*
23	MTR03	*8.2*	*8.5*	*7.8*	*22.8*	*25*	*18*	*82*	*266*	*5*	*333*	*573*	*220*	*188*	*373*	*110*
24	MTR04	*8.2*	*8.7*	*7.7*	*21.0*	*26*	*16*	*190*	*989*	*10*	*415*	*970*	*16.4*	*219*	*480*	*16*
25	MTR05	*8.0*	*9.0*	*7.5*	*22.8*	*26*	*20*	*199*	*683*	*34*	*111*	*158*	*28*	*57*	*102*	*18*
Overall mean		*8.18*	*8.6*	*7.5*	*24.92*	*26*	*22*	*199*	*296.8*	*34*	*158*	*265.9*	*57.2*	*73.9*	*157.4*	*35*

Key: Av refers Average, Ma refers Maximum & Mi refers Minimum

Table 3.Values of Pearson correlation coefficient (r) for various physico-chemic Water Quality of Lake Tana

	pH	**Temp.**	**Turbidity**	**EC**	**TDS**	**TA**	**TH**	**Nitrate**	**Nitrite**	**Ammonia**	**Phosphate**
pH	1										
Temp.	.189	1									
Turbidity	.009	-.068	1								
EC	-.106	-.302	.400*	1							
TDS	-.073	-.280	.377	.997**	1						
TA	.030	-.157	.855**	.491*	.470*	1					
TH	-.171	-.412*	.675**	.478*	.452*	.823**	1				
Nitrate	-.122	-.082	.759**	.418*	.398*	.763**	.836**	1			
Nitrite	-.249	-.313	.608**	.285	.254	.746**	.797**	.705**	1		
Ammonia	-.212	-.423*	.627**	.522**	.490*	.777**	.932**	.747**	.787**	1	
Phosphate	-.003	-.166	.847**	.427*	.406*	.962**	.905**	.855**	.801**	.827**	1

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

pH is an important factor in determining the productivity of an ecosystem (Singh, *et al.* 2009; Laishram and Dey, 2014).The pH value in this study ranged between 6.98 to 9.97.The maximum pH (9.97) was recorded during January at Abay River Mouth (RMO3) and the minimum pH (6.98) was recorded during March, 2012 at Rib River (MTR01), which is beyond the standard range of 6.5 to 8.5.High January pH during may be due to removal of large amount of Co_2 photosynthetic process by aquatic plants. The average pH ranged 7.8 to 8.5 with the overall mean value of 8.18 which is slightly alkaline(table 2).When compared with pH values of Lake Hawassa in Sothern part of Ethiopia (ranged 7.00 to7.7 average values of 7.5 by Admasu(2015), the pH value of Lake Tana was found to be higher. Comparatively, the overall mean value of water pH of Lake Tana is slightly alkaline (8.18) than the sediment pH of Lake Tana (6.5) reported in Yirga et al.(2015).From the total 146 samples, 142 samples (97.26%) complied with the European Union Fisheries and Aquatic Life criterion (6.0-9.0).The pH of the lake is within the permissible limits of (MoWR, 2002; EEPA, 2003;WHO, 2006) for drinking, recreation, agricultural and aquatic life water use (6.5-8.5/9).The factors like photosynthesis, respiratory activity, temperature exposure to air, disposal of industries wastes etc bring out changes in the pH. The variations of pH within littoral, pelagic, river mouth and major tributary were statistically insignificant at the 5% level (0.115).pH values of this study does not have any significant correlations with other physicochemical parameters.

Temperature is an important factor, which regulates the biogeochemical activities in the aquatic environment. The temperature varies between 16.4^{o}c to 31.3 ^{o}c. The minimum (16.4^{o}c) was recorded at Dirma River(MTR04) July, 2012 and the maximum temperature (31.3^{o}c) was recorded at Abay River Mouth(RMO3) during March, 2012.The average temperature ranged between 21 to 25^{o}c with the overall mean value of 24.92^{o}c(table 2).When compared with temperature values of Lake Hawassa in Sothern part of Ethiopia (varied between 20.98 and 21.33^{o}c with an average value of 21.23^{o}c to the lake system by Admasu, 2015), the temperature value of Lake Tana was found to be higher. The temperature values in this study almost agreed with the PhD work of Ndungu (2014) on assessing water quality in Lake Naivasha (Kenya), the temperature values in the study sites the mean value ranged from 22.5 to 24.4^{o}c with the overall mean value of 23.4^{o}c. The spatial variation in temperature could be explained by altitudinal difference between tributaries that tribute into the lake and the sites in the Lake. The maximum temperature during March was due to high solar radiation, low water level, clear atmosphere and higher atmospheric temperature. The variations of temperature within littoral, pelagic, river mouth and major tributary were statistically insignificant at the 5% level (0.745).Temperature was negatively correlated with all physicochemical parameters considered in this study except pH which is positively correlated(r=0.189)

Turbidity ranges between 5.1 to 989 NTU with high seasonal variation. The maximum turbidity (989 NTU) in water was recorded during August, 2011 at Dirma River (MTR04); major tributaries of Lake Tana in Northern part of the Lake while minimum turbidity (5.1 NTU) was recorded during November at Megech River (MTR03). The average turbidity ranged between 24 to 295 NTU with the overall mean value of 199NTU (table 2).The turbidity of the lake water is higher than the permissible limit <5 NTU WHO (1984), while WHO (2006) stated that drinking water is best consumed with NTU less than 1NTU for health purposes. When compared with turbidity values of Lake Naivasha in Kenya (the mean value varied between 10.05 to 67.17NTU with the overall mean value of 30.86NTU by Ndungu (2014) and the turbidity values of Lake Hawassa in Sothern part of Ethiopia ranged between 6.82 to 20.98 NTU with an average value of 8.44 NTU by Admasu (2015), the turbidity value of Lake Tana was found to be much higher. The high turbidity during August may be due to catchment runoff, soil erosion, waste discharge from urban areas (Bahir Dar and Gonder), and recession agriculture around the Lake. The high turbidity observed in the stations is attributable to poor farming practices which result in large quantities of top soil ending up in the rivers and Lake Tana after heavy rains. The variations of turbidity within littoral, pelagic, river mouth and major tributary were statistically significant at the 5% level (0.000).Turbidity values of this study have significant positive correlation at 0.01 level (2-tailed) with other chemical parameters such as alkalinity($r= 0.855^{**}$), total hardness($r=0.675^{**}$), nitrate($r=0.759^{**}$), nitrite($r=0.608^{**}$),ammonia($r=0.627^{**}$) and phosphate ($r=0.847^{**}$).

The values of EC ranged between 60 µS/cm to 1000µS/cm. The EC values of this study agreed with the previous baseline water quality monitoring study of Lake Tana by TaSBO (2011) of EC value ranged 40 to 1000µS/cm. The high value of conductivity was recorded during March in Rib River (MTR01), and low value was recorded during August in Abay River Mouth (RMO3) and Abay River (MTR05). The average EC varies between 111 to 415µS/cm with the overall mean value of 158 µS/cm is in far below the WHO guideline value prescribed for drinking purpose (1500 µS/cm) and EPA guideline (1000 µS/cm).When compared with the EC values of Lake Naivasha in Kenya(the mean value varied between 251to 421µS/cm with the overall mean value of 302.28µS/cm by Ndungu (2014) and the EC values of Lake Hawassa in Sothern part of Ethiopia with an average value of 750.1µS/cm by Admasu (2015), the EC value of Lake Tana was found to be much lower. The variations of EC within littoral, pelagic, river mouth and major tributary were statistically significant at the 5% level (0.001).There was a positive correlation between EC and TDS ($r =0\ 997^{**}$). The correlation is significant at the 0.01 level (2-tailed).This was expected because the properties of conductivity are governed by the characteristics of the constituents inorganic salts dissolved in water.

The total dissolved solids in water comprise mainly of inorganic salts and small amount of organic matter such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium. The total dissolved solid (TDS) values were found to be in the range of between 20 to 500 mg/l. The TDS values of this study agreed with the former baseline water quality monitoring study of Lake Tana by TaSBO (2011) of TDS value ranged 20 to 490mg/l. The minimum TDS (20mg/l) was recorded at Abay River Mouth(RMO3) during August, 2011 while the maximum TDS (500mg/l) was recorded at Rib River(MTR01) during March, 2012.The average TDS ranged between 57 to 219mg/l with the overall mean value of 73.9mg/l(table 2).When compared with the TDS values of Lake Naivasha in Kenya(the mean value varied between 124 to 205mg/l with the overall mean value of 152 by Ndungu(2014) and the TDS values of Lake Hawassa in Sothern part of Ethiopia with the highest value of 455.6 mg/l by Admasu(2015), the TDS value of Lake Tana was found to be lower. The variations of TDS within littoral, pelagic, river mouth and major tributary were statistically significant at the 5% level (0.001). TDS showed positive correlation with all physicochemical parameters considered in this study except pH(r=-0.073) and temperature(r=-0.280). Particularly TDS showed highly significant positive correlation with electrical conductivity (0.997^{**}), alkalinity (0.470^{*}), total hardness (0.452^{*}), nitrate (0.398), ammonia (0.490^{*}) and phosphate ($r=0.406^{*}$).

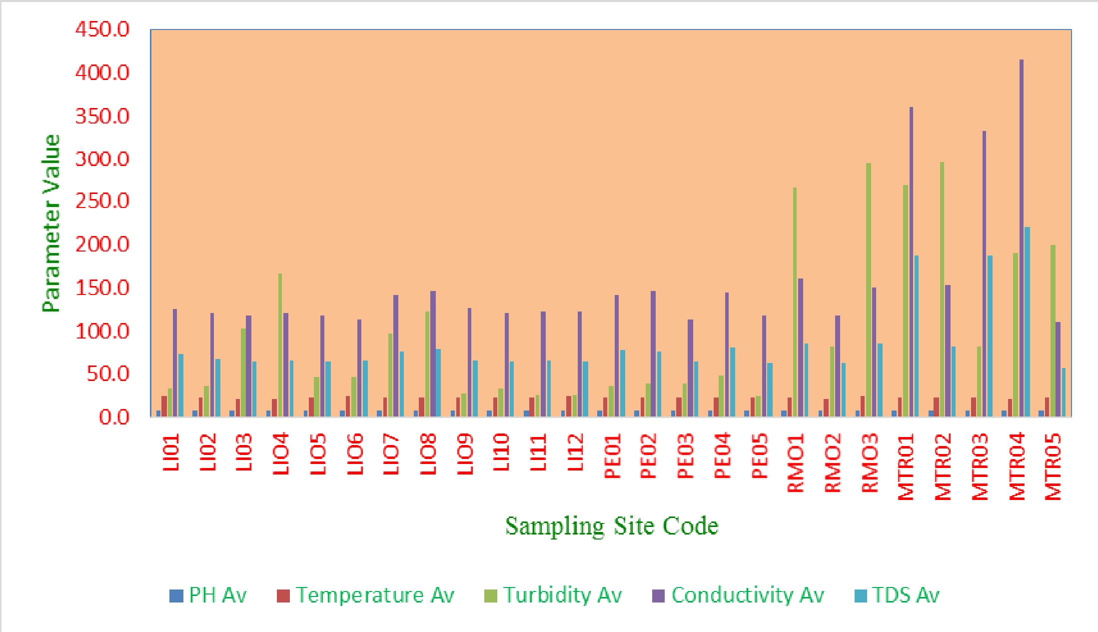

Figure 3.Graphs of Average Spatial Variation of Physical Water Quality of Lake Tana

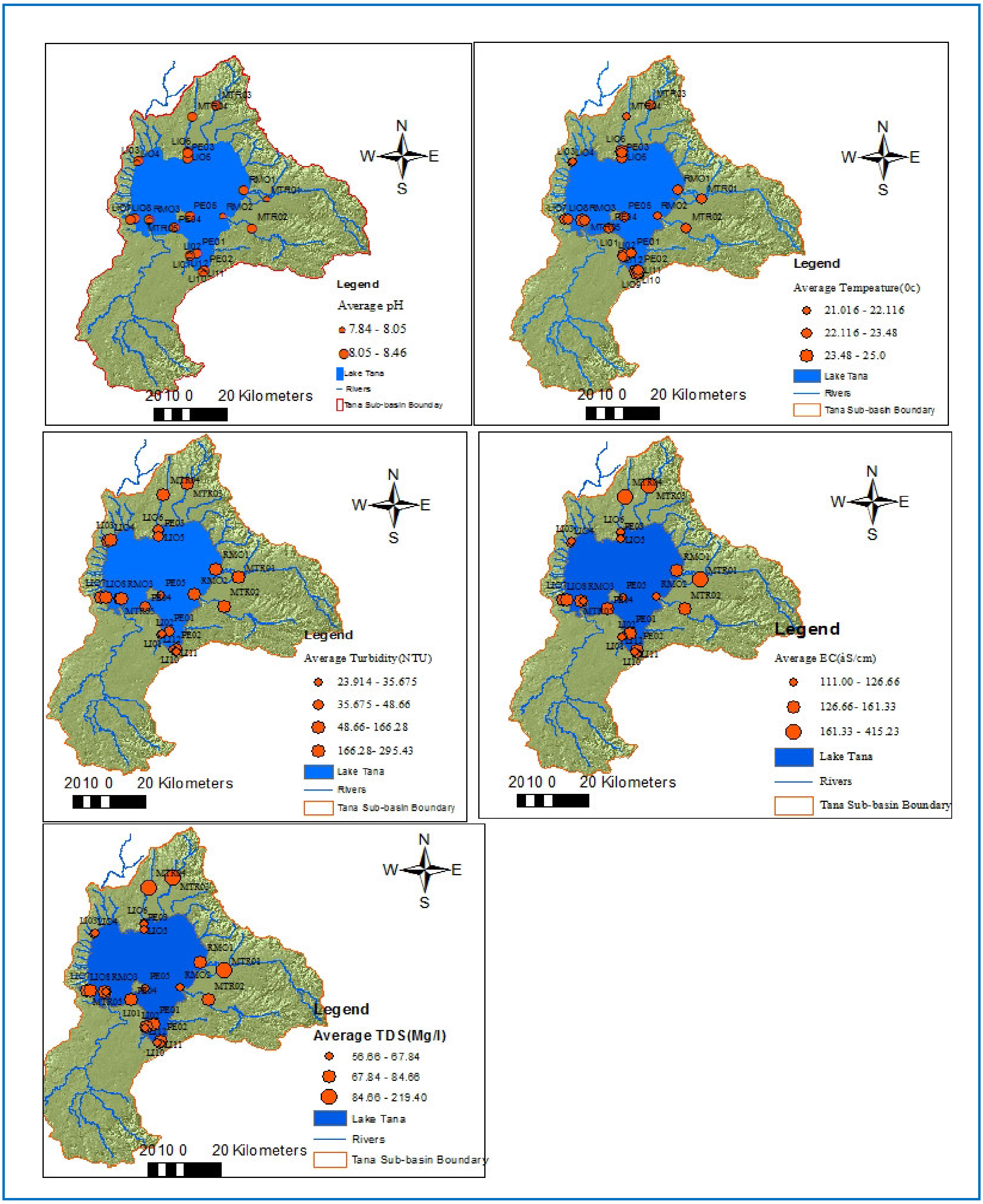

Figure 4.Maps of Average Spatial Variation of Physical Water Quality of Lake Tana

3.1.2Chemical Water Quality of Lake Tana

Table 4.Average, Maximum and Minimum Values for Various Chemical Parameters of Lake Tana Water

No	Site Code	Alkalinity(mg/l)			Hardness(mg/l)			Nitrate(mg/l)			Nitrite(mg/l)			Ammonia(mg/l)			Phosphate(mg/l)		
		Av	Ma	Mi	Av	Ma	Mi	Av	Ma	Mi	Av	Ma	Mi	Av	Ma	Mi	Av	Ma	Mi
1	LI01	92.2	117	56	86.17	102	75	0.16	0.28	0.02	0.01	0.02	0	0.3	0.02	0.27	0.18	0.26	0.1
2	LI02	94.2	121	73	87.17	108	75	0.21	0.42	0.02	0.04	0.19	0	0.1	0.02	0.07	0.26	0.75	0
3	LI03	307	1120	112	153	280	80	0.09	0.20	0.03	0.04	0.1	0	0.2	0.05	0.14	0.39	0.75	0.14
4	LIO4	182	265	103	224.2	500	85	0.09	0.24	0.04	0.07	0.16	0	0.3	0.04	0.24	0.64	1.16	0.12
5	LIO5	112	143	90	98.67	130	80	0.14	0.47	0.00	0.02	0.04	0	0.1	0.03	0.04	0.25	0.51	0.14
6	LIO6	83.3	112	21	99.17	130	80	0.11	0.19	0.01	0.02	0.03	0	0.1	0.01	0.05	0.25	0.51	0.1
7	LIO7	124	193	95	136.5	280	85	0.13	0.33	0.05	0.04	0.08	0	0.2	0.05	0.18	0.53	1.38	0.12
8	LIO8	136	168	108	146.3	220	85	0.12	0.31	0.06	0.04	0.08	0	0.2	0.05	0.11	0.36	0.58	0.16
9	LIO9	89.3	103	73	86.17	102	75	0.14	0.32	0.06	0.01	0.03	0	0.1	0.02	0.07	0.16	0.28	0.02
10	LI10	89.8	108	65	88.33	108	75	0.16	0.38	0.04	0.01	0.02	0	0.3	0.05	0.21	0.45	1.72	0.04
11	LI11	89.3	135	65	85.83	95	70	0.11	0.37	0.01	0.04	0.18	0	0.1	0.02	0.12	0.22	0.61	0.07
12	LI12	86.3	100	73	80	90	70	0.08	0.15	0.02	0.03	0.09	0	0.3	0.02	0.24	0.07	0.16	0
13	PE01	97.3	117	76	86.67	95	75	0.124	0.27	0.021	0.01	0.04	0	0	0.07	0.02	0.3	1.5	0.02
14	PE02	84.8	108	38	87.33	102	75	0.082	0.19	0.018	0.01	0.02	0	0.2	0.83	0.02	0.2	0.4	0.06
15	PE03	95.5	130	73	105	210	75	0.058	0.13	0.012	0.01	0.03	0	0	0.03	0.02	0.2	0.4	0.07
16	PE04	98.6	112	80	88.4	102	80	0.075	0.13	0.021	0.02	0.02	0	0	0.06	0	0.2	0.2	0.04
17	PE05	80.6	95	60	76	85	65	0.092	0.17	0.032	0.01	0.01	0	0	0.05	0.01	0.2	0.2	0.06
18	RMO1	761	3400	173	1068	5000	155	0.894	4.7	0.047	0.36	1.69	0	1.2	4.8	0.05	3.5	15	0.36
19	RMO2	683	3500	95	976.7	5300	80	0.283	0.83	0.036	0.44	2	0	1	4.8	0.04	2.9	14	0.12
20	RMO3	996	3630	95	235.8	560	85	0.308	0.94	0.08	0.13	0.44	0	0.2	0.45	0.03	3	16	0.18
21	MTR01	683	2100	173	624.2	2350	75	0.519	1.12	0.021	0.28	1.28	0	0.7	2	0.04	2.2	9.7	0.32
22	MTR02	576	2100	117	645.5	2800	108	0.447	0.94	0.1	0.28	1.21	0	0.8	2.9	0.1	2.7	8.9	0.24
23	MTR03	312	702	188	347.5	650	175	0.336	0.45	0.13	0.11	0.49	0	0.2	0.61	0.02	1.3	4.2	0.02
24	MTR04	869	2500	215	903.3	3250	165	0.369	0.85	0.085	0.41	1.78	0	1.6	6.6	0	2.8	9.1	0.02
25	MTR05	636	2100	130	551.2	2200	95	0.47	1	0.14	0.81	3.4	0	0.8	3.6	0.02	2.5	7.5	0.24
Overall mean		298.3	931	97.9	286.7	994	89.7	0.2	0.615	0.04	0.15	0.5	0	0.80	1.09	0.1	1.03	3.83	0.11

Key: Av refers Average, Ma refers Maximum & Mi refers Minimum

The alkalinity value varies between 21to3630mg/l. The minimum alkalinity value (21mg/l) was recorded at Gorgora-02(LIO6) during July, 2012 while the maximum alkalinity value (3630mg/l) was recorded at Abay River mouth (RMO3) during July, 2012.The average alkalinity varied between 80.6 to995.5mg/l with the overall mean value of298.3mg/l(table 4).When compared with the total alkalinity values of Lake Naivasha in Kenya(the mean value varied between 96 to 153mg/l with the overall mean value of 113mg/l by Ndungu (2014), the total alkalinity value of Lake Tana was found to be higher. The addition of large amount of sewage waste and organic pollutant in the lake also effect photosynthesis rate, which also result in death of plants and living organism. The degradation of plants, living organism and organic waste might also be one of the reasons for increase in a carbonate and bicarbonate which result in an increase in alkalinity value. The variations of alkalinity within littoral, pelagic, river mouth and major tributary were statistically significant at the 5% level (0.000).Alkalinity values of this study have significant positive correlation with other chemical parameters such as total hardness($r=0.823^{**}$), nitrate($r=0.763^{**}$, nitrite($r=0.746^{**}$), ammonia($r=0.777^{**}$) and phosphate (0.962^{**}).

The total hardness recorded in the water of lake ranges between 65 to 5300 mg/l. The highest value (5300 mg/l) of total hardness in the water of lake was recorded during July at Gumara River (MTR02) and the minimum value (65 mg/l) of total hardness was recorded during March, 2012 at Deke Estifanos (PE05). The average total hardness ranged between 76 to1067.5mg/l with the overall mean value of 286.7mg/l(table 4).When compared with the total hardness values of Lake Naivasha in Kenya(the mean value varied between 26 to 48mg/l with the overall mean value of 33mg/l by Ndungu (2014) and the total hardness values of Lake Hawassa in Sothern part of Ethiopia with values 106.07 to 137.16 mg/l with an average value of 121.87 mg/l by Admasu (2015), the total hardness value of Lake Tana was found to be much higher. High values of hardness are probably due to regular addition of large quantities of sewage and detergent into lakes and river from the nearby residential localities. Total hardness values of this study have also significant positive correlation with other chemical parameters such as alkalinity($r=0.823^{**}$), nitrate($r=0.836^{**}$), nitrite($r=0.797^{**}$), ammonia($r=0.932^{**}$) and phosphate ($r=0.\ 905^{**}$).

The concentration of nitrate ranged from 0.003 mg/l to 4.7 mg/l, and the maximum concentration was recorded at Rib Mouth (RMO1) during July and the minimum amount of nitrate were recorded in Gorgora-01(LIO5), littoral area, which are under the permissible limit for nitrate in water (10 mg/l).The average nitrate varied between0.1 to 0.9mg/l with the overall mean value of 0.2mg/l. From the total 146 samples, 146 samples (100%) complied with the Russia Fisheries and Aquatic Life criterion (40mg/l).The nitrate values in this study almost agreed with the PhD work of Ndungu (2014) on assessing water quality in Lake Naivasha (Kenya), the nitrate values in the study sites the mean value ranged from 0.167 to 0.247mg/l with the overall mean value of 0.200mg/l(table 4) whereas the mean value of nitrate obtained in this study disagreed with the work of Admasu(2015) on physicochemical and biological water quality assessment of Lake Hawassa for multiple designated water uses, the highest mean value of 8.87 and 8.46 mg/l nitrate were obtained in the lake with an average value of 5.27 mg/L to the lake system which is much higher than nitrate values of Lake Tana(this study site).All Lake Tana water quality monitoring stations except Angara(PE03), Near Dik(PE02) and Bahir Dar Tana Hotel(LI12) observed concentration of nitrate in excess of 0.2mg/l $N0_3$-N which can stimulate algal growth and indicate possible eutrophic conditions. This water quality monitoring result seems coincide with the reality.

Currently in the littoral and major River mouths of Lake Tana algal growth and eutrophic conditions set in. Nitrate values of this study have significant positive correlation at 0.01 level (2-tailed) with other chemical parameters such as alkalinity(r=0.763**) total hardness(r=0 .836**), nitrite(r=0.705**), ammonia(r=0.747**) and phosphate (r=0.855**).

The value of nitrite ranges from not detectable to 3.4 mg/l-N. The maximum value (3.4 mg/l-N) was recorded during August at Abay River (MTR05) and the minimum value (not detectable) was recorded during March at Rib River(MTR01).The average nitrite varied between 0.1 to 0.81mg/l with the overall mean value of 0.15mg/l(table 4).From the total 148 samples, 81samples (54.72%) complied with the European Union Fisheries and Aquatic Life criterion (0.01-0.03mg/l).When compared with the nitrite values of Lake Naivasha in Kenya(the mean value varied between 0.010 to 0.014mg/l with the overall mean value of 0.012mg/l by Ndungu (2014) and the nitrite values of Lake Hawassa in Sothern part of Ethiopia with nitrite values of the three months were 0.052 mg/l, 0.031 mg/l and 0.029 by Admasu (2015), the nitrite value of Lake Tana was found to be higher. Nitrite values of this study have significant positive correlation at 0.01 level (2-tailed) with other chemical parameters such as alkalinity(r=0.746**), total hardness(r=0.797**), nitrate(r=0.705**), ammonia(r=0.747**) and phosphate (r=0.855**).

The ammonia value varies between 0 to 6.6mg/l. The maximum value of ammonia (6.6 mg/l-N) was recorded during July, 2012 at Dirma River (MTR04) whereas minimum value (not detectable) was recorded during November, 2011 at the same sampling site. The average ammonia varied between 0.02 to 1.55mg/l with the overall mean value of 0.80mg/l(table 4).From the total 94 samples, 38 samples (40.42%) complied with the European Union Fisheries and Aquatic Life criterion (0.04-1.0).When compared with the ammonia values of Lake Naivasha in Kenya (the mean value varied between 0.045 to 0.085mg/l with the overall mean value of 0.063mg/l by Ndungu (2014), the ammonia value of Lake Tana was found to be higher. Ammonia values of this study have significant positive correlation at 0.01 level (2-tailed) with other chemical parameters such as alkalinity(r=0.777**), total hardness(r=0.932**), nitrate(r=0.747**), nitrite(r=.787**) and phosphate (r=0.827**).

Phosphate is one of the limiting factors for phytoplankton productivity because of geochemical shortage of phosphate in drainage basin. There were significant difference in phosphate concentration among sampled stations and the phosphate concentration in major tributaries of Lake Tana station were significantly higher than other stations with mean value of 1.55mg/l and with a Standard deviation of 2.33. The value was ranged between not detectable at Zegie-02(LI02) during January, 2012 and at Bahir Dar Tana Hotel (LI12) during November, 2011 to 15.8 mg/l at Abay River mouth (RMO3) during July,2012. The average phosphate varied between 0.07 to 3.50 mg/l with the overall mean value of 1.03 mg/l(table 4).When compared with the phosphate values of Lake Naivasha in Kenya(the mean value varied between 0.021 to 0.025mg/l with the overall mean value of 0.022mg/l by Ndungu (2014), the phosphate value of Lake Tana was found to be higher whereas lower than phosphate values of Lake Hawassa in Sothern part of Ethiopia with the highest phosphate concentration observed at recreational area (1.42 mg/l) and inlet of Tikurwuha river (1.36 mg/l).The maximum allowable concentration of phosphorous that should be available in environmental waters is 1mg/l (WHO, 2003). The high value of phosphate during July month is mainly due to rain, surface water runoff, Agricultural runoff, washer man activity could also have contributed to the inorganic phosphate content; as well as continuous entry of domestic sewage in some area are responsible for increase in amount of phosphate. Phosphate values of this study have significant positive correlation at 0.01 level (2-tailed) with other chemical parameters such as alkalinity(r=0.962**), total hardness(r=0. 905**), nitrate(r=0.855**), nitrite(r=.801**) and ammonia(r=0.827**).

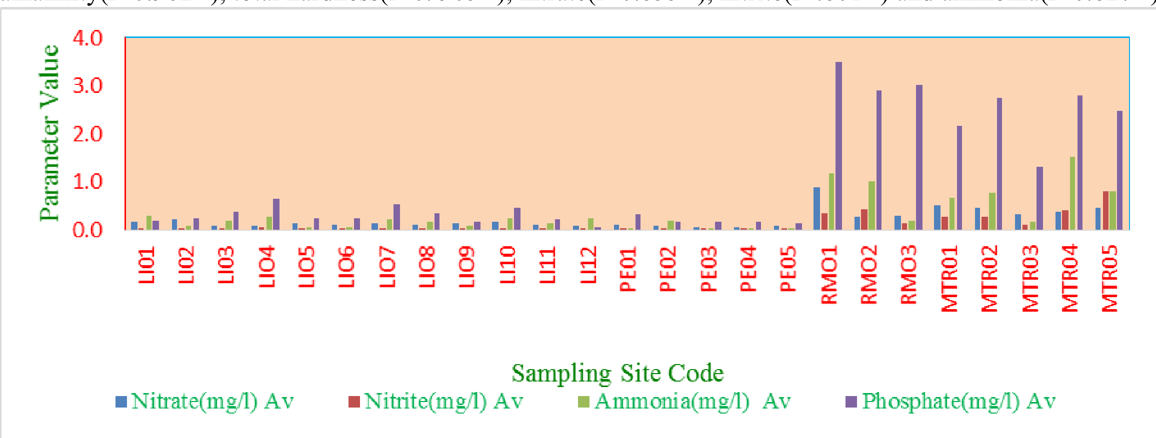

Figure 5.Graphs of Average Spatial Variation of Chemical Water Quality of Lake Tana

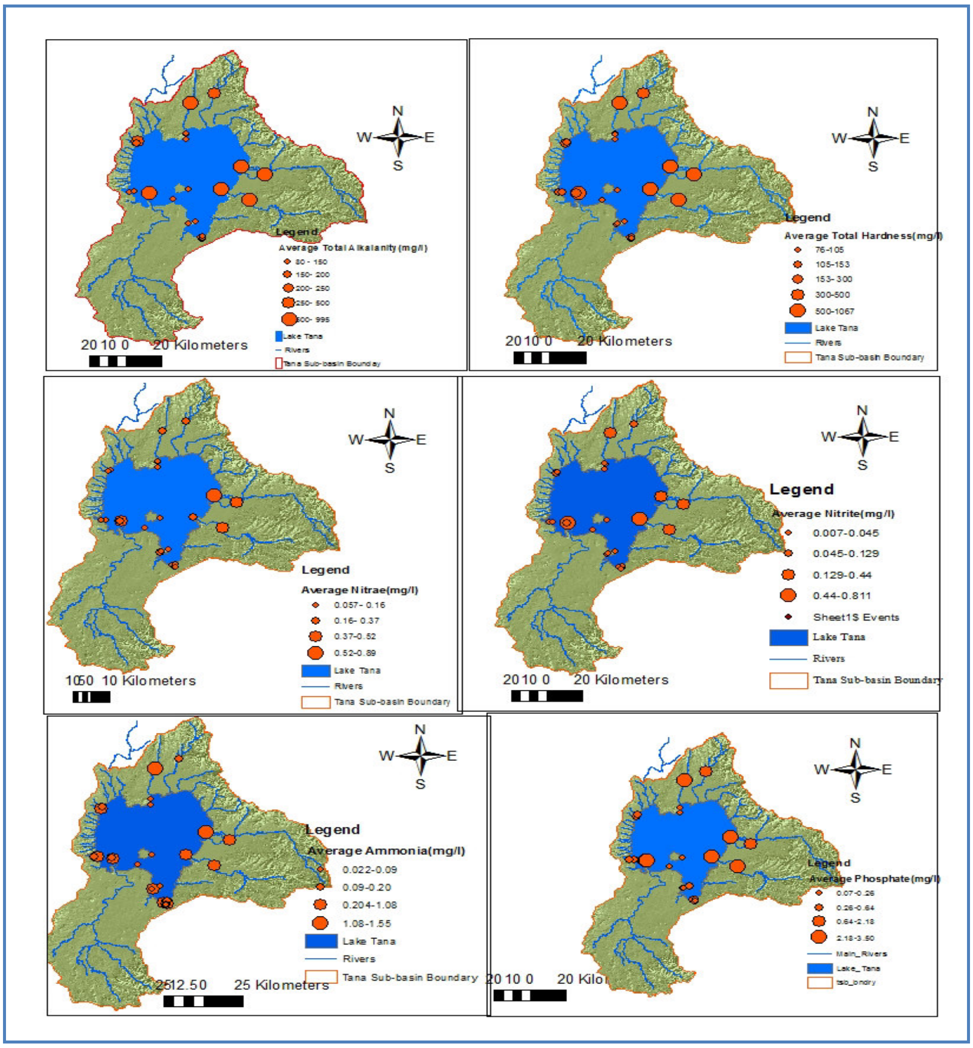

Figure 6.Maps of Average Spatial Variation of Chemical Water Quality of Lake Tana

3.2 Trends of Physico-chemical Water Quality of Lake Tana

3.2.1Trends of Physical Parameters

PH

Over the period 2011 and 2012, downward trends were noted at all sites. The median RSKSE value was -0.0475 per year suggesting that, overall, the PH value of Lake Tana is decreasing slightly. There was overall a statistically significant trend in a negative direction in PH at Lake Tana level (binomial test p=2.98023E-0.8).

Temperature

Over the study period, downward trends were noted at 18 sites where as increasing trends were observed at 7 sites. The median RSKSE value was -0.03676 per year suggesting that, overall, the temperature value of Lake Tana is decreasing. There was overall significant decreasing trend in temperature at Lake Tana level (binomial test p=0.02164).

Turbidity

Stable/no trend was observed at three sites namely: Angara (PE03), Bahir Dar Tana Hotel (LI12) and Zegie-02(LI02).Decreasing trends were noted at 14 sites where as increasing trends were observed at 8 sites. At the Lake Tana level, there was no significant trend. The median RSKSE value was -0.2940 per year showing that, overall, the turbidity value of Lake Tana is decreasing slightly. There was no overall significant decreasing trend in turbidity at Lake Tana level (binomial test p= 0.053876).

Electrical Conductivity

Stable/no trend was observed only at one site (Bahir Dar Fishery). Upward trends were observed at 17 sites and downward trends were noted at 7 sites. At the Lake Tana level, there was no significant trend. The median RSKSE value was 0.089735 per year suggesting that, overall EC value of Lake Tana is increasing slightly. There was overall a statistically significant trend in a positive direction in EC at Lake Tana level (binomial test p=0.02164).

Total Dissolved Solid

Stable/no trend was observed at two sites such as Angara (PE03), and Bahir Dar Tana Hotel (LI12). Increasing trends were noted at 8 sites where as decreasing trend was observed at 15 sites. At the Lake Tana level, there was no significant trend of total dissolved solid. The median RSKSE value was -0.3291478 per year suggesting that, overall, the TDS value of Lake Tana is decreasing. There was no overall significant decreasing trend in turbidity at Lake Tana level (binomial test p= 0.053876).

3.2.1Trends of Chemical Parameters

Total Hardness and Total Alkalinity

Over the period 2011 and 2012, increasing trends were noted at 22 sites where as decreasing trend was observed at 3 sites. The median RSKSE value was -0.2940 per year showing that that, overall, the turbidity value of Lake Tana is decreasing slightly. There was no overall significant decreasing trend in turbidity at Lake Tana level (binomial test p= 0.053876).

Stable/no trend was observed at two sites namely: Deke Estifanos (PE05) and Megech River (MTR03). Increasing trends were noted at 13 sites where as decreasing trend was observed at 10sites. At the Lake Tana level, there was no significant trend except Rib mouth (RMO1) which has 0.042 probability i.e. <0.05.The median RSKSE value was 0.037924 per year suggesting that; overall, the total alkalinity value of Lake Tana is increasing. There was no overall a statistically significant trend in a positive direction in total alkalinity at Lake Tana level (binomial test p= 0.212).

Nitrate, Nitrite and Ammonia

Increasing trends were noted at 10 sites where as decreasing trend was observed at 15sites.At the Lake Tana level, there was no significant trend. The median RSKSE value was -0.405497 per year suggesting that, overall, the nitrate value of Lake Tana is decreasing. There was no overall a statistically significant trend in a positive direction in total alkalinity at Lake Tana level (binomial test p= 0.212).

Upward trends were observed at 11 sites where as downward trends were observed at 14 sites. At the Lake Tana level, there was no significant trend. The median RSKSE value was -0.223529 per year suggesting that, overall, the nitrite value of Lake Tana is decreasing. There was no overall a statistically significant trend in a positive direction in total alkalinity at Lake Tana level (binomial test p= 0.3450).

Stable/no trend was observed at three sites such as: Angara (PE03), Gogora-01(LIO5) and Zegie open (PE01).Upward trends were noted at 15 sites where as downward trends were observed at 7 sites. The median RSKSE value was 1 per year suggesting that; overall, ammonia value of Lake Tana is increasing. There was overall a statistically significant trend in a positive direction in total alkalinity at Lake Tana level (binomial test p= 0.0216).

Phosphate

Stable/no trend was observed at two sites namely: Bahir Dar Alma (LI11) and Deke Estifanos (PE05). Upward trends were noted at 11 sites where as downward trends were observed at 12 sites. The median RSKSE value was 0 per year suggesting that; overall, the phosphate value of Lake Tana is stable trend or no trend. There was no overall a statistically significant trend in a positive direction in total alkalinity at Lake Tana level (binomial test p= 0.3450).

4. Conclusion

This study has provided useful information on the Lake Tana water quality status for the management of the Lake ecosystem as well as the ecosystem of the entire Tana sub-basin. The study enabled the definition of existing conditions, and short-term trends detection as well as information for determining cause-and-effect relations with respect to anthropogenic activities around Lake Tana, and in and along the rivers of Tana sub-basin. The physico-chemical characteristics of the major tributary rivers of Lake Tana, river mouths and lake shore areas were significantly different from open (pelagic) station of the Lake and it had been recognized that the major drivers of change of physical and chemical water quality of Lake Tana were major tributaries and anthropogenic activities in the shore areas and the catchment at large. Anthropogenic activities influenced water quality of the Lake and its environs and chemical contaminants was higher in the gulf, tributaries and river mouths than the open site except pH and temperature. There were generally mixtures of both increasing and decreasing trends for all analyses. There were increasing overall trends for electrical conductivity, ammonia, total alkalinity and total hardness and decreasing overall trends for pH, temperature, turbidity, total dissolved solid, nitrate and nitrite. No trend or stable overall trends for phosphate.

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