Eth.J.Sci & Technol. 5(1) 17-41, 2007
ISSN 1816-3378

The physio-chemical characteristics of a highland crater lake and two reservoirs in north-west Amhara Region (Ethiopia)

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Abstract

Seven water quality parameters were monitored in one highland Crater Lake (altitude 2500 m) and two reservoirs (altitude 1800 m) in the period December 2004 to July 2005. Surface water temperature ranged from 19 to 26^{O}C, dissolved oxygen from 4 to 10 mg l^{-1}, turbidity from 5 to 30 NTU, pH from 7.7 to 8.7, conductivity from 55 to 185 µS cm^{-1}, total dissolved solids from 33 to 150 mg l^{-1}, and nitrate from 2.6 to 4.5 mg $l^{-1}NO_3$ –N. The lowest values, except for dissolved oxygen and pH were observed in Zengena Crater Lake. The two reservoirs showed elevated levels of nutrients and total dissolved solids, high turbidity, and high conductivity. This was the result of a high sediment and nutrient load from the catchments. These results show that these reservoirs are heavily influenced by agricultural practices and municipal effluent. We recommend that water quality management measures like controlling allochthonous nutrient loadings should be taken to stop eutrophication in these reservoirs.

Key words: Tropical limnology, East Africa, Water quality management

INTRODUCTION

Water is an essential resource for development. Sustainable use of water depends on functionality of the whole ecosystem. Individual patterns of physical and chemical characteristics are determined by the climatic, geomorphological and geochemical conditions in the drainage basin and the connected aquifer. Parameters such as total dissolved solids, conductivity and redox potential provide a general classification of water bodies with a similar nature (UNESCO/WHO/UNEP 1996). The development of aquatic life (flora and fauna) in surface waters is influenced by a variety of environmental conditions that determine the species as well as the physiological performance of individual organisms. The flora and fauna present in specific aquatic systems are a function of the combined effects of various hydrological, physical and chemical factors (UNESCO/WHO/UNEP 1996). Water resources all around the world are under pressure and especially eutrophication is a major environmental problem. Visible effects of eutrophication are development of planktonic scum and rooted plant biomass, increased algal growth, death of fish, increase in sedimentation, decrease in dissolved oxygen concentration and reduction of water transparency (Klapper, 1991). It is caused by excessive loading of dissolved and particulate organic matter and inorganic nutrients (C, N and P).These nutrients are loaded by municipal and industrial sewage discharges and/or from diffuse sources in catchments areas. Phosphorus is one of the main factors in phytoplankton growth (Correll, 1998).In addition to external nutrient loadings and even after their reduction, eutrophication can be maintained by internal loading, which corresponds to the release of nutrients from the lake sediments into the water column. The chemical inactivation of phosphorus by aluminum sulphate (alum) addition is a common chemical treatment of eutrophication (Klapper, 1991).

The physico-chemical water quality parameters are useful tools for monitoring the ecosystem integrity. In South Ethiopia, the physico-chemical characteristics of the Rift valley lakes have been studied systematically and in much detail (e.g. Kebede et al., 1994; Zinabu et al., 2002). This in contrast with the North Ethiopian water bodies where information on physico-chemical water quality parameters is generally rare and often of expeditions origin (e.g. Talling & Talling, 1965; Baxter & Golobitsch, 1970; Wood & Talling, 1988; Kebede et al., 1992).The present study is the first systematic attempt to study the water quality of three water bodies in North Ethiopia.

MATERIALS AND METHODS

Study area description

Lake Zengena, Geray and Tikurweha reservoirs are located out side the rift valley in the northern high lands of Ethiopia at Agewawi zone, Ankesha gaugesa woreda and West Gojjam administrative zone, Jabithinan woreda respectively. The absolute geographical position of Lake Zengena, Geray and Tikurweha reservoirs are 10^0 54' 47.7'' N, 36^0 57' 56.4''E, 10^0 39' 59.7''N, 37^0 17.9' 2.8''E and 10^0 40' 19.9''N, 37^0 22' 11.6'' E respectively. Lake Zengena is found relatively in higher altitude (2500 m a. s. l) than Geray and Tikurweha reservoirs (1800 m a. s. l). Lake Zengena was probably formed through volcanic eruption (Crater Lake).Like the other crater lakes, it is circular in shape and surrounded by cliff covered with vegetation. It is a closed basin with no in let and out let. There are no permanent rivers which tribute to the lake and no outlet. Geray and Tikurweha reservoirs are artificial water bodies primarily used for irrigation of the surrounding farm land. Lake Zengena, Geray reservoir and Tikurweha reservoir cover an surface area of about 20 – 25, 10 and 4 hectares respectively. The maximum depth of Lake Zengena was ca. 160 m in the middle of the lake (10^0 54' 47.7''N ,36^0 57' 56.4''E).Geray and Tikurweha reservoirs are rather shallow and had a mean depth of 4 and 2 m respectively. The emergent and submergent aquatic vegetations were dense in Geray and Tikurweha and sparse in Lake Zengena though the littoral area has a small macrophyte belt and the vegetation of its catchments is well developed.

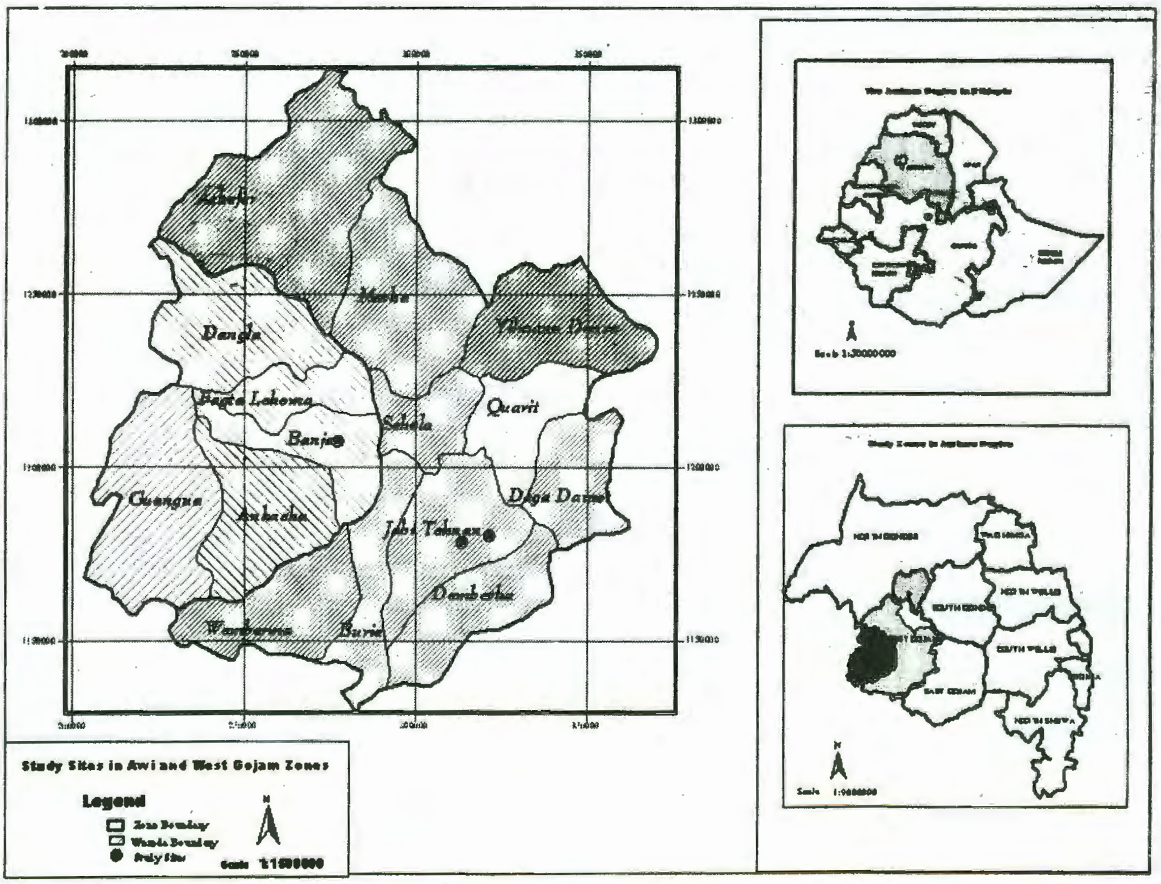

Fig 1. Location of Banja and Jabi Tehnan Woredas and the sampled sites for physical and chemical characteristics study.

Sampling

A total of 24 surface water samples, eight from each water body, were collected from Lake Zengena, Geray and Tikurweha reservoirs (Fig.1) in between Dec.2004 and Jul.2005.

Aliquots of surface water samples were collected monthly from the inshore zone of each water body using acid –washed 2L polyethylene bottles. The nutrient analysis and insitu-measurments of physical parameters were done also on a monthly basis as follows

Determination of physico-chemical parameters

In-situ measurements of electrical conductivity, pH, dissolved oxygen, temperature and total dissolved solids were measured with probes. pH and temperature were measured with coupled pH/mV/O Meter (Model CE 370 pH meter 01186, EU). Electrical conductivity and TDS were measured with Cond/TDS meter (Model CE 470 Cond Meter 01189) and dissolved oxygen with oxygen meter (OXi 31 5i, WTW82362). Measurements were taken by dipping the probe about 3-5 cm below the water surface.

Analyses of turbidity and nitrate samples were done immediately after collection with a mobile water analysis kit (Wagtech international, Palintest transmittance display photometer 5000, Palintest Ltd., UK)). Water samples were filtered through a 0.45 μm mesh membrane filter before analyses. Turbidity and Nitrate concentration of the water was determined photo electrically using the palintest photometer. In order to separate the effect of turbidity and color the samples were compared against filtered portion of the same water i.e. the filtered water sample was used as a blank for each site. Nitrate was determined by the palintest-nitratest method. Samples of expected high concentrations of the respective chemicals were diluted so that they could be measured within the linear detectable range. The detection limit is over the range of 0 - 20 mg l^{-1} for nitrate, and 5 - 400 turbidity units for turbidity.

Data analysis

All statistical analysis was done with the statistical package for social sciences, SPSS for windows, version 12 (SPSS Inc; Chicago, Illinois). Differences among the three water bodies (n = 3 x 8) were tested with the non-parametric Kruskal – Wallis H tests, whereas the non-parametric Mann -Whitney U tests was used for pair wise comparisons of sites.

RESULTS AND DISCUSSION

1. Dissolved Oxygen (DO)

The seasonal variation of dissolved oxygen (DO) values in the three water bodies is shown in Fig. 1. DO values of the three water bodies are significant ly different (Kruskal-Wallis H test, $P < 0.05$, n = 8 x 3). Furthermore, DO values of Tikurweha and Geray reservoirs were significantly lower than DO values of Lake Zengena (Mann-Whitney U test, $P < 0.05$).

The maximum observed DO values for Geray, Zengena and Tikurweha were 10.4, 8.7 and 7.8 mg l^{-1} and the minimum values were 3.9, 4.5 and 3.6 mg l^{-1}

respectively. The minimum DO values for Geray, Zengena and Tikurweha were observed in June, May and Jan.2004/ 2005 respectively. The maximum DO values for the above sites were observed in January except Tikurweha which was observed in July (Fig 1). Lake Zengena had higher mean DO values than Geray and Tikurweha reservoirs. Most likely because it was the only water body not receiving allochthonous organic material in the form of sewage. The breakdown of organic material by microbes increases ecosystem respiration, and therefore reduces DO concentrations in the reservoirs.

The lowest DO values were observed in Tikurweha reservoir because it was receiving heavy organic and inorganic load from the municipality and the agriculture. The sewage line carrying municipal waste from Giga was diverted to the reservoir. All sites had the highest DO concentration (10.4 mg l^{-1} for Geray; 8.7 mg l^{-1} for Zengena and 7.8 mg $l^{-1}$for Tikurweha) during post rain season i.e. in January. Nutrient inputs as a result of rain together with better light conditions could stimulate the phytoplankton and macrophytes to produce more oxygen as a byproduct of photosynthesis.The main sources of dissolved oxygen in the water column are from photosynthesis by plants (APHA 1995).According to Dejen et al. 2004, dissolved oxygen measured in Lake Tana ranged between 5.9 - 7.3 mg l^{-1} The minimum was observed in December and maximum in April. A maximum valve of 10.4 mg l^{-1} of DO was achived in Geray which has the same altitude as that of Lake Tana .This could be mainly because of the difference in trophic status of the lakes as Lake Tana has been categorized as ologotrophic based on photosynthetic community (chlorophyll content) and primary production(Wondie etal.,2007).

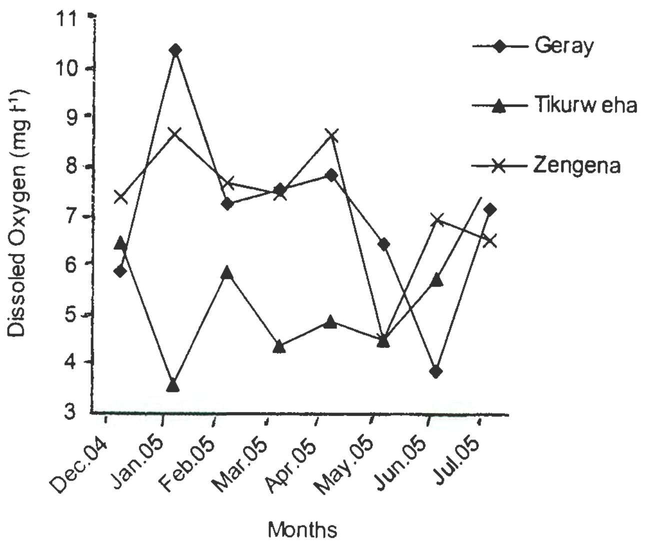

Figure 1. Seasonal variation of dissolved oxygen (mg l^{-1}) in Lake Zengena ,Geray and Tikurweha reservoirs during the research period (Dec. 2004-Jul.2005;n = 8 x 3.

2. Surface water temperature

The seasonal variation of surface water temperatures in the three water bodies is shown in Fig. 2. Surface temperatures differ significantly among the three water bodies (Kruskal-Wallis H test, $P < 0.05$, n = 8 x 3). The temperatures of Tikurweha reservoir were significantly higher than the temperatures in Lake Zengena (Mann -Whitney U test, $P < 0.05$) during the study period (Dec. 2004 - July 2005).

The observed maximum temperature in Tikurweha, Geray and Zengena water bodies were 28, 26 and 25^{O}c respectively. The minimum temperatures detected were 21, 21 and 19 °C respectively. The highest temperature for Tikurweha and Zengena water bodies were recorded in June and for Geray it was in April. The

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ISSN 1816-3378

lowest temperatures for all sites were noted in December except Tikurweha in April.

The lowest temperatures were observed in Lake Zengena, most likely because this water body is located at a substantial higher altitude (i.e. 2500 m) than the other two reservoirs (ca. 1800 m).

From Vijverberg et al, 2009,it is possible to understand that Water temperature increases with decreasing altitude and the surface water temperature varied between 19 and 26 °C, with the lowest values observed in the mountain lake Ashenge (altitude 2409 m) in the north, and the highest temperature in L. Chamo (altitude 1233 m) in the south .L. Tana with a similar altitude to Tikurweha reserviour(1800 m) showed relative low temperature values(23.5 $\pm$1.8 °C according to Wondie etal.,2007; 21°C according to Vijberg etal.,2008) but comparable and in the same range like that of Tikurweha reserviour where maximum surface water temperature was noted. Lakes in the Southern Rift Valley with low altitudes showed higher values. The northern crater lake, L. Hayk, in the highlands showed a surprisingly high water temperature (altitude 2030 m). This may have been the result of volcanic activity (.Vijberg et al, 2008).

Water bodies undergo temperature variations along with normal climatic fluctuations. These variations occur seasonally and in some water bodies, over periods of 24 hours. Latitude, altitude, and season, time of the day, air circulation, cloud cover and the flow and depth of the water body influence the temperature of surface waters. The minimum values of temperature were noted in December and maximum values in April for Geray and Zengena and June for Tikurweha. This pattern follows seasonal fluctuations of the air temperature as December is one of the coldest month and April and June (rare cases) are one of the hottest months.

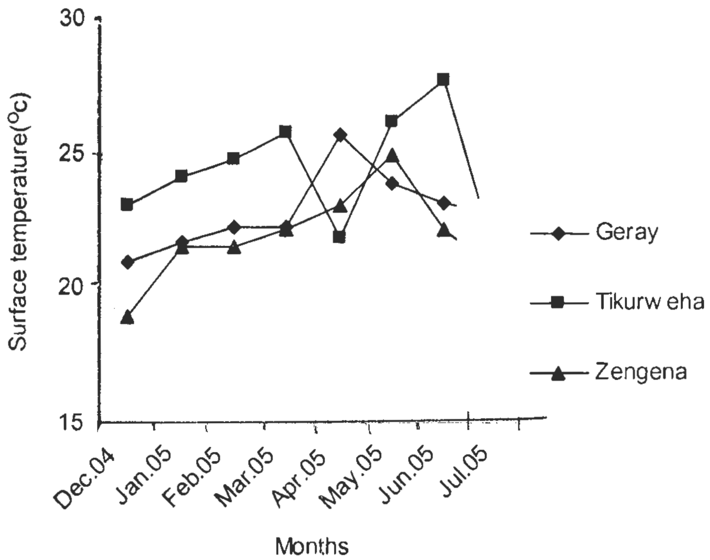

Figure 2. Seasonal variation of temperature (^{O}C) at Lake Zengena and Geray and Tikurweha reservoirs during the research period (Dec.2004-Jul.2005).

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3. Turbidity

The seasonal variation in turbidity (NTU) in the three water bodies is shown in Fig. 3. There was no significant difference in turbidity among water bodies (Kruskal-Wallis H test, $P > 0.05$, $n = 8 \times 3$).

The maximum observed turbidity of Geray, Tikurweha and Zengena water bodies were 14, 30 and 5 NTU and the minimum for Geray and Tikurweha reservoirs were 4 NTU and for Zengena 5 NTU.

Turbidity in Lake Zengena remained uniform throughout the study period. In Tikurweha level of turbidity reached maximum in December and lowest in the period May to June. The lowest turbidity is also noted in Geray in the month of June and maximum were noted in March.

The concentrations of both phosphate (Goraw Goshu, unpublished work) and nitrate (Table 2) in Lake Zengena were very low resulting in very low plankton densities. Nitrogen is generally considered a limiting nutrient in tropical water bodies (Talling & Talling, 1965).This low phytoplankton densities with absence of any inflowing river could lead to almost uniform turbidity. The maximum turbidity in Tikurweha reservoir noted in December after the rainy season could be most likely due to sediment load from the municipal waste and there by wind-induced resuspension of shallow bottom sediments. Low secchi - disk depths were also recorded in Lake Tana during the main -rainy season because of high silt loads from the inflowing rivers together with higher wind speeds during rainy periods (Wondie et al, 2007).Geray reservoir also receives excess sediment load from the agricultural farms found in the near vicinity during the peak rainy season but the macrophyte belt in the shore could probably play a significant role in filtration of soil and trapping nutrients leading to low turbidity. The maximum turbidity of Geray reservoir is observed in March before the onset of rain season. This maximum turbidity was noted most likely because of phytoplankton growth as a result of increased nutrient availability and higher temperature,

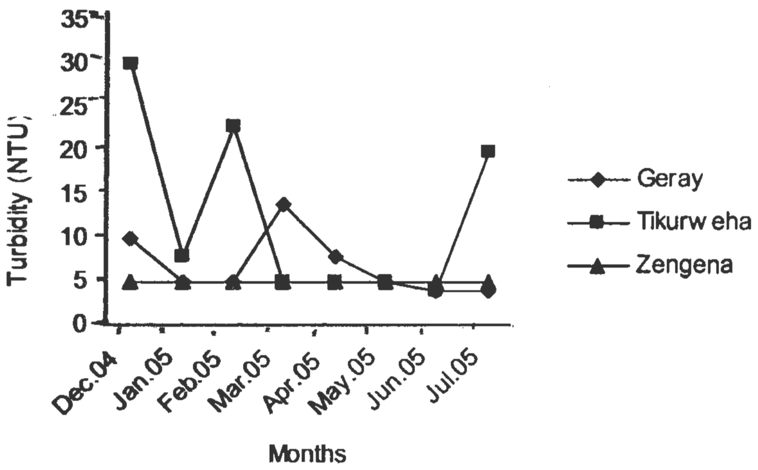

Figure 3.Seasonal variation in turbidity (NTU) at Lake Zengena and Geray and Tikurweha reservoirs during the research period (Dec. 2004-Jul.2005).

4. Nitrate

The seasonal variation in Nitrate concentrations in the three water bodies is shown in Fig. 4. There was no significant difference in nitrate among water bodies (Kruskal-Wallis H test, $P > 0.05$, $n = 8 \times 3$).

The highest maximum concentration of nitrate was observed in Geray reservoir (4.18 mg l^{-1}) and the lowest in Lake Zengena 2.86 (mg l^{-1}).The minimum concentrations of nitrate noted in Geray, Tikurweha and Zengena were 0.97, 0.53 and 0.18 mg l^{-1} $NO_3 - N$ respectively. The minimum concentrations of nitrate for all sites were noted in the month of June and the maximum were noted in the month of April for Geray and Zengena and in February for Tikurweha reservoir. In Tikurweha there were also other peaks in April and August. The peak value of Nitrate in April in Lake Zengena could be explained as a result of decomposition of organic leaf falling from the trees surrounding the lake.

In lake Tana, the concentration of nitrate reached maximum (600μg l^{-1}) during the second part of the rainy season and the post rainy season between October and November (Wondie etal.2007) ; a situation different from what was observed in all of the study sites. The nitrate concentration in ground and surface water is normally low but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources (WHO, 2004).Tikurweha reservoir was receiving the most excessive sediment load from the diversion of the sewage line that carried Giga municipal waste and agricultural wastes from the catchments. Geray reservoir has received sediment and other associated loads from the agriculture though it did not receive wastes from the municipality. Nevertheless, due to very good vegetation cover of the shore area that could serve for filtration and trapping of nutrients, it did not show peak in the rainy season but showed peak later in April. The role of wetlands here regarding gradual release of nutrients was shown. It has been suggested that papyrus swamps may act as a nutrient filter or trap Viner 1975; Thompson 1976

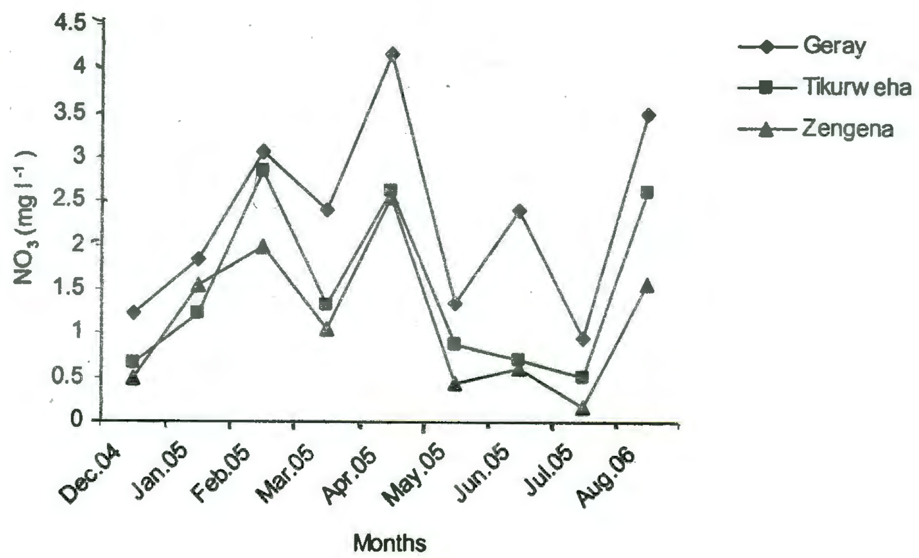

Figure 4. Seasonal variation of NO_3 (mg l^{-1}) in Lake Zengena and Geray and Tikurweha reservoirs during the research period (Dec. 2004-Jul.2005).

5. pH

The seasonal variation in pH in the three water bodies is shown in Fig. 5.

There was no significant difference in pH among water bodies (Kruskal-Wallis H test, $P > 0.05$, $n = 8 \times 3$).

The maximum values of pH for all sites were recorded in May except Lake Zengena i.e. in June. The minimum values of pH for all sites were noted in January. The maximum and minimum values of pH noted were 8.7 and 6.9 respectively.

In unpolluted waters, pH is principally controlled by the balance between the carbon dioxide, carbonate and bicarbonate ions as well as other natural compounds such as humic and fluvic acids. The natural acid-base balance of a water body can be affected by industrial effluents and atmospheric deposition of acid-forming substances (APHA, 1995). pH is an important variable in water quality assessment as it

Eth.J.Sci & Technol. 5(1) 17-41, 2007 ISSN 1816-3378
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influences many biological and chemical processes within a water body and all processes associated with water supply and treatment (APHA, 1995). When measuring the effects of an effluent discharge, it can be used to help determine the extent of the effluent plume in the water body. At a given temperature, pH (or the hydrogen ion activity) indicates the intensity of the acidic or basic character of a solution and is controlled by the dissolved chemical compounds and biochemical processes in the solution. Changes in pH can indicate the presence of certain effluents, particularly when continuously measured and recorded, together with the conductivity of a water body. The pH of most natural waters is between 6.0 and 8.5, although lower values can occur in dilute waters high in organic content, and higher values in eutrophic waters, groundwater brines and salt lakes (APHA, 1995).

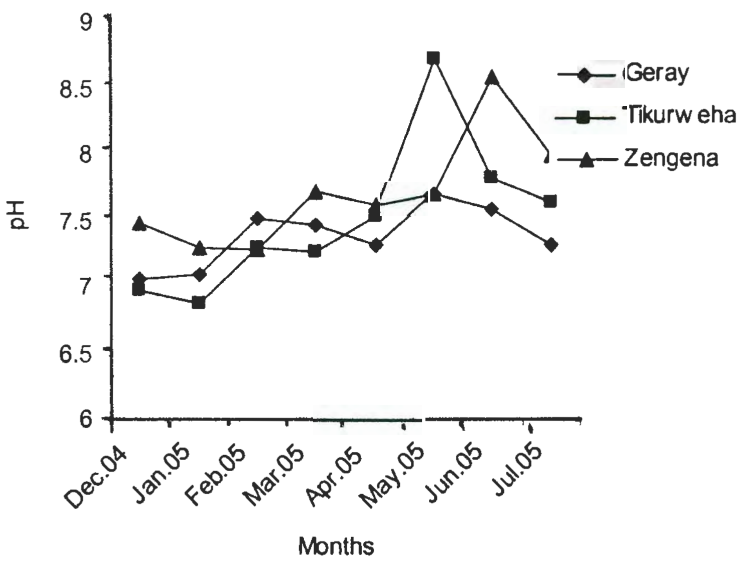

Figure5. Seasonal variation of pH in Lake Zengena and Geray and Tikurweha reservoirs during the research period (Dec.2004-Jul.2005).

6. Total dissolved solids (TDS)

The seasonal variation in total dissolved solids (TDS) in the three water bodies is shown in Fig. 6. TDS in the three water bodies were significantly different from each other (Kruskal-Wallis H test, $P < 0.05$, $n = 8 \times 3$). The TDS values of Lake Zengena were significantly lower than Geray reservoir, and TDS values in Tikurweha reservoir were significantly higher than Lake Zengena and Geray reservoir (Mann -Whitney U test, $P < 0.05$).

The highest mean TDS was recorded in Tikurweha and the lowest in Zengena. The TDS values recorded in Tikurweha, Geray and Zengena ranged from 142 – 150, 98 - 111 and 30 - 33 mg l^{-1} respectively. The maximum TDS values in all three water bodies were observed in June and the minimum in February except Zengena in April. Second lowest peak in Zengena was also noted in February.

In rift valley lakes, the smallest value of salinity was noted in koka (200 mg l^{-1}) which has an altitude of 1660 m and the highest value (44920 mg l^{-1}) in Chitu with an altitude of 1600 m (Kebede et al ,1994). A clear concentration difference in salinity between the three investigated highland water bodies of north-west Amhara region and rift valley lakes could be most likely attributed to different geological regions owing to differences in the solubility of minerals as it has been also indicated in WHO, 2004.Salinity is primarily determined by evaporative concentration, enhanced in lakes associated with past marine influence or recent volcanic activity by readily soluble minerals in the catchment ,and by some thermal –reflux pathways(Wood and Talling,1998).Total dissolved solids comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water .TDS in water originate from natural sources, , urban runoff, and industrial wastewater.

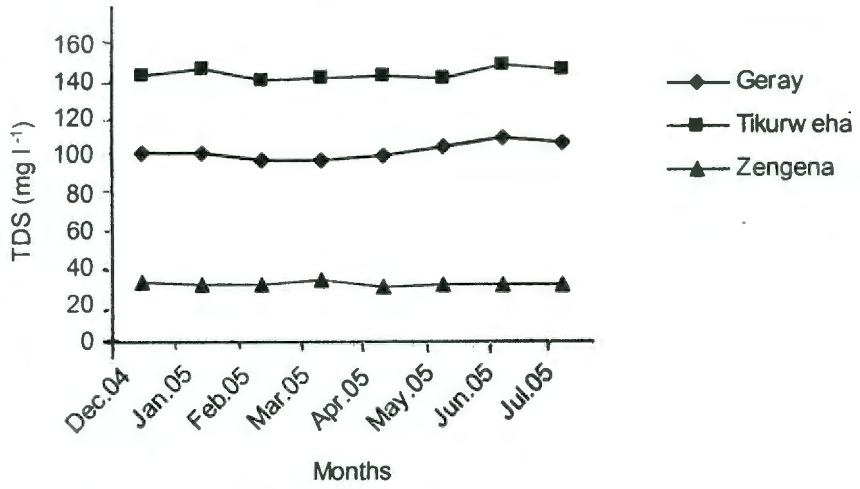

Figure 6. Seasonal variation in of TDS (mg l^{-1}) in Lake Zengena and Geray and Tikurweha reservoirs during the research period (Dec. 2004-Jul.2005).

7. Conductivity

The seasonal variation in conductivity in the three water bodies is shown in Fig. 6. TDS in the three water bodies were significantly different from each other (Kruskal-Wallis H test, $P < 0.05$, $n = 8 \times 3$). The TDS values of Lake Zengena were significantly lower than in Geray reservoir, and TDS values in Tikurweha reservoir were significantly higher than in Lake Zengena and Geray reservoir (Mann -Whitney U test, $P < 0.05$).

The highest and lowest conductivity was recorded in Tikurweha reservoir and Lake Zengena respectively. Geray reservoir had laid in between the rest two sites. Conductivity ranged between 236 – 250, 63 - 185 and 50 - 55 μS cm^{-1} for Tikurweha, Geray and Zengena study sites respectively. For all sites conductivity reached maxima in the month of June except Lake Zengena that is in March. The minimum values of conductivity for Tikurweha, Geray and Lake Zengena were recorded in the months of February, March and August respectively.

Tikurweha and Geray reservoirs have a similar altitude to Lake Tana (1800 m a.s.l).The highest values of Electrical conductivity we noted in Tikurweha reservoir in June were comparable but a bit higher than the maximum electrical conductivity of Lake Tana (183.63 ± 29.8 μS cm^{-1};) noted in post rainy season during May-June(Wondie et al,2007). According to Kebede et al.,1994 the lowest(286μS cm^{-1}) and highest(49100 μS cm^{-1})values of electrical conductivity were noted in lake koka and chitu that has an altitude of 1660 and 1600 m a.s..l respectively. Conductivity is sensitive to variations in dissolved solids, mostly mineral salts. The degree to which these dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on conductivity (APHA,1995).The highest total dissolved solids noted In Tikurweha reservoir in the month of June supported the observed maximum Electrical conductivity in Tikurweha reservoir . Conductivity is related to the concentrations of total dissolved solids and major ions. The conductivity of most fresh waters ranges from 10 to 1000 μS Cm⁻1, especially in polluted waters, or those receiving large quantities of land run-off. Conductivity can be used as a rough indicator of mineral content. The highest and lowest conductivity observed in Tikurweha and Zengena respectively could be most likely attributed to variations in temperature and organic load from the catchments.

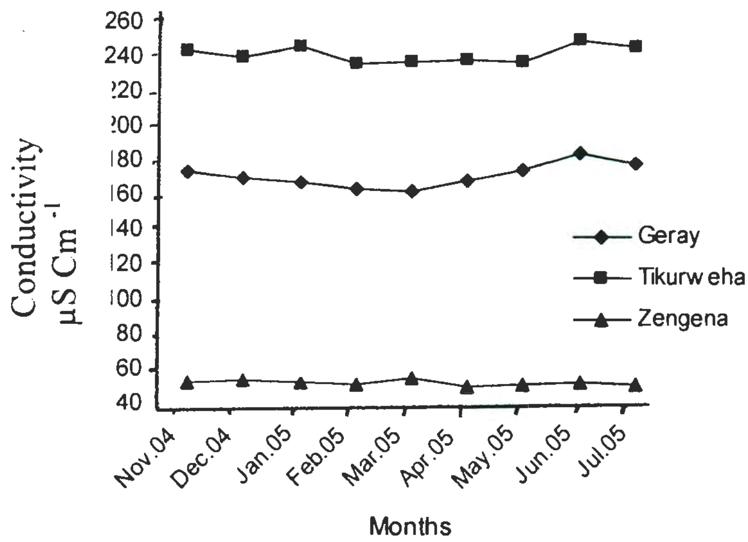

Figure 7. Seasonal variation in conductivity (µS cm^{-1}) in Lake Zengena and Geray and Tikurweha reservoirs during the research period (Dec. 2004-Jul.2005).

Table 1. Means and standard errors of water physical and chemical parameters; Lake Zengena, Geray and Tikurweha reservoirs; T^{O}, = surface water temperature, DO = dissolved oxygen, Tur., = turbidity, NTU = Nephlometric Turbidity Units, Con = conductivity, TDS = total dissolved solids, Min = minimum, Max = maximum, SE = standard error.

	Statistic	T^{O} (^{O}C)	DO mgl^{-1}	Tur. (NTU)	pH	Con μSCm^{-1}	NO_3-N mgl^{-1}	TDS mgl^{-1}
Geray	Mean	23	7.1	7	7.4	172	2.19	103
	Min	21.0	3.9	4	7.1	163	0.97	98
	Max	26	10.4	14	7.7	185	4.18	111
	SE	0.51	0.65	1.26	0.1	3	0.38	1.6
Tikurweha	Mean	24	5.4	13	7.5	242	1.35	145
	Min	21	3.6	4	6.9	236	0.53	142
	Max	28	7.8	30	8.7	250	2.86	150
	SE	0.81	0.48	3.62	0.2	2	0.32	1.0
Zengena	Mean	22	7.3	5	7.7	52	1.11	31.4
	Min	19.0	4.5	5	7.3	50	0.18	30.0
	Max	25.0	8.7	5	8.6	55	2.55	33
	SE	0.62	0.47	0	0.1	1	0.30	0.4

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CONCLUSION AND RECOMMENDATIONS

We observed differences in water quality among the three water bodies we studied. These differences can be explained by different patterns of land use, point source pollution, forest cover and geochemistry of the feeding catchments areas. No significant seasonal changes in conductivity, turbidity, total dissolved solids and pH observed in Lake Zengena. This may indicate that mixing of the water column either due to internal waves or wind action is completely lacking. Especially the physico chemical properties of Geray and Tikurweha reservoirs were heavily influenced by agricultural and municipal effluents from the catchments. Associated with these; generally elevated levels of nutrients, high turbidity, high conductivity and high total dissolved solids in Geray and Tikurweha reservoirs. These levels were significantly lower in highland Crater Lake Zengena.

We recommend that water quality management measures like catchments treatment and controlling allochthonous nutrient loadings should be taken as soon as possible to stop eutrophication in these reservoirs. The reservoirs shouldn't be considered as a waste basket and especially the Giga municipality should not direct the sewerage line to the reservoir. It is also recommended that a detail study of the water bodies (including the biotic components) should be done year round.

ACKNOWLEDGMENTS

I thank Ethiopian Agricultural Research Institute and Amhara Regional Agricultural Research Institute for funding this research work. I acknowledge Dr. Vijberg Koos for correcting and reviewing the manuscript critically. I am also grateful to Bahirdar Fishery & Other Aquatic Life Research Center for providing field car to collect samples. I acknowledge Birhane Abebe, GIS Expert of Amhara Region Environmental Protection and Land use Authority for preparing the study area map. Last but not least I thank Derje Tewabe, Wondie Zelalem, Germew Hailue, and Getinet Temessgen for their technical assistance during the field work and laboratory analysis and Tewodros Mitka as car driver, Ayenew Gedif and Endalmaew Assrese as boat drivers.

Eth.J.Sci & Technol. 5(1) 17-41, 2007 ISSN 1816-3378

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