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Spatial Variation of Sediment Physicochemical Characteristics of Lake Tana, Ethiopia

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Abstract
The purpose of this study was to assess the physico-chemical properties of sediments of Lake Tana, Ethiopia. The parameters monitored include: pH, conductivity, percentage of organic carbon, percentage of total nitrogen, available phosphorous and percentage of organic matter. Sediment sampling was done with the help of Eckman grap sediment sampler, from August 2011-July 2012 at 20 sampling sites. The physical properties of sediments of Lake Tana namely: average pH and conductivity reported between 5.81 to 7.02 with the overall mean value of 6.5 which is slightly acidic and 0.09 to 0.72 dS/m with the overall mean value of 0.27 dS/m respectively. The sediment nutrients: percentage of total nitrogen and available phosphorous of Lake Tana revealed average values 0.07 to 0.54% with overall mean value of 0.18% and 9.56 to 52.23 mg/kg with the overall mean value of 21.83 mg/kg respectively. There was a positive correlation between sediment percentage of total nitrogen and percentage of organic matter (r = 0.759) as well as between sediment available phosphorous and organic matter(r =0.630). Those correlation values revealed that both nitrogen and phosphorous are originated from organic sources than inorganic sources. The correlation values between nitrogen and phosphorous(r=0.513) indicated that they are generated from the same sources. The average organic carbon (%) was recorded between 0.82 to 5.03 % with the overall mean value of 1.99 while the average organic matter (%) of Lake sediment was recorded between 1.33 to 6.98 % with the overall mean value of 3.13%. In this study, the ratio of total organic carbon to total nitrogen(C:N ratio) for 20 sediments were between 7.5 to 16.3,which indicated that the source of organic matter could be related to aquatic sources of Lake Tana. As it is the first time where monitoring physico-chemical properties of sediments of Lake Tana are presented, this study can be used as baseline data for comparison in future environmental assessment of the lake.
Keywords: Available phosphorous, eckman-grap, inverse distance weighting, lake sediments, organic carbon, organic matter, total nitrogen, available phosphorous.

1. Introduction

Sediment is the loose sand, silt and other soil particles that settle at the bottom of a body of water (USEPA, 2002). Bottom sediments are a mixture of material both, organic and inorganic, derived chiefly from the lake and its catchment, but material in trace quantities are also derived from the atmosphere (Battarbee et al.,1999). Being a result of lake life, bottom sediments are extremely important for its nutrient economy, acting as sink or source of nutrients depending upon the redox conditions(Matisoff et al.,1985; Sahoo et al., 2007).

Sediment is an integral part of aquatic ecosystem, providing habitat, feeding, spawning and rearing areas for many aquatic organisms. Protecting sediment quality is an important part of restoring the biological integrity of water bodies as well as protecting aquatic life, wild life and human health(Issa et al, 2011).Sediment analysis is increasingly important in evaluating qualities of the total ecosystem of a body of water, in addition to the water sample analysis practiced for years(Pravin et al, 2011). Total organic carbon (TOC) is a measure of the amount of organic matter preserved within sediment, while the amount of sediment nutrients is assessed as total nitrogen (TN) and total phosphorus (TP) coming from organic and inorganic sources. Organic matter breakdown (mineralization) reduces sediment carbon, while nutrient concentrations and dissolved nutrients are released from the sediment to the water column (Froehlich et al., 1979; Golterman, 2004).

With the increasing anthropogenic pressure on inland fresh water resources because of sewage pollution, soil erosion, agricultural and industrial dumping of waste etc., it become highly important to monitor the sediment quality which ultimately accumulate all of these excessive wastes. As compared to the usual water testing, sediment testing reflects the long term quality situation which is independent of current inputs (Hadson,1986; Haslam,1990).Because pollutants are conserved in sediments over long periods of time according to their chemical persistence and the physical-chemical and biochemical characteristics of the substrata.

In an attempt to consolidate data collected from the 1960's and 70's, Wood and Talling (1988) surveyed records on 28 Ethiopian lakes and gave an overview of the relationships between ionic composition, nutrients and phytoplankton. Assessment of the chemical features is found in Elizabeth et al,1994; Zinabu,1998. 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. Ayalew et al(2007) studied seasonal variation in primary production of a large high altitude tropical lake (Lake Tana, Ethiopia): effects of nutrient availability and water transparency. In their study they measured chlorophyll and phytoplankton biovolume and related with nutrient availability and water transparency. Ayalew(2012) studied location dynamics of the major phytoplankton and Zooplankton communities and their role in the food-web of Lake Tana, Ethiopia. Etafa et al(2010) reviewed ecohydrological status of Lake Tana. The results of this review showed that reduced lake water level with its annual fluctuations and seasonal floods associated with high flows are becoming amplified and frequent, and the total average annual sediment load of the four major tributaries showed an increasing trend. Few limnological studies have been undertaken in Lake Tana since early 1900s(Seyoum, et al, 2009).More studies have been done on the fisheries than the limnology. The PhD studies of Wudneh(1998), Nagelkerke(1999),de Graaf(2003) and Dejen(2003) all deal with fisheries and evolutionary fish biology. Setegn(2010) in his PhD study, modeling hydrological and hydrodynamic process in Lake Tana Basin. 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(2011)and in the year 2013, annual report on Lake Tana water quality monitoring was also produced by TaSBO(2013).

Although a substantial amount of data is available on faecal pollution, primary production, dynamics of the major phytoplankton and Zooplankton communities, fishery, ecohydrological status, hydrological process and water quality of Lake Tana, no one focused in sediment characteristics of Lake Tana. In Ethiopia studies on physico-chemical properties of sediments of Lakes are rare. Habiba & Seyoum (2012) studied the ecological assessment of Lake Hora, Ethiopia, using benthic and weed-bed fauna. In this study, they determined the total organic matter in the Lake sediment and sediment texture(grain size).But they didnot include other important sediment quality parameters such as total organic carbon, total nitrogen and available phosphorous.

Unfortunately, no research works have been done on the sediment quality of Lake Tana. In Tana sub-basin, Lake and Major Rivers water quality monitoring were already established within the framework of Tana-Beles integrated water resource development project(TBIWRDP). Conducting water quality monitoring at Lake Tana is not sufficient to manage the Lake Tana ecosystem. Monitoring the sediment quality of Lake Tana is increasingly important in evaluating the environmental quality of the Lake Tana ecosystem, in addition to the Lake Tana water quality monitoring practiced since the year 2010. The environmental quality of the water and the associate components of an aquatic ecosystem cannot be evaluated without the study of bottom sediments characteristics. The presence of organic matter in aquatic systems and liquid wastes has attracted an intensive research interest concerning environmental studies (Hoppe-Jones et al, 2010; Larsen et al, 2011).The Lake Tana Basin is one of the most affected area by soil erosion, sediment transport and land degradation(Setegn, 2010). An accelerated deforestation in the lake Tana Basin and surface run-off from agricultural fields has resulted in higher accumulation of sediments in the lake Tana.

In view of the above facts, this study was conducted to understand the physico-chemical properties of sediment samples collected from different parts of lake Tana (pelagic, littoral and river mouths) which is subjected to pollution load due to agricultural runoff and discharge of sewage. To our knowledge, our present study is the first attempt in determining the sediment quality status of Lake Tana. Thus, in this study the parameters such as: pH, conductivity, percentage of organic carbon, percentage of total nitrogen, available phosphorous and percentage of organic matter were monitored. It is expected that the pollution data generated from such regular scientific study will help to implement policies and programs to gauge the extent of pollution. Results from studying the sediment physical and chemical characteristics from Lake Tana (Ethiopia) will facilitate the management of the water and similar water bodies. It also provides base line data for further studies.

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 $12^{o}00'$N, and longitude $37^{o}15'$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.

With regard to the origin and geology of Lake Tana, it was originally much larger (Rzoska, 1976) and much deeper (Lamb *et al*, 2007; Seyoum et al,2009) than it is today. The lake was formed by volcanic activity about 1.8 million years ago that blocked and reversed the previously north-flowing Blue Nile of the early Pleistocene (Mohr, 1962; Seyoum, et al, 2009) and created one of Africa's greatest waterfalls, Tis Issat. Geological evidence indicates that these quaternary volcanoes, also called Aden volcanoes or the Aden Volcanic Series, arose from tectonic movements. The volcanic basalt flow filled the exit channel of the Blue Nile River resulting in the present natural dams found in the Tana Sub-basin.

Based on chemical parameters, Lake Tana is mesotrophic but with a low chlorophyll content and primary production by tropical lakes standards (Ayalew et al 2007). Its bottom substrate is volcanic basalt mostly covered with a muddy substratum with little organic matter (Howell & Allan, 1994).

The climate around the lake is a warm-temperate tropical highland monsoon with a mean temperature of 21.7°C, large diurnal but small seasonal changes of 5°C and two temperature peaks around May/June and October/November. Rainfall is strongly seasonal with a dry season between October/November and May/June and a pronounced rainy season (*kiremt*) between July and September(MSF,2012).

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.

The Lake is the source of a major outlet, namely the Blue Nile River. According to Abeyou(2008), in 1996 a low height weir was constructed at Chara-chara across the [Blue Nile River] at the source of the Lake. The weir is equipped with two radial gates which allow the release from Lake Tana to be totally controlled as long as the water level of the Lake remains lower than the elevation of the spillway(1987masl), the minimum operating level of the weir is 1784 masl. This outlet has an international character as it joins and empties into the White Nile, where its waters are then shared by Sudan and Egypt. Tana-Beles Hydropower Scheme constructed near Kunzila, on the Western side of the Lake. In this area, there is a tunnel diversion(artificial outlet)of inter-basin transfer of water to Beles basin to generate hydropower and allow water to flow into a tributary of Abay(Blue Nile) far downstream in the western low lands of Ethiopia.

The Lake Tana region is of national and international importance in many ways: it is rich in biodiversity with many endemic plant species and cattle breeds; it contains largest areas of wetlands; and it is home to many endemic birds and cultural and archaeological sites. In particular, Lake Tana has 37 islands of which 20 have Ethiopian Orthodox churches and monasteries with an enormous historical and cultural value, dating back up to the 14th century (MSF,2012).Currently Lake Tana is registered as a biosphere reserve site by United Nation Educational Scientific and Cultural Organization(UNESC0).

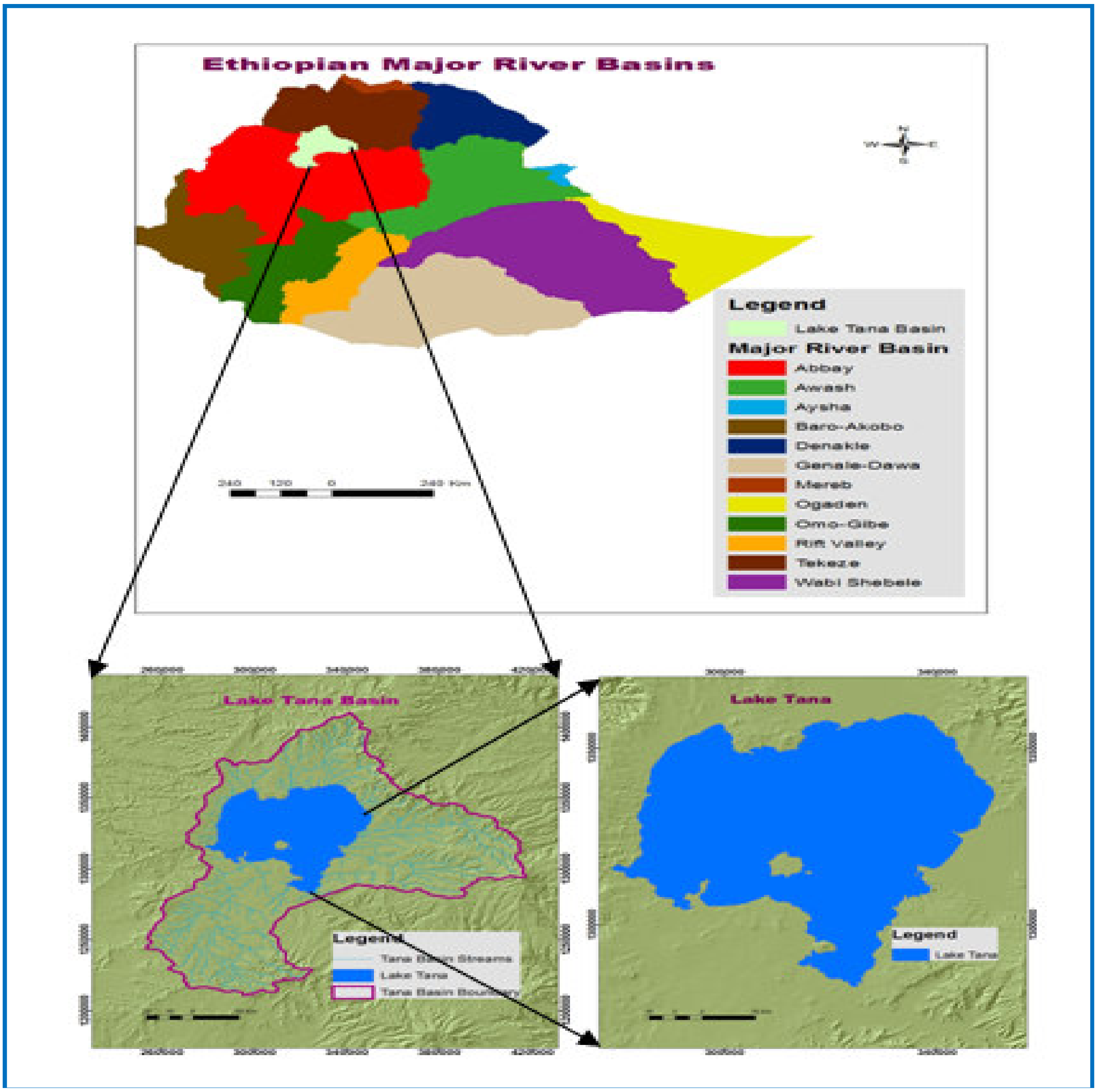


Figure 1:Location Map of the study area (adapted from Abay River Master Plan of Ethiopian Ministry of Water Resources(MoWR):Map of Lake Tana Sub-basin and Lake Tana were extracted from Abay Basin shape file using ARC GIS 10.1 Software, Analysis Tool of Extract by Clip).

2.2 Sampling Site

Sediment samples from the littoral, pelagic(open) and river mouth stations of lake Tana were collected. Littoral parts are mainly the shore areas /or the periphery of the lake while pelagic parts are the open(the interior parts of the Lake) that are relatively free from anthropogenic sources of pollution. The river mouths are the places where the major perennial rivers joined with Lake Tana. Twenty sampling stations (12 sites from littoral station both in the southern and northern part of the lake, 3 sites from river mouth stations and 5 sites from open water) were chosen based on baseline monitoring objectives, parts of the Lake where affected by development activities and parts of the Lake where relatively free from anthropogenic impacts.

Table 1:Sediment Sampling Station in Lake Tana

No.	Sampling Site Name	Sampling Site Code	Category of Sampling Sites	GPS Coordinates	
				Easting	Northing
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 Center	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	Abbay River Mouth	RMO3	River Mouth	0293925	1314066

Figure2: Location map of Sediment Sampling Stations(Sampling Site Code) in Lake Tana

2.3 Sediment Sampling and Laboratory Analysis

Sediment sampling was done with the help of Eckman grab sampler, operating from a boat at 20 sampling sites from August 2011- July 2012. Sediment samples were transferred to the laboratory in polythene bags. The samples were air dried for 1 week and grounded into fine particles using pistil and mortar and sieved through 2mm sieve. Physico-chemical parameters were determined according to standard methods: pH: by pH meter

HI(Hanna Instrument)-2211, conductivity: by conductivity meter-306, total organic carbon and total organic matter: by Walkley and Black rapid titration method, total nitrogen: by Kheldahl's method-24 and total phosphorus: by Olsen and Sommers method.

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 (2007) and IBM SPSS, 20. Using Microsoft Excel(2007), differences among the littoral, pelagic (open) and river mouths of Lake Tana sediments 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 sediments among the categories of the sampling sites of Lake Tana i.e., littoral, pelagic(open) and river mouth. Furthermore, data analysis was performed with SPSS to analysis the correlation between the variables of the physico-chemical parameters of Lake Tana sediments.

In this study the spatial variability of physico-chemical parameters in sediments of Lake Tana was assessed by inverse distance weighting (IDW) interpolation technique. The Geostatistical analyst, an extension to Arc GIS, a product of the Environmental Systems Research Institute (ESRI), was applied to analyze the spatial variation of physico-chemical parameters in sediments of Lake Tana. Inverse distance weighting (IDW) uses the measured values surrounding the prediction location in which it weights the points closer to the prediction location greater than those farther away. In Inverse distance weighting (IDW), the weight of the value decreases as the distance increase from the prediction point.

3. Results and Discussions

3.1 Physico-chemical Parameters of Lake Tana Sediments

The experimental data on physico-chemical properties of sediment samples collected at 20 different sampling stations from the littoral, pelagic (open) and river mouth of lake Tana is presented in table 2.

Table 2: Average, Maximum and Minimum Values for Various Physico-chemical Parameters of Lake Tana Sediments

	Site Code	Parameters																	
		PH			Conductivity(dS/m)			Organic Carbon(%)			Total Nitrogen(%)			Available Phosphorus(mg/kg)			Organic Matter(%)		
		Av^a	Max^b	Min^c	Av^a	Max^b	Min^c	Av^a	Max^b	Min^c	Av^a	Max^b	Min^c	Av^a	Max^b	Min^c	Av^a	Max^b	Min^c
1	LI01	6.44	7.03	6.04	0.19	0.31	0.07	1.14	2.37	0.12	0.07	0.11	0.01	18.52	33.01	2.34	1.40	1.40	1.40
2	LI02	6.47	7.43	5.68	0.18	0.37	0.03	2.31	3.89	0.62	0.31	0.77	0.05	21.41	45.76	1.35	4.20	4.20	4.20
3	LI03	7.02	7.51	6.16	0.26	1.12	0.01	2.06	3.04	0.97	0.18	0.24	0.08	26.97	108.79	1.14	3.46	5.24	1.68
4	LIO4	6.83	7.96	5.44	0.20	0.81	0.02	1.04	2.11	0.16	0.09	0.18	0.01	9.65	31.22	0.40	1.80	6.28	1.12
5	LIO5	6.27	6.60	5.78	0.18	0.35	0.06	2.03	4.05	1.05	0.18	0.30	0.09	17.74	39.00	1.58	3.37	4.21	2.52
6	LIO6	6.24	6.88	5.80	0.18	0.39	0.02	2.66	4.20	0.39	0.22	0.34	0.03	27.69	49.97	2.06	6.98	7.24	6.72
7	LIO7	6.13	6.70	4.91	0.72	2.83	0.02	4.37	10.92	0.78	0.37	0.89	0.07	21.92	42.28	0.56	3.78	5.03	2.52
8	LIO8	6.24	6.57	5.82	0.53	1.50	0.04	3.43	8.39	0.86	0.21	0.38	0.07	34.45	88.32	2.30	4.00	4.76	3.24
9	LIO9	6.13	6.78	4.90	0.72	1.40	0.11	4.17	8.39	0.59	0.34	0.73	0.05	52.23	106.76	3.93	5.86	8.40	3.31
10	LI10	5.81	7.23	5.09	0.74	1.30	0.23	5.03	8.49	2.60	0.54	1.38	0.22	29.98	51.40	1.73	5.86	7.24	4.48
11	LI11	6.96	7.38	6.57	0.26	0.51	0.05	1.70	2.76	0.56	0.16	0.30	0.04	13.15	21.87	1.17	2.87	4.76	0.97
12	LI12	6.36	6.81	5.80	0.16	0.49	0.01	1.27	1.62	1.00	0.11	0.14	0.07	9.56	21.31	0.42	2.26	2.80	1.72
13	PE01	6.31	7.31	5.50	0.24	0.50	0.03	1.26	2.27	0.23	0.12	0.27	0.02	15.52	27.97	1.13	2.86	3.92	1.79
14	PE02	6.69	7.10	6.07	0.19	0.47	0.02	1.27	2.76	0.24	0.13	0.24	0.02	21.13	32.13	1.50	2.59	4.76	0.41
15	PE03	6.71	6.80	6.30	0.15	0.26	0.03	1.19	1.79	0.68	0.12	0.15	0.05	11.71	40.31	2.08	2.58	3.08	1.17
16	PE04	6.83	7.09	6.30	0.09	0.33	0.01	0.84	1.95	0.66	0.06	0.18	0.06	20.25	26.35	1.51	1.33	3.36	1.79
17	PE05	6.43	7.30	6.43	0.26	0.49	0.04	1.06	2.27	0.28	0.12	0.20	0.02	14.08	37.50	1.80	1.51	3.92	0.48
18	RMO1	6.59	7.49	6.40	0.14	0.21	0.01	1.07	1.09	0.56	0.09	0.08	0.04	29.41	39.20	1.92	2.13	1.68	0.97
19	RMO2	6.75	7.56	6.07	0.21	0.32	0.01	1.05	1.14	0.43	0.11	0.11	0.04	18.53	41.69	1.97	2.20	1.96	1.10
20	RMO3	6.86	7.10	5.30	0.14	0.96	0.01	0.82	2.16	0.12	0.07	0.35	0.01	22.76	41.57	0.88	1.53	2.80	0.21
Overall Mean		6.50	7.13	5.82	0.27	0.75	0.04	1.99	3.78	0.64	0.18	0.37	0.05	21.83	46.32	1.59	3.13	4.35	2.09

Key: Av^a refers Average, Max^b refers Maximum & Min^c refers Minimum

Table 3:Values of Pearson correlation coefficient (r) for various physico-chemical parameters of Lake sediments

	PH	**Conductivity**	**Organic Carbon**	**Total Nitrogen**	**Available Phosphorus**	**Organic Matter**
PH	1.000					
Conductivity	-.671**	1.000				
Organic Carbon	-.738**	.921**	1.000			
Total Nitrogen	-.705**	.834**	.942**	1.000		
Available Phosphorus	-.409	.611**	.642**	.513*	1.000	
Organic Matter	-.626**	.590**	.809**	.788**	.630**	1.000

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

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

3.1.1Sediment pH

The sediment pH ranged between 4.9 to 7.96. The maximum value was recorded during August at Delgie-02; whereas the minimum value was recorded during November at Bahirdar Fishery Research Center (LI10).The average pH ranged between 5.81 to 7.02 with the overall mean value of 6.5 which is slightly acidic. The mean value of the sediment pH obtained in this study disagreed with the work of Chandrakiran and Shama(2013) on assessment of physico-chemical characteristics of sediments of a Lower Himalayan Lake(Mansar, India), the mean value of 7.55 ±0.46 reported in alkaline range whereas almost agreed with the work of Ezekiel et al(2011) on the Sediment Physical and Chemical Characteristics in Sombreiro River(Niger Delta, Nigeria), the mean value 5.59 which was acid across the stations. Comparatively, the overall mean value of sediment pH of Lake Tana is slightly acid (6.5) than the water pH of Lake Tana(8.14) reported in TaSBO(2013).pH very often act as index for reflecting conditions associated with release of nutrients, physical condition of soil and potency of toxic substances (Carpenter; and Lodge,1986; Baer,1988, Sharma et al, 2013).Thus, pH is having primary importance in deciding the quality of the sediment. Therefore, the average sediment pH value of Lake Tana is slightly acidic. At Bahirdar Fishery Research Center (4.9 pH), young aquatic organisms tend to be more sensitive to this acidic medium but in other stations the pH value is slightly acidic and neutral pH. So toxicity to aquatic species would unlikely expected. pH was related to organic matter ($r^2 = -0.626$).This inverse relationship was possibly because of the fact that decomposition of organic matter release organic acids into the sediments which decrease its pH.

3.1.2 Sediment Conductivity

Conductivity of the sediments ranged between 0.01 to 2.83 dS/m. The maximum value was recorded during July at Kunzela-02 station and the minimum value was recorded during January in Abbay River, Delgie-01, Abbay Mouth, Sekelet, and Rib Mouth stations of the lake. The average conductivity of the sediments was reported between 0.09 to 0.72 dS/m with the overall mean value of 0.27 dS/m. It is well known that electrical conductivity is a good measure of dissolved solids. Conductivity is a measurement used to determine mineralization and determining amounts of chemical reagents or treatment chemicals to be added to the water. It was also observed that the highest average conductivity values reported at the littoral part particularly in southern gulf of the Lake Tana boarder with Bahir Dar town at Bahir Dar Alema (LI11), Bahirdar Fishery Research Center (LI10) and Kunzeila-02(LIO8), indicating increase in deposition of dissolved salts from Bahir Dar city.

3.1.3 Sediment Organic Carbon

The organic carbon of Lake Sediment ranged between 0.12 to 8.49%. The maximum value was recorded during January at Bahirdar-Alema(LI11) and the minimum value was recorded during November at Abay Mouth (RMO3). The average organic carbon (%) was recorded between 0.82 to 5.03 % with the overall mean value of 1.99, which is high organic carbon because Griggs(1975) reported that sediments with values exceeding 1% are said to have high organic carbon. The mean value of organic carbon(1.99%) obtained in this study is above the mean value of 1.02% obtained from Lake Kariba (Central Africa) by Mclachlan and Mclachla (1971) and below the mean value of 2.68% obtained from River Sombreiro(Nigeria) by Ezekiel et al(2011). US EPA (2002) recommended the following assessment categories for total organic carbon in sediments: low impact: ≤ 1%,intermediate impact: 1 to 3% and high impact: >3%. According to this recommendation, the organic carbon concentration in the analyzed sediments were in the intermediate impact level that may affect benthic communities.

An excellent correlation existed between total organic carbon and total nitrogen in the sediments of the studied lake ($r = 0.942$) which suggested that the concentration of total nitrogen might be regulated by organic source. The ratio of total organic carbon to total nitrogen(C:N ratio) has been used as an indicator of the source of organic matter in sediments(terrestrial Vs. aquatic). When the source of OC is terrestrial, the ratio of OC/TN is greater than 15 (C/N >15), when the source of OC is marine the ratio of OC/TN is lower than 10 (C/N < 10) (Wakeham, et al., 2002). In this study, the C:N ratio for 20 sediments were between 7.5 to 16.3, which indicated that the source of organic matter could be related to aquatic sources. According to Muluneh(2005), the littoral region of the eastern and southern part of the lake Tana is dominated by macrophytes such as papyrus reed *Cyperus papyrus*, common bulrush *Typha latifolia* and common reed *Phragmites karaka* ,whereas the snake root *Persicaria senegalensis*, hippo grass *Vossia cuspidata*, other bulrushes (*Scirpus* spp.) and the tiger lotus (or water-lily) *Nymphaea lotus* are common. The presence of these macrophytes in a littoral zone of Lake Tana possibly stimulate sedimentation of organic matter and provide direct source of organic carbon. The C:N ratio values(7.5 to 16.3) with the mean value of 11 for 20 sediments obtained in this study is slightly above the C:N ratio values(8.2-12.1) obtained from Lake Daihai by Dekun et al, 2013**.**The spatial distribution of the C:N ratio is fairly uniform except LIO1(Zegie-01) and LI08(Kunzeila-02) which are much higher whereas LI02(Zegie-02) is much lower(figure 3).

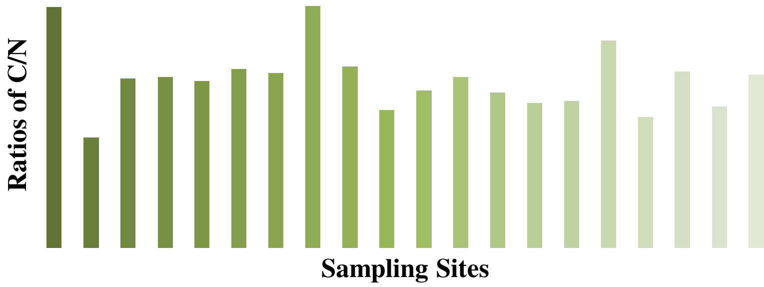


Figure 3:The ratios distribution of C/N in surface sediments of the Lake Tana

3.1.4 Sediment Total Nitrogen

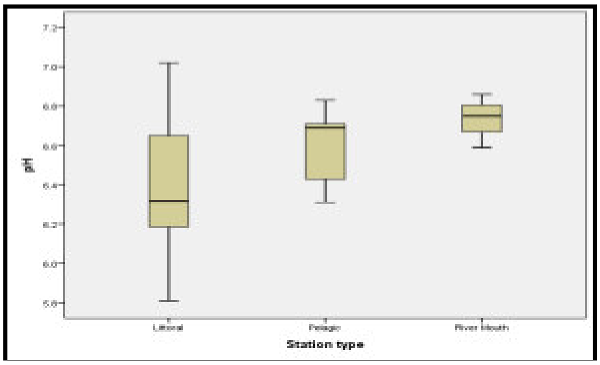
The sediment total nitrogen (%) varied between 0.01 to 1.38%. The maximum values was recorded during January at Bahirdar Alema station and the minimum value was recorded during November at Abay Mouth. The average sediment total nitrogen(%) was 0.07 to 0.54% with overall mean value of 0.18%.When compared with sediment total nitrogen of Lower Himalayan Lake, Mansar, India (1.66 ±0.56%) by Chandrakiran and Shama(2013), the overall mean values of sediment total nitrogen of Lake Tana(0.18%) were found lower. The mean values of sediment total nitrogen obtained in this study were also lower than the total nitrogen values(0.81%) of Lake Kariba reported by Mclachlan and Mclachlan (1971).There was a positive correlation between sediment nitrogen and organic matter(r = 0.788). The correlation is significant at the 0.01 level, 2-tailed (table 3). The significant correlation of organic matter with nitrogen suggests that most of the nitrogen come from organic matter as probably bound to it. It is well known that organic matter in sediments act as reservoir of nutrients, aids in nutrient holding and binds nutrient thereby preventing them from becoming permanently unavailable. If nitrogen and phosphorous in the sediments are generated from the same source, they should have a good correlation(Dekun et al, 2013). It is indicated that the correlation between nitrogen and phosphorous is 0.513 which is significant at the o.o5 level(2-tailed) in the surface sediment of the Lake Tana, showing the same sources(table 3).

3.1.5 Sediment Available Phosphorous

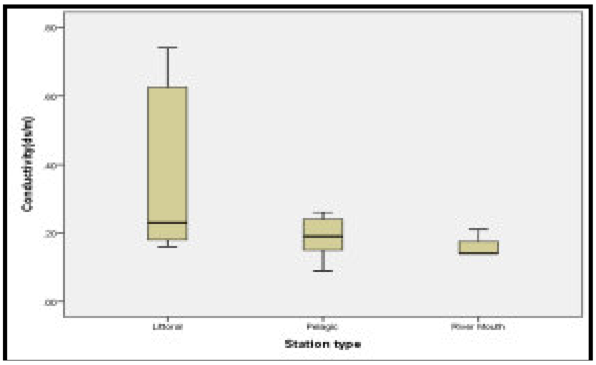
The sediment available phosphorous ranged between 0.4 to 108.79 mg/kg. The maximum value was noted during July, 2012 at Delgie-02 while the minimum value was obtained from Delgie-02 during January. The average sediment available phosphorous was between 9.56 to 52.23 mg/kg with the overall mean value of 21.83 mg/kg. There was a positive correlation between sediment availble phosphorous and organic matter(r = 0.630). The correlation is significant at the 0.01 level, 2-tailed (table 3). The significant correlation of organic matter with available phosphorous suggests that most of the availble phosphorous come from organic matter as probably bound to it. It is well known that organic matter in sediments act as reservoir of nutrients, aids in nutrient holding and binds nutrient thereby preventing them from becoming permanently unavailable. Phosphorus from inorganic sources from the agricultural area in the form of fertilizers and detergents etc. from domestic households is relatively low as compare to the organic sources. Unlike nitrogen and carbon, phosphorous has no gaseous form. Therefore, phosphorous does not cycle out of the system like nitrogen by way of denitrification or carbon by respiration. Thus phosphorous tends to accumulate in the sediments. Once in the sediments, phosphorous is slowly released into the interstitial water as organic material is oxidized.

3.1.6 Sediment Organic Matter

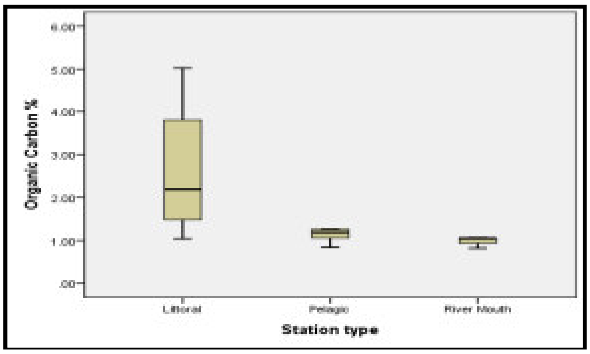
Organic matter of Lake sediment ranged between 0.21 to 8.4 %. Bahirdar Fishery station has maximum value during August 2011 at and the minimum value was recorded at Abay Mouth station during November 2011. The average organic matter (%) of Lake sediment was recorded between 1.33 to 6.98 % with the overall mean value of 3.13%. These values are lower than percent organic matter ranged from 2.3% (March) to 31% (March) reported for Lake Hora, Ethiopia (Habiba &Seyoum, 2012).When compared with the organic matter of Lower Himalayan Lake, Mansar, India (2.49 ±0.55%) by Chandrakiran and Shama(2013), the overall mean value of organic matters of Lake Tana(3.13%) were found higher. The average organic matter (%) in this study suggested that the sediments are high organic in nature because sediments with organic matter values exceeding 1% was usually called organically rich (Griggs,1975).



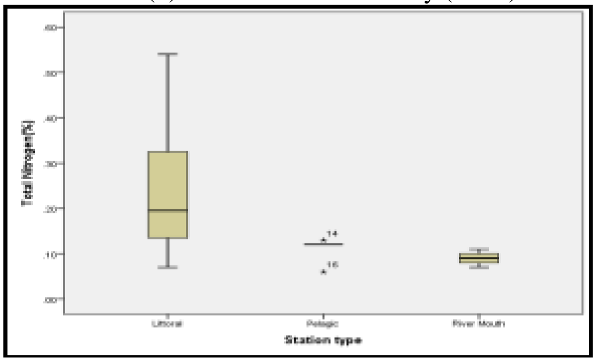
(a) Sediment pH



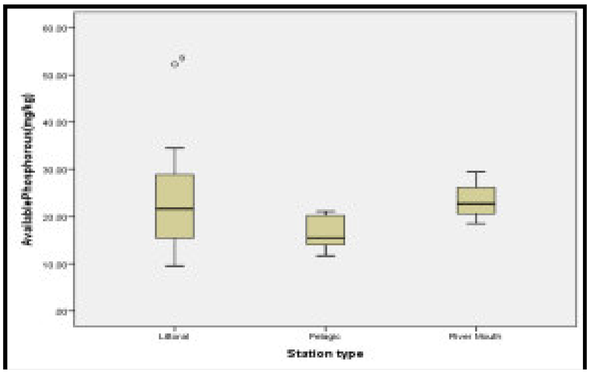
(b) Sediment Conductivity (dS/m)



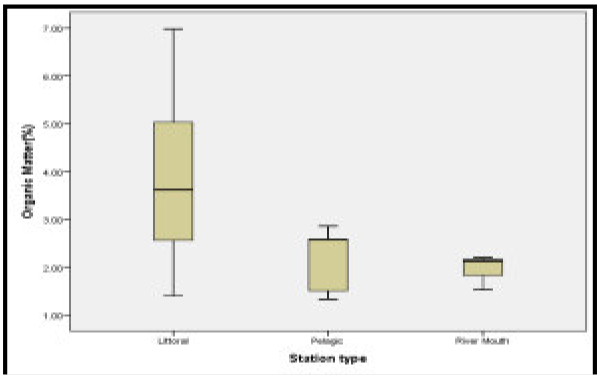
(C) Sediment Organic Carbon(%)



(D) Sediment Total Nitrogen (%)



(E) Sediment Available Phosphorous (mg/kg)



(F) Sediment Organic Matter (%)

Figure 4:Average Spatial Variation of Physicochemical Parameters in Sediments of Lake Tana

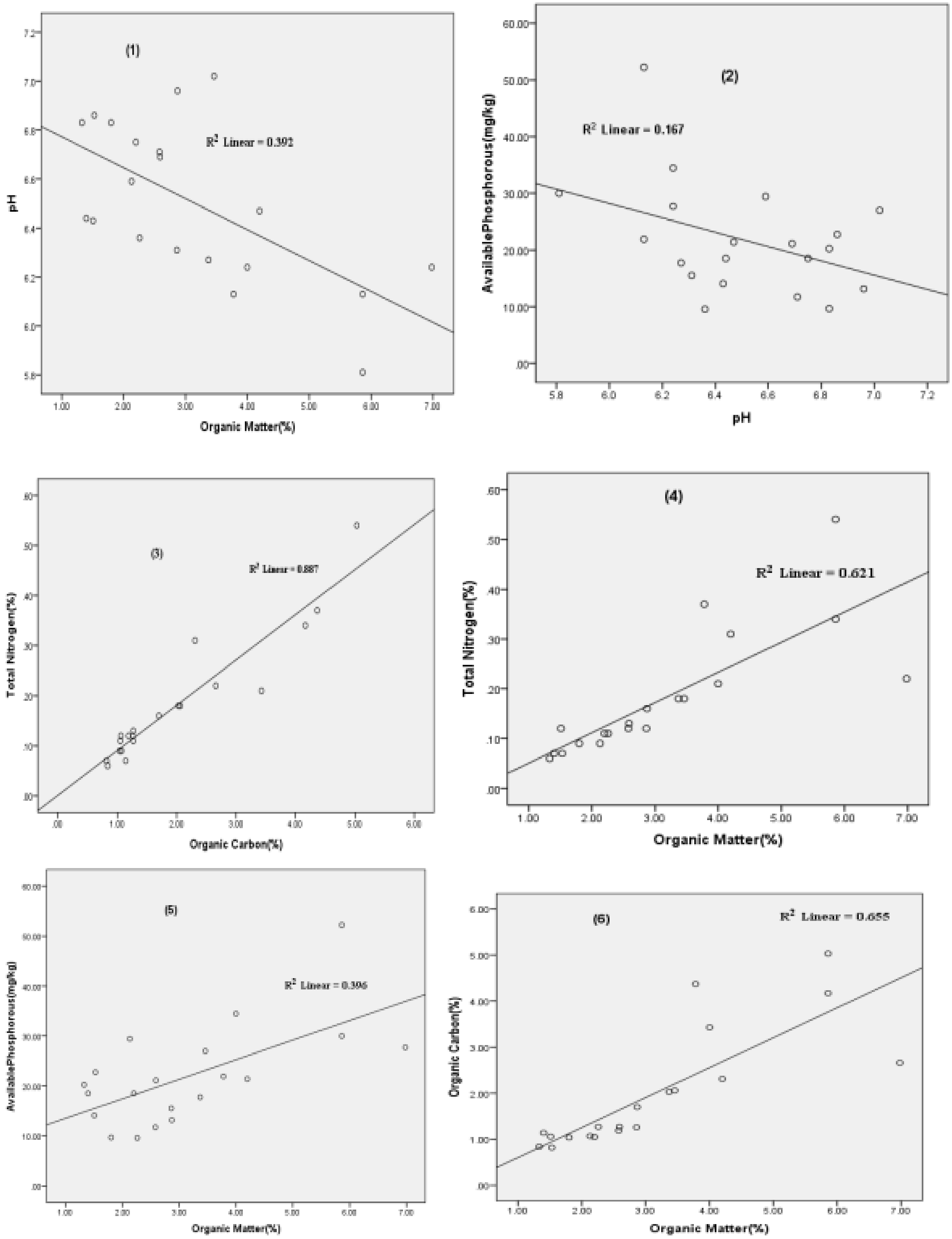


Figure 5:Relationship between various physico-chemical parameters of lake sediments:(1) pH Vs Organic Matter,(2) Available Phosphorous Vs pH, (3) Total Nitrogen Vs Organic Carbon, (4) Total Nitrogen Vs Organic Matter, (5) Available Phosphorous Vs Organic Matter and(6) Organic Carbon Vs Organic Matter

3.2 Spatial variability of physico-chemical parameters of sediments of Lake Tana by inverse distance weighting (IDW) interpolation technique

According to(Ji (2007) currents and orbital velocities in the lake bottom are usually stronger in shallow areas than in deeper areas. This leads to the accumulation of coarser sediments in shallow water and finer sediments at depth. Consequently, the sediments that are fine - grained and richer in organic materials tend to form a deposition zone at the center (and deeper part) of a lake. However, our study indicates that Lake Tana posses especial organic carbon and matter distribution. Rich in organic matter and carbon tend to form a deposition zone at Southwest part of Lake Tana. The organic matter distribution pattern obtained in this study disagreed with the work of Jin and Ji (2004) on modeling of sediment transport and wind-wave impact in Lake Okeechobee, rich in organic materials tend to form a deposition zone at the center (and deeper part) of a lake. This result also disagree with the result of Lake Hora study indicates that total organic matter content of the 3 stations increased from littoral to the profundal zone of the lake (Habiba and Seyoum, 2012).The result of the bathymetric interpolation of Lake Tana by Abeyou (2008) showed that the central area that covers some 25% of the total surface is characterized by average depth of some 12m and an absolute maximum depth of 14m that is observed at about 5km Deqe Estifanos Island in NNW direction. As it can be seen from the map(figure 6), deepest part of Lake Tana(near to the pelagic parts of Deqe Estifanos sampling site or PE05 sampling code) has low organic carbon as well as low organic matter. organic carbon was lower towards the inlets(river mouths), open(pelagic) of the Lake and even the deeper zones, outlet zone of Blue Nile and higher at western part of the Lake(Kunzila area and southwest part of the Lake(around Bahir Dar Fishery Research Center)(figure 6,map of organic carbon).

The application of inverse distance weighting (IDW) interpolation technique for organic carbon revealed that about 2,651.5ha(0.86%), 29,7171ha (96.5%) and 7,908.2ha (2.57%) of Lake Tana are low impact(≤ 1%), intermediate impact (1 to 3%) and high impact (>3%) respectively(table 5).The assessment result of organic matter showed that the major parts of Lake Tana was mapped in the range of low organic matter between 1.33 to 3.5% which covers around 172, 208ha(92.7%). Relatively high organic matter areas(4.5-6.94%) were aerially very small which accounts only o.7%(2163.77ha). This area found in extreme North and Southwest part of the Lake Tana (figure-6, Map of organic matter). The values of organic matter ranged between 3.5-4.5%, which accounts 6.64%(20444.4ha) are found in the northern, western and southwestern littoral part of the lake (figue-6, Map of organic matter).

Both organic carbon and organic matter deposition were aided by winds, flow conditions and hydraulic residence time. According to (Dargahi and Setegn, 2011), the flow structure is characterized by large recirculation and secondary flow regions and also composed of several large recirculation areas near the island, the lake outlet region and the shorelines of Lake Tana. This leads to the accumulation of less organic materials due to strong currents and orbital velocities induced from these several large recirculation that leads to the accumulation of coarser sediments in shallow water. Consequently, the sediments that are poor in organic materials tend to form a deposition in those areas. Setegn(2010) in his PhD study of modeling hydrological and hydrodynamic process in Lake Tana Basin revealed that the rotation direction changed with the wind direction. NE and NW winds induced anticlockwise and clockwise rotations, respectively. The island causes a flow spilt that in turn creates smaller recirculation zones. The flow also splits at the lake outlet region into two distinct zones, one to the east side leading into the outlet, and a second to the west side. The latter flow interacts with shoreline to create another recirculation area(Setegn,2010). The flow structure at the lake outlet region into two distinct zones, one to the east side leading into the outlet, and a second to the west side supported the organic carbon and organic matter deposition of Lake Tana at the Southern region(Gulf of Bahir Dar). The former split leads to the less accumulation of organic matter at Southeast outlet region of Lake Tana due to short hydraulic residence time around the outlet region whereas the latter split leads to relatively high accumulation of organic matter at southwest part of Lake Tana due to less recirculation and absence of outlet in this region.

Spatially, major parts of Lake Tana was mapped in the range of low total nitrogen between 0.06-0.20% which covers around 289067ha(94%). Relatively high total nitrogen areas(0.30-0.54%) were aerially very small which accounts only o.56%(1738.1ha). Those relatively high total nitrogen distribution were observed in the sediment extreme west and southwest part of the Lake Tana (figure-6, Map of total nitrogen). The values of total nitrogen ranged between 0.20-0.30%, which accounts 5.5%(16927ha) are also found in the western and southwestern part of the lake (figure-6, Map of total nitrogen).The spatial distribution of available phosphorous indicated that major parts of Lake Tana was observed in the range of low available phosphorous between 9.69-20.60 mg/kg which covers around 289067ha (94%). Relatively high available phosphorous (20.60-51.19 mg/kg) were aerially very small which covers only 1465ha (0.48%).

Hydraulic residence time(flushing time or retention time) can have a significant influence on the responses of a lake to nutrient enrichment i.e. a short hydraulic residence time can reduce the time available for plant growth and result in less accumulation of biomass whereas long residence times result in recycling and greater nutrient retention(Ji , 2007).

According to Setegn(2010) Lake Tana has relatively long flushing time (1 year) and he investigated the flushing features of Lake Tana using a numerical dye tracers experiment and his result revealed that the lowest dye concentration was 60% that was found near the area affected by the Lake outlet and the highest concentration i.e., 100% is seen at North West part of the Lake due to the surface flow direction from east to west as well as the existence of permanent secondary flows in that region. Low total nitrogen and available phosphorous distribution at the Southeast part of the Lake Tana i.e., near the area affected by the Lake outlet of this study agree with the work of Setegn(2010) on modeling hydrological and hydrodynamic process in Lake Tana Basin, the lowest dye concentration(60%) whereas the highest concentration dye(100%) seen at North West part of the Lake disagree with total nitrogen and available phosphorous distribution of this study which have low enrichment of total nitrogen and available phosphorous.

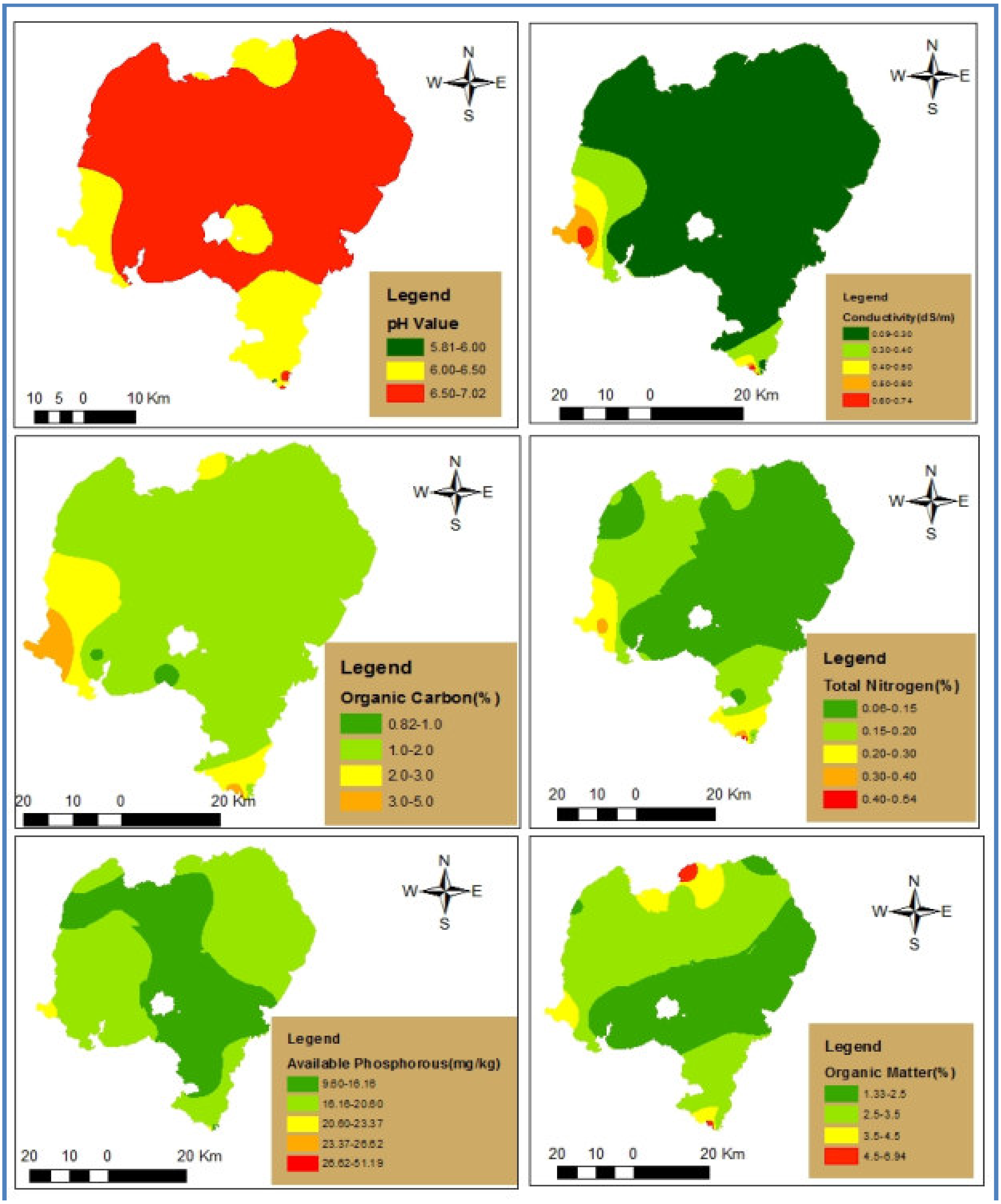


Figure 6: Maps of horizontal spatial distribution of physico-chemical parameters in the surface sediments of the Lake Tana by inverse distance weighting (IDW) interpolation technique

Table 4:Area (ha) and Percentage(%) Tabulation of physico-chemical Parameters of sediments of Lake Tana

Parameters																	
PH			Conductivity(dS/)			Organic Carbon(%)			Total Nitrogen(%)			Available Phosphorus(mg/kg)			Organic Matter(%)		
Range	Area(h)	%	Range	Area(h)	%	Range	Area(ha)	%	Range	Area(ha)	%	Range	Area(ha)	%	Range	Area(ha)	%
5.81-6.00	65.177	0.02	0.09-0.30	269580	88	0.062-1.0	2651.5	0.86	0.06-0.15	199591	64.9	9.69-16.16	126994	41.269	1.33-2.5	122130	39.7
6.00-6.50	60551	19.7	0.30-0.40	24029	7.8	1.0-2.0	265348	86.2	0.15-0.20	89476	29.1	16.16-20.60	179261	58.254	2.5-3.5	162995	53
6.50-7.02	247116	80.3	0.40-0.50	7619.1	2.5	2.0-3.0	31823	10.3	0.20-0.30	16927	5.5	20.60-23.37	1456.7	0.4734	3.5-4.5	20444.4	6.64
			0.50-0.60	4834.2	1.6	3.0-5.03	7908.2	2.57	0.30-0.40	1609	0.52	23.37-26.62	7.7884	0.0025	4.5-6.94	2163.77	0.7
			0.60-0.74	1670.2	0.5				0.40-0.54	129.1	0.04	26.62-51.19	0.5187	0.0002			

4. Conclusion

The present study concluded that the sediment nutrients mainly nitrogen and phosphorous of Lake Tana are originated from organic sources than inorganic sources. The correlation between nitrogen and phosphorous revealed that they are generated from the same sources. The ratio between total organic carbon and total nitrogen of Lake Tana sediment indicated that the source of organic matter mainly from aquatic ecosystem than terrestrial. Both organic carbon and organic matter deposition were aided by winds, flow conditions and hydraulic residence time. Relatively high total nitrogen (0.30-0.54%) and available phosphorous(20.60-51.19 mg/kg) were spatially very small which account only o.56%(1738.1ha) and 0.48%(1465ha) of the total Lake area respectively. The present data on pollution in sediments from Lake Tana also points out to the need of regular monitoring of the Lake Tana sediment. As it is the first time where monitoring physico-chemical properties of sediments of Lake Tana are presented, this study can be used as baseline data for comparison in future environmental assessment of the lake. A limitation that can be pointed to this study is that analysis of sediment particle size and benthic organism were not included. As a result of this, the study is conducted without correlating sediment physicochemical parameters with sediment particle size and benthic organism. Therefore, in the future research on Lake Tana sediment quality monitoring, sediment particle size and benthic organism analysis should be included. Further research on Lake Tana sediment transport modeling should be done.

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