Water Quality Monitoring within the Abaya - Chamo Drainage Basin

Ababu Teklemariam [1] and Bernd Wenclawiak [2]

[1] Arbaminch University. Department of Water and Environmental Engineering, P.O.Box 21, Arbaminch, Ethiopia.
[2] Department of Chemistry – Biology, Analytical Chemistry, Siegen University, Adolf Reichwein Str., 57068 Siegen, Germany.

Abstract

Only little scientific water quality assessment work has been done in the past for the Abaya-Chamo drainage basin[1, 2]. This Research Paper assesses the results of water quality monitoring for water resources within the Abaya –Chamo basin Southern Ethiopia.
A range of water quality and hydrological variables were monitored within the period 2002-2004 on lakes Abaya and Chamo, rivers Hare and Kulfo and a number of other water sources within the basin. The variation of monitored values for the lakes and rivers were studied with respect to known physical and geo- chemical water quality interrelationships.
The seasonal variation of water quality and the factors that influence these variations are discussed. The monitored data for the lakes were coupled with few measurements undertaken several years back in order to examine the long-term trend due to major hydrological events and human development as opposed to cyclic seasonal variation within the lakes. Frame Work for Water quality Monitoring Design and Modeling based on the research study is presented and discussed.

1 Introduction

Water quality monitoring of rivers plays an important role in water resources and ecological management. The Abaya Chamo drainage basin as a sub basin of the rift valley lakes system has been an area of rapid population growth and settlement. Following this growth is the increasing land use and degradation of the natural ecosystem because of deforestation by increasing fire wood demand, clearing lands for agriculture, burning of forests and bushes for livestock and grazing purposes.

Because of the sustained dry period and lack of soil moisture, land irrigation with river waters is under a steadily increasing practice in the area. As a result there is an ever increase utilisation of the rivers for drinking and irrigation uses. By increasing population and water demand, the need for environmental protection calls for a systematic management of resources of which the river water qualities are an integral and essential part.

Lake Chamo has in the past been affected by water quality changes resulting in the death of aquatic habitat and wild life (zebras) reportedly due to toxic cyano bacterial blooms, and possibly due to other toxic noxious gases cased by increased hypolimnetic activity in the lake. It is thought that the river pollution as well as river flow loss may play a part in the deterioration of the lake environmental quality.

2 The Abaya – Chamo Lakes Basin

The Abaya Chamo lakes basin is a sub basin of the rift valley that crosses through Ethiopia midway in the north south direction. The basin comprises mainly the two lower lying lakes, Lake Abaya and lake Chamo and rivers like Gelana, Bilate, etc the drain in to Lake Abaya.
The rivers Kulfo and Sile enter into Lake Chamo and the overflow from Lake Chamo drains in to Sagan River, which in turn drains finally to the Chew bahir.
The main rivers draining into Lake Abaya are listed as: Gelana, Milate, Gidabo, Hare, Baso, and Amesa. In addition a number of small brooks and ephemeral rivers enter the Abaya Lake. The rivers draining into Lake Chamo are listed as: Sile, Argoba, Wezeka, Sego, in addition to the over flow from Lake Abaya which confluences with river kulfo and eventually drains to Lake Chamo. The Abaya and Chamo Lake are hydrologically interconnected. An overflow from Lake Abaya flows in to Kulfo River that in turn ends up in to the Chamo Lake.

The level difference between the two lakes is 62 meters, Abaya Lake being higher than Chamo Lake. The altitude of the region varies between 4200 m above sea level, (Mount Guge) and 1108 m above sea level (at the outflow from the Chamo Lake). The region is located in the range 37 – 38 ^{o} in eastern longitude and 5 – 8 ^{o} in the northern latitude. The two lakes have been used for transport (Lake Abaya), fishery and tourism. The lakes have not been used for irrigation. However, the tributaries (rivers Bilate, Kulfo, etc) have been used intensively for irrigation.

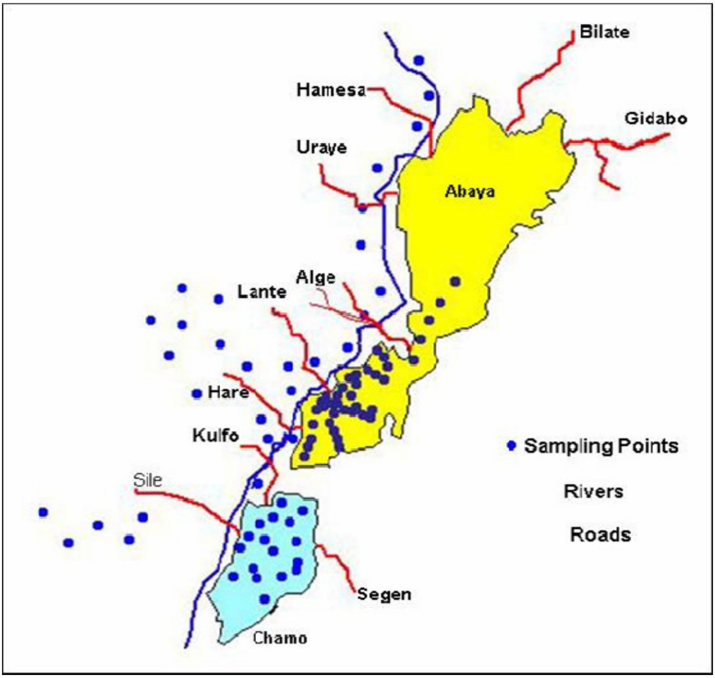


Figure 1 The Abaya - Chamo lakes basin sampling space

3 Analytical Methods

The procedures for all determinations have been referred to the standard methods for Examination of Water and Waste Water and the German Standard Code (DIN). The parameters determined include Absorption Data, Air Pressure, Air Temperature, Alkalinity, Ammonia, BOD (Winkler), Calcium, COD, Chloride, Chlorophyll a and b, Conductivity, Dissolved Oxygen, Hardness, Nitrate, Nitrite, pH, Phosphate, Potassium, River Discharge, Silica, Sodium, Sulfate, Sulfide, Total Filterable Residue, Total Residue, Total, Non.Filterable Residue, Total Volatile and fixed residue, Turbidity.
All chemicals and reagents used for determinations are of analytical reagent grade type. Laboratory distilled water has been used for blank and for dilution of reagents and rinsing purposes. The protocols stated in the procedures with respect to sampling, sample pretreatment and sample determinations have been followed in the determinations. A minimum of three repetitions have been carried out for each sample measurement.

The relative standard deviation for most measurements falls below 5%. Method detection limits where applicable were determined by running blank determinations using the same procedures as the sample procedure. Flame photometric and Spectrophotometeric determinations were calibrated by running a minimum of six calibration standards where at least three solutions were prepared for each of the standards. Few determinations such as Nitrate required more than three standards repetitions. Standardisation for titrants in Titration measurements were carried out using primary reference standards.

Turbidity and absorption measurements for water clarity assessment were carried out by single dilution for absorption measurements and multiple dilutions for turbidity measurements. The pH meter has been calibrated between each measurement by a laboratory prepared buffer. The stability of conductivity meter reading has been checked with the help of a standard 3M KCl solution. The analytical balance instrument has been calibrated with the standard weights supplied with the instrument.

4 Results and Discussion

4.1 Surface Water Quality Composition and Seasonality

The table below summarises ranges of water quality variation for the lakes and rivers analysed.

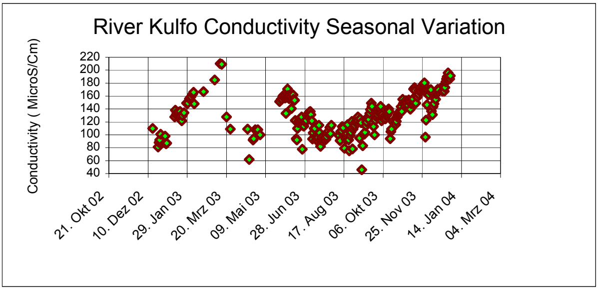
Ion	chemical formula	Unit	Lake Abaya	Lake Chamo	River Hare	River Kulfo	River Sile
pH		PH Units	8.5- 9.0	9-9.23	6.5 - 7.6	7.5-8.7	7.8- 8.4
Conductivity		µS/Cm	1030-1110	1810 - 1960	40 - 90	80 - 200	
Turbidity		NTU	64 - 90	40-100	10-750	7-1950	9-389
Spectrophotometric absorption (500 nm)		Abs	0.08 – 0.14	0.08 –0.135	0.003 – 1.5	0.01 - 11	0-1.3
Total Solids		mg.L-1	700-975	1200-1500	40 -2725	65-5620	215-660
Volatile Solids		mg.L-1	165-380	360 -478	14-257	6-564	15-170
Suspended Solids		mg.L-1	60-250	50-350	5 - 2660	5 - 5500	5 - 310
Dissolved Solids		mg.L-1	911.10	1522.45	25 - 60	53 - 132	76 - 350
Alkalinity	$CaCO_3$	mg.L-1 as $CaCO_3$	450 - 540	765 - 910	20 - 90	40 -160	60 - 380
Calcium	Ca^{2+}	$mg.L^{-1}$	15-24	12-20	4-15	5-20	5-25
Magnesium	Mg^{2+}	$mg.L^{-1}$	2-5	7-12	1-7	2-13	3-40
Sodium	Na^{+}	$mg.L^{-1}$	213 - 250	375 - 440	2-7	3-9	5-20
Potassium	K^{+}	$mg.L^{-1}$	15-19	22-28	0.5 – 1.40	0.5 –2.0	1.1 – 3.2
Ammonia	NH_3	$mg.L^{-1}$	0.16-0.58	0.03-0.45	0-019	0.006-0.35	0.005-0.23
Ammonium	NH_4^{+}	$mg.L^{-1}$	0.6-0.7	0.07-0.3	0-1.74	0.014-0.95	0.005-0.87
Carbonate	CO_3^{2-}	$mg.L^{-1}$	30- 55.24	60- 117	0-0.7	0-2.5	0- 3.32
Bicarbonate	HCO_3^{-}	$mg.L^{-1}$	400-500	750-850	20-120	40-190	60- 337
Chloride	Cl^{-}	$mg.L^{-1}$	64-78	127-160	2-14	3-12	7-42
Sulphate	SO_4^{2-}	$mg.L^{-1}$	25-34	12-26	1-9	1-8	1-13
Nitrate	NO_3^{-}	$mg.L^{-1}$	0.6-1.8	0.7-3	0-1	0.5-1.8	0.5-2.1
Nitrite	NO_2^{-}	$mg.L^{-1}$	0-0.05	0-0.02	0-0.03	0-0.05	0-0.06
Phosphate	PO_4^{3-}	$mg.L^{-1}$	0-0.19	0-0.03	0-0.06	0-0.06	0- 0.07
Silicacid	H_2SiO_3	$mg.L^{-1}$	44.29	3.14	22.26	21.42	28.97
H-Sillica	$HSiO_3^{-}$	$mg.L^{-1}$	6.04	0.76	0.10	0.92	1.25
Siliciumion	SiO_3^{2-}	$mg.L^{-1}$	0.00	0.00	0.00	0.00	0.00

Table 1 Ranges of variation of Chemical Concentrations of Rivers and Lakes

All river chemistry is dominated by Calcium-Magnesium-Bicarbonate compounds which are characteristic of basaltic formation of parent rock in the region. The Chloride content of rivers at lower elevation such as Sile River is higher. This is probably due to evaporative influence and longer residence time in lower elevations.

Bicarbonate and other ions are also greater in these rivers due probably to the same influence. The water qualities of the rivers Hare, Kulfo and Sile are influenced by the capacities of the respective catchments to retain the H+ ions and in return exchange it for Calcium, Magnesium and Sodium. The rivers contain higher

concentrations of bicarbonate and equivalent divalent Calcium and Magnesium ions followed by Sodium and Potassium. The concentrations of chloride, sulphate and nitrate are relatively low.
Looking at silica concentrations, all the rivers contain higher silica concentrations which are again characteristic of the parent rock formation. The rate of Silica weathering appears to be of the same order of magnitude for the rivers because of the close pH range in which the dissolved silica (mainly Silicic acid) appears constant.
Both lakes are characterised as alkaline –saline lakes with dominant ions of sodium-bicarbonate and chloride. Lake Chamo possesses greater concentration of these ions than Lake Abaya because of Lake Chamo's tributary rivers increasingly saline water quality, the longer retention time of the lakes and the higher rate of evaporation in the lake as well as on the catchment at lower elevations in which Lake Chamo and its catchment are situated.
Water Quality Variation of dissolved solids for both rivers and lakes follow a seasonal pattern.



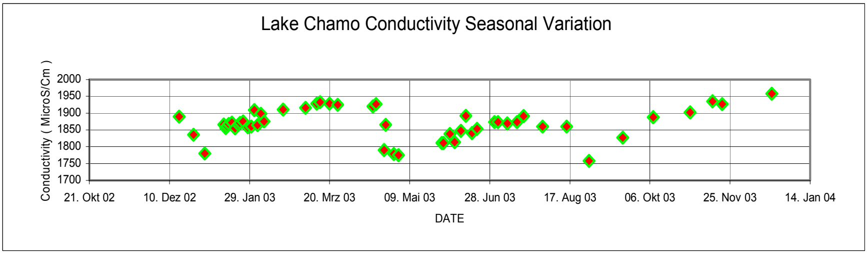


Figure 2 River and lake conductivity seasonal variation

4.2 Buffering Capacity, Nutrient Transport and Rates of Weathering

The effect of sodium dominance on pH and alkalinity can be evaluated in terms of the Sodium fraction present in the water. It is seen that generally the alkalinity increases with decreasing sodium percentage present in the water. This implies that catchments with greater sodium fraction have less buffering capacity and hence are more sensitive to pH variation than do catchments with greater sodium fraction.
The influence of the soil buffering capacity is apparent by the seasonal measurement of ammonium ion concentrations. Kulfo catchment has a stronger retention for ammonium. With increased flow release rate is moderate. For river Hare the ammonium concentration increases more than that of Kulfo River with increase in flow.
Sulphate and nitrate values are normally recorded low (between 0 and 1 mg.L-1). The inputs associated with these chemicals, such as domestic waste pollution and fertilizer application are thought to be low for the upstream catchment area. Acid rain effects normally that results in higher levels of sulphate and nitrate in the water is not expected in this catchment.
Precipitation water quality analysis shows higher pH and low values of these nutrients. A strong retention of the catchment for H^+ and NH_4^+ is observed by the steady increase in pH during the dry season and the consequent depletion of ammonium concentration measurements taken during this time. The weathering rate of

both catchments is not surface controlled. In fact weathering seems to increase with increase in flow for both rivers.

4.3 Long Term Trend in the Water Quality of Lakes Abaya and Chamo

Lake Chamo shows increase in salinity by about 40% in the last 40 years. This trend seems linear and unabated. Since major change in the ions distribution of the catchment inflow is not anticipated to have an impact on the lake salinity, the major cause of the increase in salinity is due to drought and the decrease in the lake inflow and the relative increasing influence in the evapotranspiration from the lake.

As the lake is an economic resource for the area, this trend is a cause for concern. On the contrary lake Abaya‘s annual average water balance model shows that there is an excess outflow which assists in reducing the salinity increases. However, contrary to this model‘s estimate, the salinity of Lake Abaya is also increasing at a moderate rate over recent years.

Examination of the salinity trend for Lake Abaya shows that it falls in the period 1960 – 1980 and after which there is a rapid increase in salinity and later evening out to a gradual increase. Generally the concentration of nutrients have increased in both Abaya and Chamo except for the soluble reactive phosphorous in Lake Chamo which did not show significant increase. Observing the rapid increase in nitrate concentration in both lakes since 1991, it is possible to anticipate that an increase in nutrient levels has already occurred in the lakes in response to pollution from the tributary catchment. Silica is low for Lake Chamo.

Lower Silicate concentrations have been related to diatom crop in Lake Chamo (Zenabu Gebermariam, 2002). Dissolved oxygen in the summer fell below 3 mg.L-1 with loss of soluble reactive phosphorous. Algal respiration and death of may have led to a decrease in dissolved oxygen concentration and an increase in the concentration of ammonia observed for Lake Chamo.

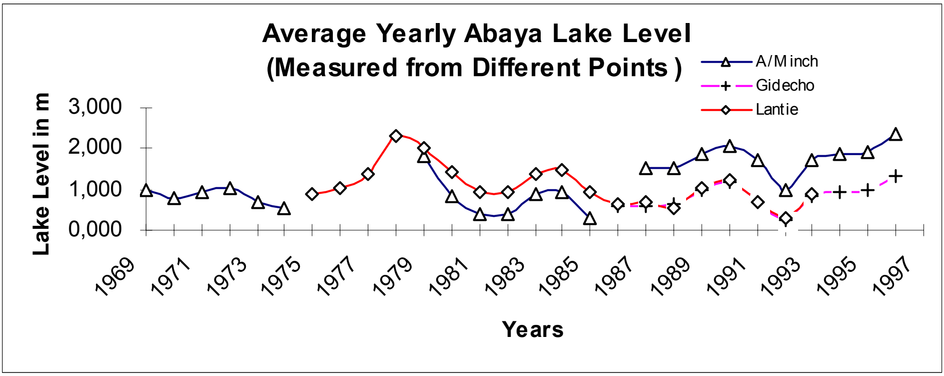


Figure 3 Average yearly Abaya Lake level

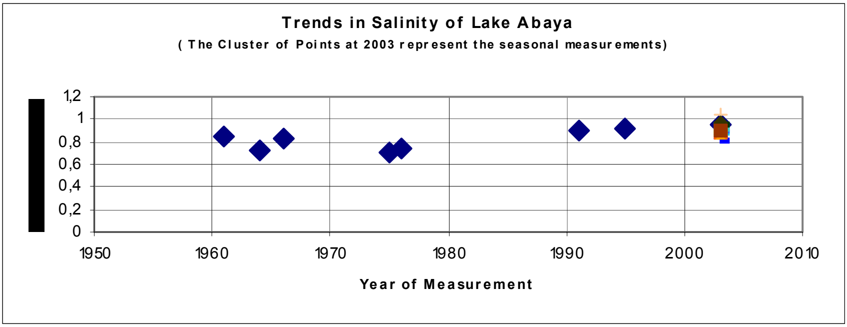


Figure 4 Trends in salinity of Lake Abaya

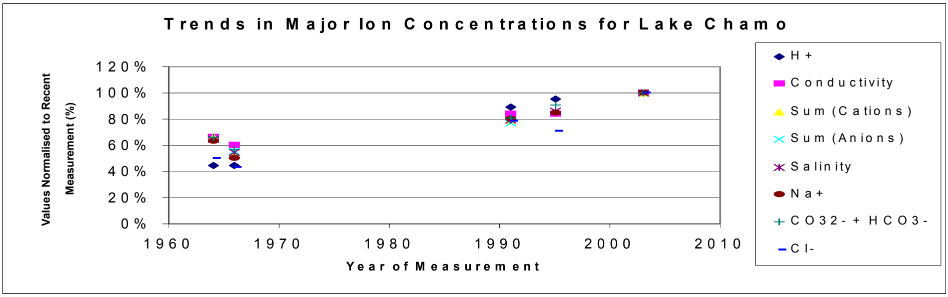


Figure 5 Trends in major ion concentration for Lake Chamo

4.4 Piper Trilinear Plot of Surface and Subsurface Water Samples of Abaya-Chamo Basin

Most of the ground water sources plot in the high Bicarbonate–Magnesium–Calcium area which is characteristics of the basaltic formation of the geology of the area. Samples which represent near surface flow conditions (1 and 2 from Humbo ground water, 5 – Spring water from Basa region) plot nearer the surface water samples (river sources) indicating their surface flow conditions. Their TDS value is intermediate between well evolved high TDS ground water and unevolved low TDS spring water sources.

Rain water from Arbaminch (Elevation = 1200) and Abela (Altitude = 1700 m), plot in the high Chloride-Calcium-Magnesium area. The spring water sources near Mirab Abaya plot near the rain water than others indicate chemically unevolved spring which may as well display intermittent flow conditions. This is further confirmed by their lowest Total Dissolved Solids Conditions.

Arbaminch springs plot near to the rivers Kulfo, Sile and Hare. This spring water has its source in the upland catchment and its chemical characteristics resemble that of the base flow river conditions. Therefore, there is a possibility that pollution from the sources may travel in much the same way as such pollution travel as subsurface flow and appear with the rivers base flow.

4.5 Investigation of Ground Water Sources for Pollution

Ground water sources investigated show direct pollution from human and animal wastes because of lack of appropriate protection (unprotected wells, open sources, rivers and springs) therefore posing immediate health dangers from water borne illnesses and nitrate interference in blood hemoglobin activity in infants. Such sources are identified by very high coliform counts as well as relatively high values of Nitrite/Nitrate.

The aquifer characteristics in some ground water favored leaching of wastes from animal and human origins as well as possibly agricultural fertilizers showing high nitrate and phosphate as well as nitrite. Well protection measures must be taken including walling and capping of open wells, removal of toilets from near wells, fencing of wells and excluding animals and human wastes from around water sources, treatment of river water and even spring water sources with slow sand filters and management of application of fertilizers as well as locating wells away from areas of agricultural activities. Samples loaded highly on to factor 1 (the highest varying factor) are: polluted open well that is near to toilet, turbid river water, spring water from a shallow ground water source. Nitrite is more closely related to coliforms.

4.6 Design of Water Quality Monitoring System for Water Sources in the Basin

Monitoring analysis classifies the variables in 4 groups. For group 1 variables, including conductivity, alkalinity, sodium, pH and hardness, there are two major peaks corresponding to monitoring frequencies of 2 months and 2 weeks. The optimum monitoring length is 2 weeks giving on average 85% of the variance information. A monitoring length of 1 month on average gives 75% of the information which is more than adequate for the physical factor model interpretation.
For group II variables, characterized by a high frequency peak events monitoring length needs to be much shorter or continuous monitoring approach needs to be adopted that will also allow auto correlative and cross correlative modelin. Turbidity monitoring, for example, with 2 days interval will only give 80% of the information. The optimum monitoring of 3 days interval will on average give only 75% of the information.

Since particulate pollutants and pollutants adsorbed on to the soil surface vary directly with solids content, at least, some of these variables need to be monitored continuously. This requirement goes well for discharge, turbidity (solids) and rainfall as well. Rainfall measurement location will have to be investigated so as to give a representative real common factor. Spatial monitoring design by means of hierarchical cluster analysis carried out for Lake Abaya indicated a cluster length of 10 km along the fetch and about 5 km across the width.

Considering the total area of the lake (1085 Km2) this gives a total of about 32 sampling points. Following the same analogy for Lake Chamo gives a spatial monitoring set of 12 points. This sampling interval is dictated by the more dynamic variables such as pH and dissolved oxygen which have greater number of clusters spatially.

4.7 Water Quality Modelling.

For group I monitoring variables auto-regressive modelling between variables and within a single gives a good estimate. State-space modelling is a subset of this modelling. For group II monitoring variables (rainfall, turbidity, solids, ammonia, etc) auto-regressive modelling is not suggested as the fit is not good. Instead spectral level regression gives a better modelling. Discharge-base water quality modelling also gives a better estimate. A result of such modelling using a mean value derived from the expected value of the rating curve equation is shown in the figure below.

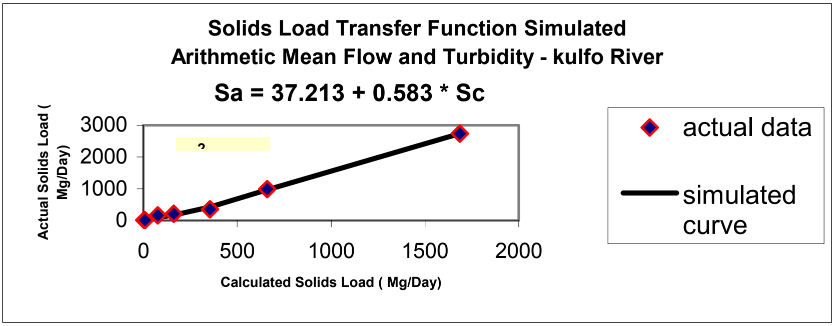


Figure 6 Trends in major ion concentration for Lake Chamo

5 Summary and Conclusion

The water quality parameters are a function of the geo-chemistry of the catchments, hydrological events including atmospheric inputs and the catchment morphology where land use is a factor. The lower lying Sile River is characterized by increased alkalinity and salinity than the upper lying Hare and Kulfo rivers. The seasonal variation of the water quality parameters can be classified as mainly long-term seasonal variability or short-term rain induces surface flow based variability. The buffering capacity of the rivers and their alkalinity is negatively correlated with the sodium dominance ratio.
Catchments with less ratio of Sodium ion release in to rivers retain more H^+ ion and nutrients such as NH_4^+ than catchments with lower ratio. The weathering rate for Rivers Hare and Kulfo were computed by normalising the river discharges and solids load to their respective catchment areas. A plot of this normalised solids load against normalised discharge shows

Hare river has greater rate of weathering than Kulfo River. Monitoring of the variation of water quality of the lakes Abaya and Chamo over the short term follows the seasonal precipitation pattern with Lake Chamo displaying significant variation in response to seasonal changes. Lake Abaya has a more stable concentration with limited response to the seasons. Due to the fact that Lake Chamo has been subject to flow reduction and decrease in water level the impact of seasonal water quality changes has become significant and may affect the lake ecology as such.
Comparison of seasonal variation with longer term data records show that both lakes are being subject to increased salinity although Lake Abaya shows only a moderate increase. Examination of the different contributing factors points to flow decrease and the global climate regime change as being the probable cause of the salinity increase.
Since Lake Chamo depends on the outflow from Lake Abaya for its water level and chemical balance and since this overflow has ceased to exist, lake Chamo has been subjected to decrease in water level and increase in salinity for a longer period. The nutrient and chlorophyll measurements characterise both lakes as eutrophic. Dissolved oxygen measurement fall below 3 mg/L in Lake Chamo with simultaneous loss of phosphorous.

Pollution assessment of the tributary catchment shall be undertaken as part of a water quality monitoring program for the lakes. Spatial lake monitoring with a grid spacing of 10 km length by 5 km width is suggested by cluster analysis model. Factor and principal component analysis of river water quality data suggest monitoring in to 4 groups. Spectral analysis of both lakes and river water quality data suggests one month monitoring interval in most cases explains up to 3/4 of the variation, more than the minimum ratio suggested by 4-factor analysis.

6 Acknowledgement

This research has been supported by The German Agency for Technical Cooperation, GTZ Project for Arbaminch University, Ethiopia. Ababu Teklemariam wishes to thank for the research stipend.

7 References

Zinabu, G.M., Elizabeth Kebede and Zerihun Desta. Long Term Changes in the Chemical Features of waters of Seven Ethiopian Rift-Valley Lakes. Hydrobiologia 477: 81-91, 2002

Zinabu G.M., J. Nicolas and G. Pierce. Concentrations of Heavy metals and Related Trace elements in Some Ethiopian Rift-valley lakes and their in-flows. Hydrobiologia. 429. 171-178. 2003.