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Hydrodynamics of Selected Ethiopian Rift Lakes

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ABSTRACT

The Main Ethiopian Rift Valley Lakes suffer from water level fluctuations due to several natural and anthropogenic factors. Lakes located at terminal positions (no surface water outflow) are highly affected by the fluctuations. These fluctuations are disturbing the stability of the ecosystems, putting very serious impacts on the lives of many animals and plants around the lakes. Hence, studying the hydrodynamics of the lakes was found to be very essential. The main purpose of this study is to find the most significant factors that contribute to the water level fluctuations and also to quantify the fluctuations so as to identify the lakes that need special attention. The research methodology includes correlation and least squares regression of lake levels on rainfall, discharge and evaporation, multi-temporal satellite image analysis and land use change assessment. The results of the study revealed that much of the fluctuations in the lake water levels are caused by human activities especially for the lakes in the Central Ethiopian Rift. Lakes Abiyata, Chamo, Ziway and Langano are declining while Abaya and Hawassa are rising. Among the studied lakes, Abiyata is drastically reduced in size (about 28% of its area in 1986) due to both human activities (most dominant ones) and natural factors. The other seriously affected lake is Chamo with about 11% reduction in its area between 1986 and 2010. Lake Abaya was found to be relatively stable during this period (showed only a 0.8% increase in its area).

KEYWORDS: Correlation, Fluctuation, Lake Level, Landsat Satellite Images, Land Use Change, Least Squares Regression.

1. INTRODUCTION

A lake is a large, inland body of standing water that occupies a depression in the land surface.Lakes and lake shores are attractive places to live and play. Clean, sparkling water, abundant wildlife, beautiful scenery, aquatic recreation and fresh breezes all come to our mind when we think of going to the lake. Despite their great value, lakes are fragile and ephemeral (Thompson et al., 2005)

The water-level of a lake changes seasonally and fluctuates annually due to the difference of seasonal or yearly precipitation and evaporation (Kinshiro, 1974). The levels and sizes of lakes are governed by many natural and anthropogenic factors. Climatic, hydrological and man-induced factors control lake levels in many ways. Changes in lake levels result from a shift in the water balance or the net steady-state removal of water via various surface and subsurface processes. In particular, closed terminal lakes fluctuate significantly in response to climatic changes but tend to maintain equilibrium between input and output (Tenalem Ayenew, 2002). Only when we pay attention to the vicinity of a lake, we happen to recognize some terrace which shows the past shore-line or water level of the lake. In such a case, it is evident that stable and unstable periods existed in the past in regard to the secular balance of water in the lake. In general, the main factors working on the regulation of such a lake-level, that is, the reducing factors in the range of fluctuation of water storage are river discharge, ground water discharge, river inflow, ground water inflow and lake surface area (Kinshiro,1974). Especially, the change of river discharge (open lake) or ground water discharge (closed lake) greatly affects annual lake-level stability. In an arid zone, such stability of a closed lake is regulated by the change of evaporation surface, too (Kinshiro, 1974).

The Ethiopian rift is characterized by a chain of lakes of various sizes and hydrological and hydrogeological settings. The rift lakes and feeder rivers are used for irrigation, soda extraction, commercial fish farming, and recreation, and they support a wide variety of endemic birds and wild animals. The levels of some of these lakes have changed dramatically over the last three decades. Lakes that are relatively uninfluenced by human activities (Langano and Abaya) remain stable except for the usual inter-annual variations, strongly influenced by rainfall.

Some lakes have shrunk due to excessive abstraction of water (such as Abiyata); others have expanded due to increases in surface runoff and groundwater flux from percolated irrigation water such as Beseka (Tenalem Ayenew, 2009). Apart from the various inflow and outflow components, the water balances of lakes are governed by climate, anthropogenic factors, volcano-tectonism, and sedimentation (Karrow, 1963; Slay, 1973; Street, 1979 cited in Tenalem Ayenew, 2004).

1.1 General overview of the study area

The study area (the Rift Valley Basin) covers a total area of 53034 km^2 and lies between 04^{O}23'N and 08^{O}28'N latitude and 36^{O}37'E and 39^{O}22'E longitude (Fig 1).The Ethiopian Rift Valley is part of the Great East African Rift which is the largest, longest and most conspicuous feature of its kind on earth, stretching for nearly 5,600km from the Red Sea into the mouth of the Zambezi River in Mozambique. The elevation, width and tectonic setting of the Ethiopian Rift Valley are extremely variable. The interesting feature of the northern and central sectors is the existence of open and closed lakes situated within large depressions. The major lakes are located within the central Main Ethiopian Rift with relatively higher elevations as compared to Afar and Chew Bahir Rift bordering Kenya. These lakes occupy an enclave of internal drainage basins separating the tributaries of the Nile and Wabishebele River Basins (Tenalem Ayenew, 2009).

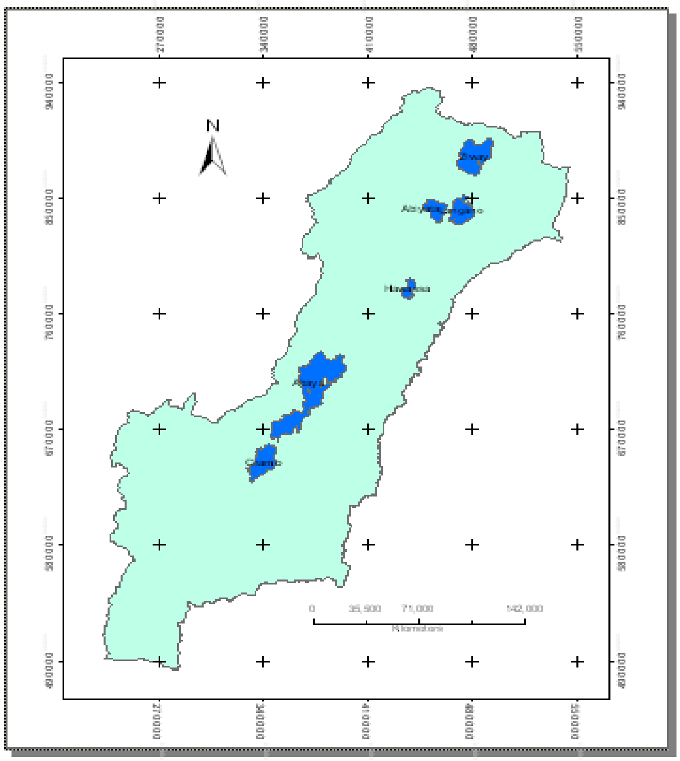

Figure 1. The study area

The Rift Valley of Southern Ethiopia runs NNE from the Kenya frontier of 600Km to the Koka Dam on the Awash River where the rift begins to open out into the Afar and Danakil depressions (Grove et al., 1975). The Ethiopian rift valley basin has three physiographic regions: the rift, escarpments and highlands. The rift where large lakes exist starts in the neighborhood of Lake Abhe and extends some 1000km southwards into northern Kenya (Tenalem Ayenew, 1998). The altitude ranges from 1600 m a.m.s.l. in the rift to over 4000 m a.m.s.l. in the large volcanic peaks of the Eastern Highlands. There are highly elevated volcanic mountains both within the rift and the highlands. The highest elevation is 4245 m.a.s.l, which is the peak of Mount Kaka located on the eastern boundary of the Ziway-Shala lake basin (Tenalem Ayenew 1998).

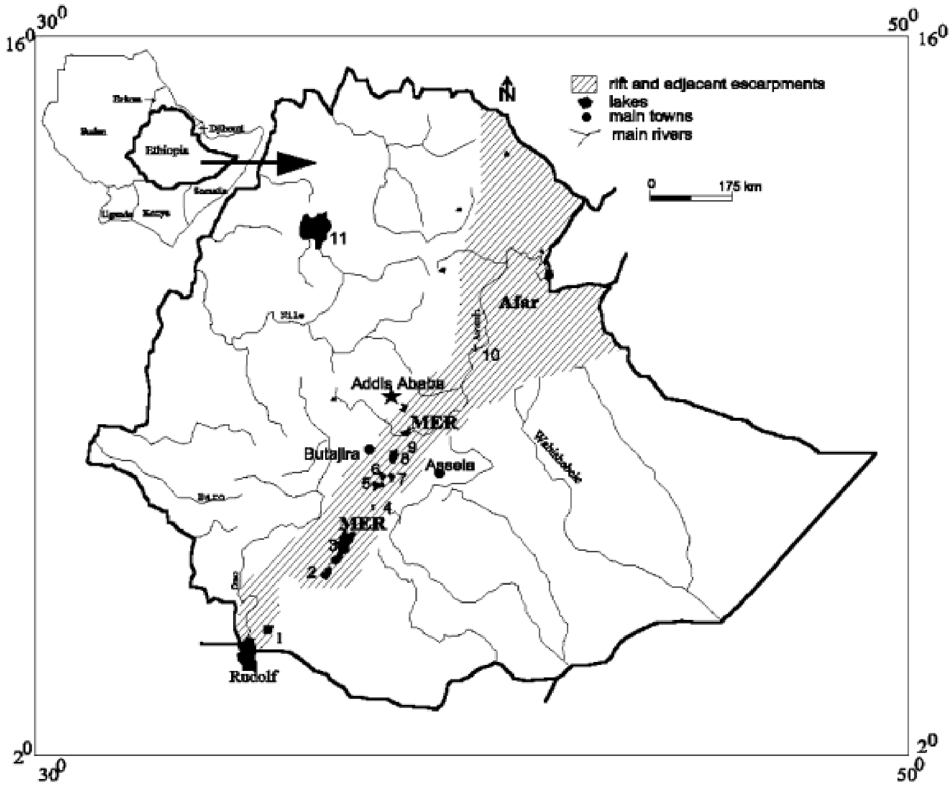

Figure2 .Location map;2:Chamo; 3: Abaya; 4:Hawassa;6:Abiyata;7:Langano; 8:Ziway

2. MATRIALS and METHODS

2.1 Collection and Organization of Data

This study is based on an assessment of existing hydrometeorological records of lake level, rainfall, river discharge and evaporation for the period of 1980-2007. The rainfall stations used for estimating the areal depth of the rainfalls corresponding to the lakes were: Arba Minch, Chencha, Hagere Selam and Hossana for Lakes Abaya and Chamo; Assela, Butajira, Kersa, Langano, Meki, Meraro, and Shashemene for the Lakes Abiyata, Langano and Ziway; Hawassa and Wondo Genet (incomplete data) for Lake Hawassa. The research is also based on the interpretation of multi-temporal satellite images acquired during 1986, 2000 and 2010. The data required for the study have been collected from various sources. Meteorological data for twenty eight years (incomplete most of the time) have been collected from the Ethiopian Meteorological Agency and the hydrological data for seven rivers (Bilate, Horakelo, Katar, Kerkersitu, Kulfo , Lipis, Meki and Tikur wuha) and six lakes(Abaya, Abiyata, Hawassa, Chamo, Langano and Ziway) have been collected from the Ministry of Water Resources.

The lake level records were used to reconstruct the recent changes and to correlate the lake levels with other catchment hydrometeorological factors. The required softwares (Microsoft Excel, ArcGIS, ERDAS IMAGINE, SPSS and Matlab) that are anticipated to support the study have been collected from different sources and utilized. Moreover, Land Sat Satellite images for three different years but the same month have been collected from Addis Ababa University department of Earth Sciences and other sources. After collecting all the required hydrologic and meteorological data, it was arranged and reorganized. Some of the required data were averaged (lake levels) and some of them were summed up (rainfall, discharge and evaporation) and used for the analysis of the hydrodynamics of the lakes. The average rainfall corresponding to each lake has been calculated and analysis on the change of lake level and size has been made by looking the historically recorded data of rainfall, lake levels, river discharges and evaporation rates.

2.2 Correlation of lake water level with precipitation, river discharge and evaporation

To see the significance of the hydroclimatic, geologic and anthropogenic factors on lake water level fluctuations, correlation with most important hydrometeorological factors (precipitation, river discharge and lake evaporation) were made. For lakes with low correlation coefficients, some possible explanations regarding the reason for the fluctuation of the water levels were presented.

2.3 Multiple regression of lake water level on precipitation, river discharge and open lake evaporation

To identify the relative importance of precipitation, river discharge and evaporation on lake level fluctuation, regression of lake level on these factors was made. Least squares regression of lake level on rainfall, discharge and evaporation was made via curve fitting methods (linear, quadratic, cubic, exponential, logarithmic, inverse etc) .By looking the level of significance (0.01,0.05 and 0.1) in each curve fitting method, the importance of each factor in lake level fluctuation was determined.

2.4 Trend analysis

After rearranging the hydrometeorological data (lake level, precipitation, river discharge and evaporation rate), the five year moving averages were calculated and plotted against time. The rainfalls, discharges and open lake evaporations were also plotted against time. The long-term trend analysis of lake water level, precipitation, river discharge and lake evaporation rates were made.

2.5 Multi-temporal satellite image analysis

By zooming in the images and then digitizing their boundaries (perimeters), shape files for each lake corresponding to each year were created. By stacking the layers and then clipping the lake images with the corresponding shape files, the clipped images for each lake were presented for better visualizations. The areas of the lakes for each year were then obtained by calculating the areas of the corresponding shape files using the ArcGIS and ERDAS IMAGINE softwares.

2.6 Land use/cover change analysis

Based on the land use/cover data obtained from FAO (1997) and Ministry of Water Resources (2008), the change in the proportion of the land cover types to the total area of the Rift Valley Basin has been assessed (only the end results of the land use land cover classifications done by the above two organizations was used). This is done to relate the depletion of vegetation with lake level fluctuations.

3. RESULTS and DISCUSSIONS

3.1 Data Consistency

Hydrometeorological data are vital instruments to assess the hydroclimatic and anthropogenic contributions to the water level fluctuations of the Ethiopian Rift Valley lakes. In spite of this fact, there are problems of data inconsistency with regard to the hydrometeorological records. Due to this fact, only similar rainfall patterns corresponding to each lake were averaged, plotted together with the lake levels and then analyzed.

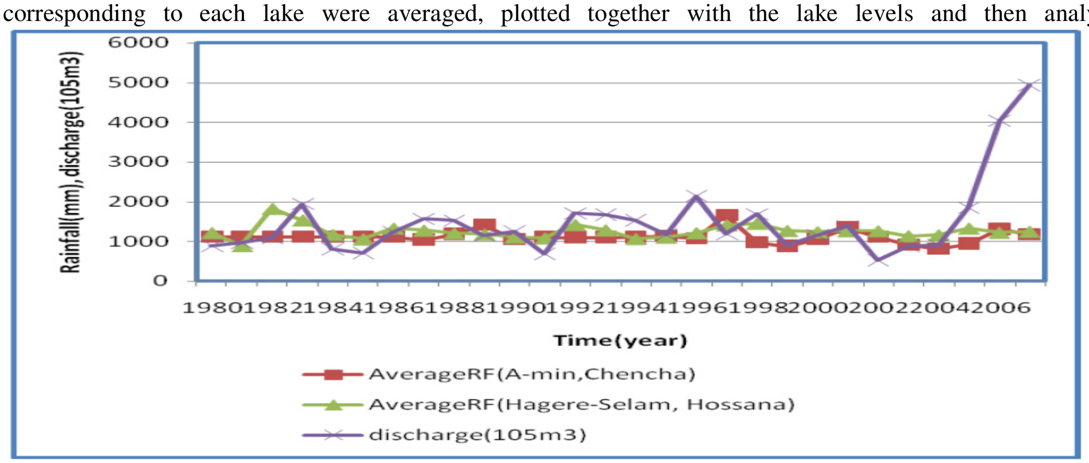

Figure 1.The average rainfalls and the discharge from Bilate River corresponding to Lake Abaya

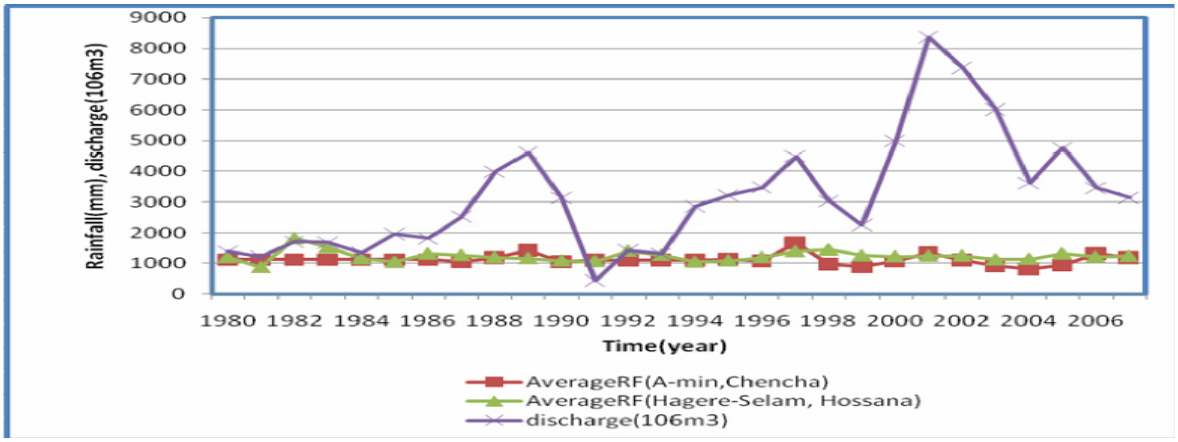

Figure 4. The average rainfalls and the discharge from Kulfo River corresponding to Lake Chamo.

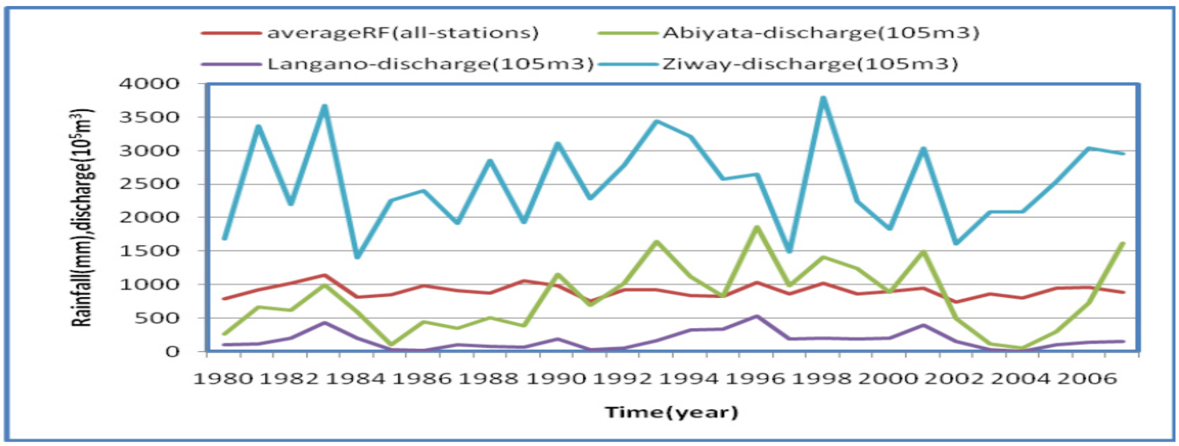

Figure5. The average rainfall for all stations and the discharges corresponding to Lake Abiyata, Langano and Ziway.

Figures 3,4 and 5 clearly show that the average rainfalls and the discharges do not show similar trends especially for Lake Chamo indicating data inconsistency. Due to this problem, more emphasis has been given to the analysis of the satellite data.

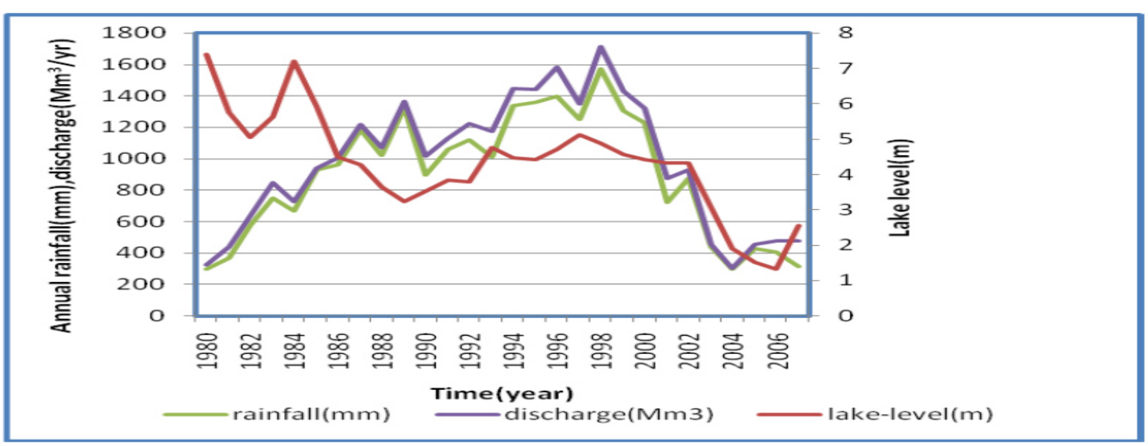

Figure 6. Yearly trends of lake level, rainfall and discharge (Lake Abiyata)

The figure 6 clearly indicates how drastically the level of Lake Abiyata is declining.

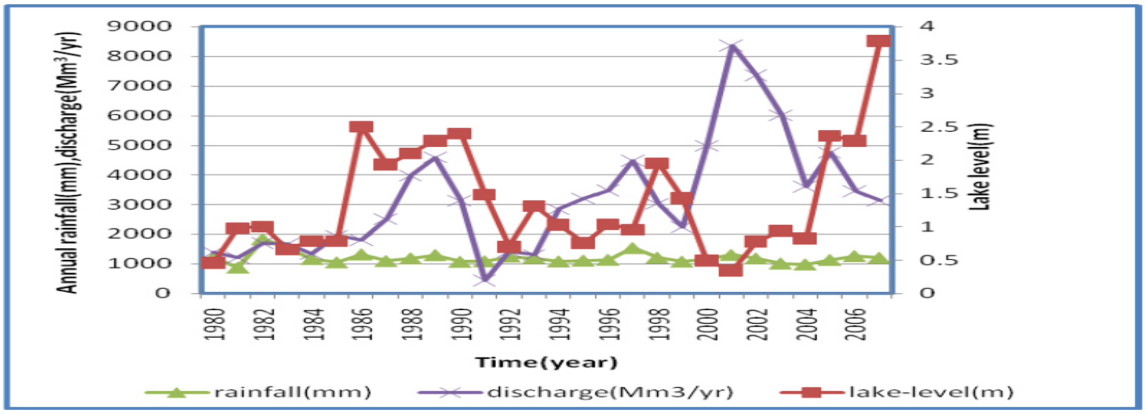

Figure 7 . Yearly trends of lake level, rainfall and discharge (Lake Chamo)

It can be clear from figure 7 that the level of Lake Chamo is not associated with rainfall and discharge indicating inconsistency of hydrometeorological data. Due to this, special emphasis has been given to the analysis of satellite images for the fluctuation of the level of the lake.

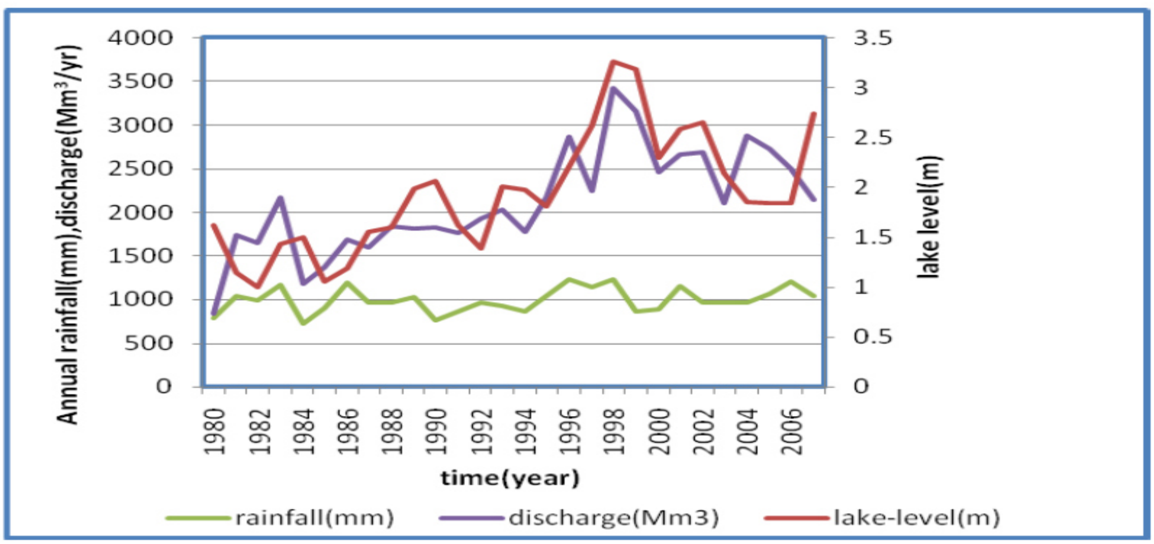

Figure 2. Yearly trends of lake level, rainfall and discharge (Lake Hawassa)

Figure8 shows that the level of Lake Hawassa is largely affected by ground water discharge since the overall rainfall pattern shows a constant trend and also due to the relatively small correlation coefficient between rainfall and river discharge.

Table 1. Correlations of rainfalls with the discharges (to check for consistency of hydrometeorological data)

Lake	Abaya	Abiyata	Chamo	Hawassa	Langano	Ziway
Correlation coefficient	0.131825	0.379668	- 0.00709	0.319599	0.306506	0.052279

As we can see from Table 1, the associations of rainfalls with the discharges have the smallest correlation coefficients for Lakes Chamo (unrealistic correlation coefficient), Ziway and Abaya which confirm some degrees of data inconsistency. As we can see from table 1, the hydrometeorological data inconsistency is much series especially for Lake Chamo.

3.2 Correlation coefficients and their interpretations

There are always time lags between precipitation events and lake level fluctuations. Moreover, most of the rainfall stations are located on the Graben Shoulder of the Highlands, only few stations are situated in the Rift valley (Stefan et al., 2004) and hence the rainfall records can be less realistic. For this reason, poor correlation coefficients between lake levels and rainfalls have been observed except for Lake Langano with a value of 0.68. Due to the same reason, the correlation coefficients between lake levels and discharges are also relatively very small or negligible except for Lakes Hawassa, Langano and Ziway with values 0.76, 0.57 and 0.40 respectively. There is a significant correlation between water level and evaporation for Lake Abiyata only. The correlation of lake level with rainfall, discharge and evaporation is summarized in Table 2.

3.3 The significance of the multiple regression equation

Least squares regression equations can be used to predict the values of a dependent variable (lake level in our case) from one or more independent variables (rainfall, discharge and evaporation) with coefficients of multiple correlations indicating the strength of the relationships between the dependent and independent variables. Relatively poor or negligible fits between lake level and rainfall, discharge and evaporation have been observed. The possible explanation for this may be due to the time lags between precipitation events and lake level fluctuations or questionable data or both.

3.4 Trend analysis for lake levels, precipitations, discharges and lake evaporations.

Figure 6 shows that the water level of Lake Abiyata is declining drastically while those of Abaya and Hawassa are slightly rising. This is in agreement with the results obtained using Landsat satellite images. The levels of Langano and Ziway seem to have constant trends and that of Chamo shows a rising trend. However, the results obtained using the satellite images show contrasting trends. As shown in table 3, the water level of Lake Abaya was below its long term average between1980 and 1993, above the long term average between 1994 and 2007. This could be due to increased deforestation of its catchment as indicated by the land use/cover maps (Figure 13 and 14).

The level of Lake Abiyata showed variable trends between 1980 and 2000, and a constant trend (declining trend) after 2000 onwards. More specifically, the lake level has been decreased by about 1.6m from its long term average (about 4.3m) and this shows that very large amount of water has been abstracted from the lake in addition to the absence of the overflow from Ziway.

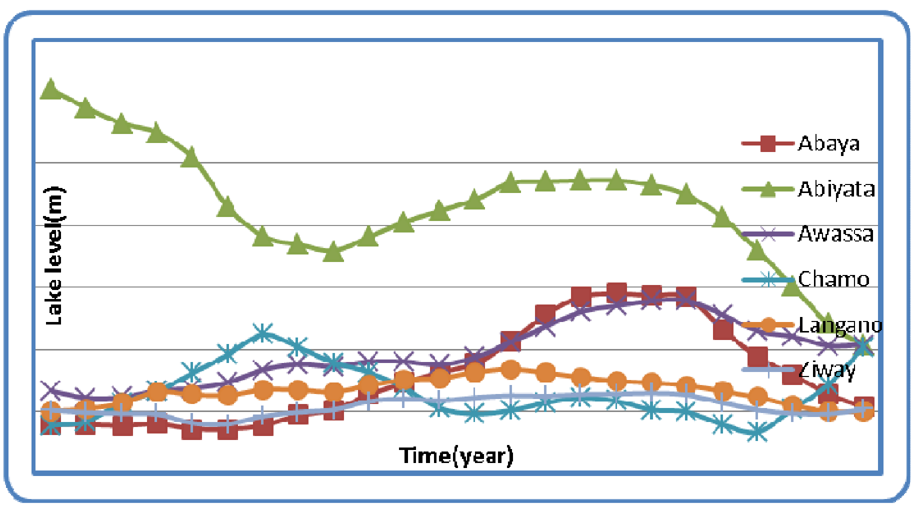

Figure9. Five Years' moving averages showing the lake levels trends

The level of Lake Hawassa showed declining trends between 1980 and 1993, rising trends after 1994 onwards which may be due to recent neotectonic activities resulting in ground water inflow into the lake. The levels of Lakes Chamo and Ziway showed increasing trends between 2001 and 2007. This result contradicts with the one obtained using Landsat satellite image analysis. The possible explanation for these contrasting results can be data inconsistency as explained in the previous subsection. The level of Lake Langano is slightly lower than its long term average indicating relatively less anthropogenic contributions to the lake level fluctuation.

Table 2.The correlation matrix indicating the association of lake levels with rainfall, discharge and evaporation

Lake	Rainfall	Discharge	Evaporation
Abaya	0.08	0.10	-0.77*
Abiyata	0.37	0.29	-0.74*
Hawassa	0.23	0.77*	-0.37*
Chamo	0.17	0.43	-0.74*
Langano	0.68*	0.57*	-0.01
Ziway	0.26	0.56*	-0.1

The level of Lake Abiyata showed variable trends between 1980 and 2000, and a constant trend (declining trend) after 2000 onwards. More specifically, the lake level has been decreased by about 1.6m from its long term average (about 4.3m) and this shows that very large amount of water has been abstracted from the lake in addition to the absence of the inflow from Ziway.

Table 3. Seven years' water level trends for the studied lakes

No	Lake	Long term (1980-2007) average(m)	1980-1986 (average)	1987-1993 (average)	1994-2000 (average)	2001-2007 (average)	Main reason for the fluctuation
1	Abaya	1.45958	0.699261 (Below average)	1.059803 (Below average)	2.613429 (Above average)	1.465826 (Above average)	**Increased surface runoff, diversion or high groundwater**
2	Abiyata	4.283525	5.914493 (Above	3.860681 (Below average)	4.648305 (Above average)	2.710621 (Below average)	**Large-scale abstraction of water**
3	Hawassa	1.932398	1.272631 (Below average)	1.744318 (Below average)	2.476688 (Above average)	2.235955 (Above average)	**Diversion from nearby water bodies,**
4	Chamo	1.265267	0.725389(Below average)	1.743975(Above average)	1.092512 (Below average)	1.49919 (Above average)	**ground water outflow, diversion of feeder rivers,**
5	Langano	1.288435	1.069915 (Below average)	1.389686 (Above average)	1.55971 (Above average)	1.134429 (Below average)	**Diversion and abstraction of water**
6	Ziway	1.088393	0.934722 (Below average)	1.064988 (Below average)	1.244583 (Above average)	1.10928 (Above average)	**abstraction of water from feeder rivers for**

Table 4. Long-term average annual water balance of the studied lakes (mcm)

P_l: precipitation on the lake; R_i: inflow from rivers; G_i: groundwater inflow; S_r: inflow from surface runoff; E_l: lake evaporation; R_o: outflow in river outlets; G_o: groundwater outflow; A: abstraction; Ng: negligible; VH: very high; H: high; M: medium; RO: rare outflow; Mcm: million cubic meter

Lake	inflow				outflow				Difference ($10^6 m^3$)
	P_l	R_i	G_i	S_r	E_l	R_o	G_o	A	
Abaya	556	VH	VH	VH	1900	RO	M	-	-
Abiyata	113	230	26.8	15	372	closed	1.2	13	-1.4
Hawassa	106	83.1	H	83.7	132	closed	58	Ng	+82.8
Chamo	406	H	H	H	900.9	RO	H	Ng	-
Langano	186	212	135.4	VH	463	46	18.9	-	+5.5
Ziway	323	656.5	80.5	48	890	184	14.6	28	-8.6

Source: Tenalem Ayenew (2004)

3.5 Analysis of multi-temporal satellite images of the lakes

The analysis of the Land sat images (with acquisition years: 1986, 2000 and 2010) indicated that Abiyata, Chamo, Ziway and Langano are declining while Hawassa and Abaya are rising slightly. The decline of Abiyata is very drastic (nearly 28% of its area in 1986) and the decline of Chamo is about 11% of its area in 1986. Table 5 summarizes the fluctuation in the size (area) of the lakes under consideration.

Table 5.Areas of the lakes (km^2) from Land Sat images

Lake name	Year			Change (%) b/n 1986 & 2010
	1986 (jan-21)	**2000** (jan-05)	**2010** (jan-31)	
Abaya	1102	1111	1111	+0.8 → Rising Trend
Abiyata	162	164	117	-27.8 → Declining Trend
Hawassa	91	96	94	+3.3 → Rising Trend
Chamo	331	312	295	-10.9 → Declining Trend
Langano	229	228	224	-2.2 → Declining Trend
Ziway	424	420	412	-2.8 → Declining Trend

Note:-acquisition dates are given in the brackets

The reductions in the sizes of Lakes Abiyata and Chamo are shown pictorially in figure 10 and figure 11 respectively. The size of Lake Hawassa has increased by 3.3% of its area in 1986. This is pictorially shown in Figure 12. The following three figures are created by overlapping the lake images corresponding to 1986, 2000 and 2010.

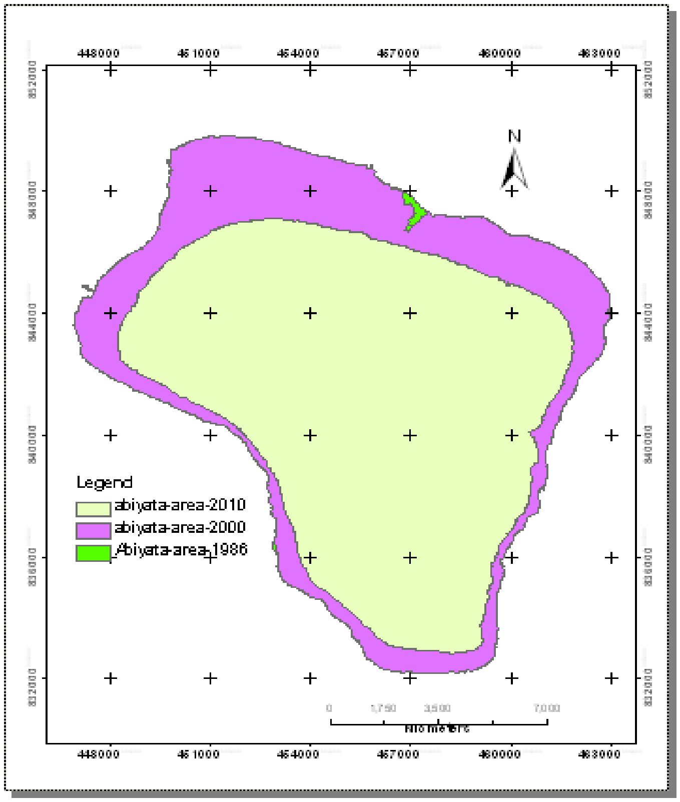

Figure 10. The size of Lake Abiyata during 1986, 2000 and 2010

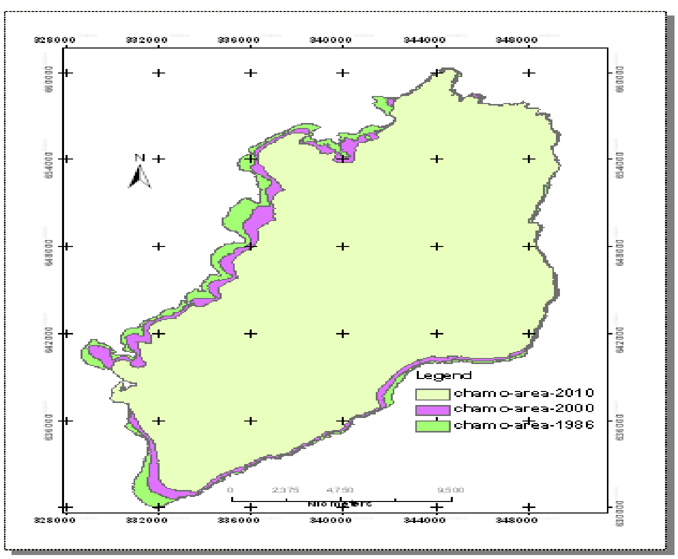

Figure 11. The size of Lake Chamo during 1986, 2000 and 2010

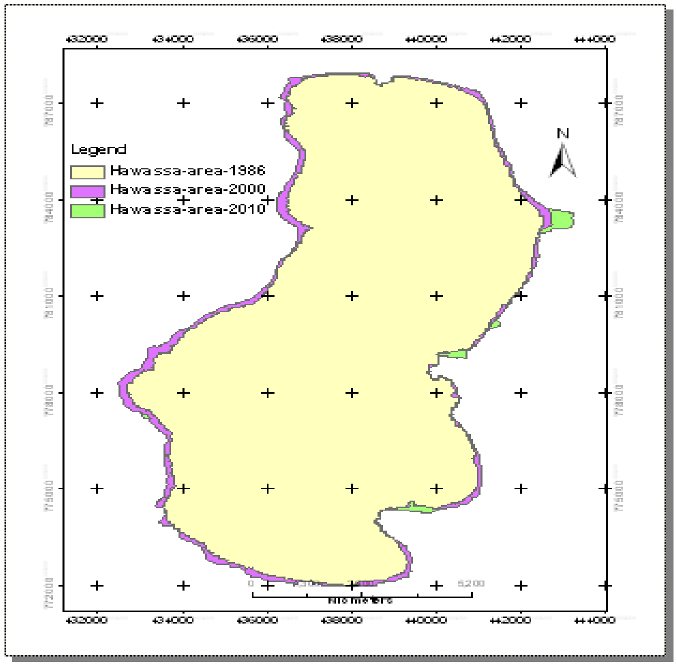

Figure 12. The size of Lake Hawassa during **1986, 2000 and 2010**

3.6 Analysis of land use/cover changes in the Rift Valley Basin

The lakes under consideration are included in the Rift Valley Basin. The major land use/cover types in the basin are indicated in Table 6. Figures 13 and 14 show the change in the land use/cover of the basin and the quantitative description is summarized in Table 6. Cultivated land and bareland have been increased by 90% and 75%, vegetation cover and grassland have been decreased by about 80% and 68% respectively between 1997 and 2008. This could imply slight rise in the level of the lakes. However, other factors also contributing to the fluctuations and the levels are actually declining except for Lakes Abaya and Hawassa.

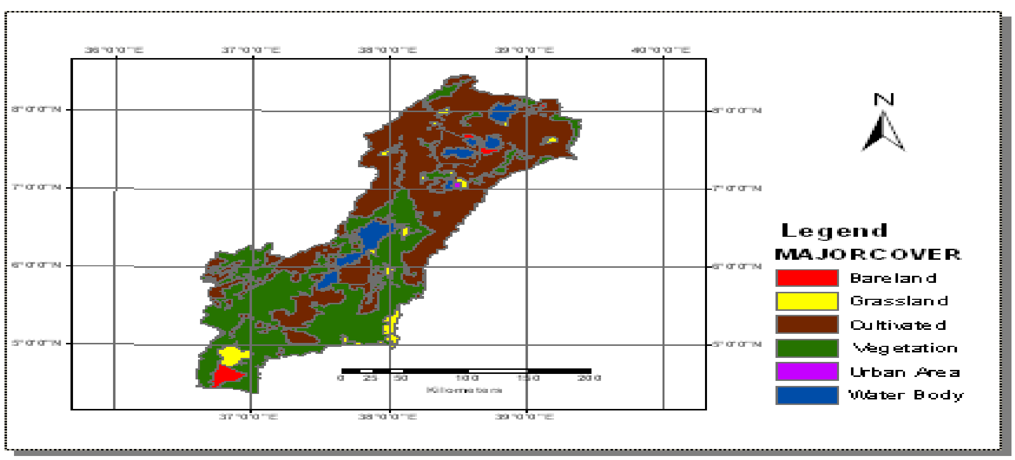

Figure 13. Land use land cover map of the Rift Valley Basin (FAO, 1997)

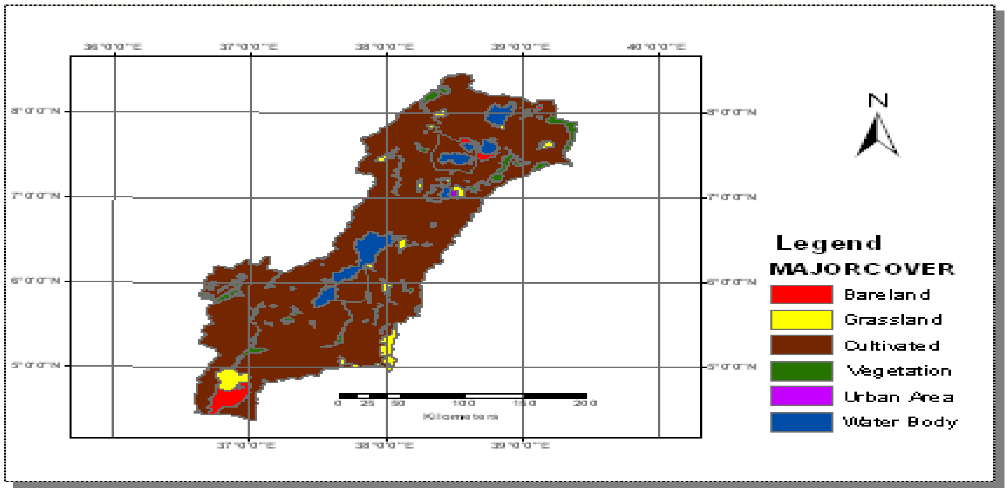

Figure 14. Land use land cover map of the Rift Valley Basin (Ministry of Water Resources, 2008)

Table 6. Change in area (km^2) of the land use/cover types for the Rift Valley Basin

No	Land use type	Data From FAO (1997)		Data From Ministry of Water Resources (2008)		Change (%)
		Value(km^2)	%	Value(km^2)	%	
1	Cultivated land	22938	43.25	43796	82.58	+90.94
2	Vegetation	20772	39.18	4142	7.81	-80.07
3	Grassland	6291	11.86	1596	3.00	-67.76
4	Water body	3023	5.70	2619	4.94	-0.13
5	Bareland	9	0.02	808	1.52	+75
6	Urban area	1	0.002	73	0.14	+69
	total	53034	100	53034	100	

Table6 shows how fast the vegetation is being depleted in the basin which can results in slight rises in the lake levels.

3.7 Synthesis

The results of the correlations and least squares regressions indicated that lake level fluctuations are not associated with rainfall variability for most of the studied lakes (except Langano). The reasons for these weak associations can be time lags between rainfall events and lake level fluctuations, less realistic lake level or rainfall data (few rainfall stations available near the lakes), and dominant anthropogenic contributions to lake level fluctuations among many others.

The associations of the lake levels with the discharges are significant only for Lakes Hawassa, Langano and Ziway. According to the study made by Tenalem Ayenew (2006), the level of Hawassa is rising (increased discharge) due to neotectonism and considerable deforestation of the lake basin which in turn resulted in increased surface runoff. The change in land use in the Rift Valley Basin, as summarized in Table 6, also confirms this result. The decline in the water level of Lake Ziway can be attributed to the abstraction of water for irrigation (Tenalem Ayenew et al., 2006; Huib and Herco, 2006) and the decline in the level of Lake Langano can be related to the decrease in discharge caused by neotectonic activities and diversion of the tributary rivers in the Arsi Highlands for small scale irrigation (Tenalem Ayenew, 2009) in addition to the slight decline in average annual rainfalls (after 1998) as indicated in table 3.

The fluctuation (decline) in the water level of Lake Abiyata is not significantly associated with rainfall and discharge variability indicating extremely high anthropogenic contributions (large-scale abstraction of water for soda ash extraction and diversion of the tributary rivers for irrigation). The level of the lake showed a declining trend between 1980 and 1998 while the rainfall and discharge showed increasing trends during the same period of time. This clearly shows very significant anthropogenic contributions towards the shrinking of the lake. As indicated in Figure 5, the rainfall and the discharge show declining trends between 1998 and 2004. This situation, together with the large-scale abstraction of water, resulted in serious decline in the level of Lake Abiyata. Other reasons for the decline may include the increased evaporation rates (although there are no sufficient evaporation data) and the decrease in overflow from Lake Ziway (Tenalem Ayenew, 2004; Huib and Herco, 2006).

The decline in the level of Lake Chamo can be connected to the increase in evaporation rates and may be to the diversion of feeder rivers for irrigation. Another possible reason may be due to groundwater outflow from the lake to the surrounding aquifers. This reason seems realistic since the lake water is more saline as compared to that of Lake Abaya.

The slight rise in the level of Lake Abaya can be related to very high groundwater inflow from the surrounding aquifers (Tenalem Ayenew, 2009) and may be to considerable deforestation of the lake catchment leading to increased sedimentation and siltation. This is evidenced by the different color in the northern portion of the image of the lake. The following Table summarizes the most significant factors that led to the lake level fluctuations.

Table7. Ordering the hydrometeorological, geological and anthropogenic factors

Lake	Most significant factor for lake level fluctuation.
Abaya	Groundwater inflow, evaporation, sedimentation and siltation (Land use change)
Abiyata	Abstraction of water, evaporation, decreased overflow from Lake Ziway, Rainfall
Hawassa	Increased discharge due to neotectonic activities(ground water inflow) and land use changes, evaporation
Chamo	Evaporation, diversion of feeder rivers, groundwater outflow.
Langano	diversion of tributary rivers, neotectonic activities, rainfall, river discharge
Ziway	Abstraction of water, river discharge.

4. CONCLUSIONS and RECOMMENDATIONS

4.1 Conclusions

The results of the study revealed that much of the fluctuations in the lake water levels are caused by human activities especially for the lakes in the Central Ethiopian Rift (CER). Lakes Abiyata, Chamo, Ziway and Langano are declining while Abaya and Hawassa are rising. This is also confirmed by the long-term average annual water balance of the studied lakes as indicated in Table 4, except for Lake Langano with a positive difference between inflows and outflows. Among the studied lakes, Abiyata is drastically reduced in size (about 28% of its area in 1986) due to both human activities (most dominant ones) and natural factors. The other seriously affected lake is Chamo with about 11% reduction in its area between 1986 and 2010.

Lake Abaya was found to be relatively stable during the indicated period (showed only a 0.8% increase in its area).Groundwater flow into Lake Abaya is very high and the flow into Lake Chamo is relatively low. Regarding Lake Abaya, surface water and groundwater flow into the lake exceeds the increase in evaporation rates plus the effects of anthropogenic factors (the variation of rainfall and discharge being negligible) leading to the slight rise in the level of the lake. As to Lake Chamo, the increases in the lake evaporation rates plus abstraction of water dominate the groundwater inflow which resulted in the decreasing trend of the level of the lake.

Lake Hawassa is rising due to the increased discharge and slight decline in evaporation. About 59% of the variation in the lake level is due to the variation in the discharge and about 14% of the variation is due to the variation in evaporation rates.

The water level of Lake Abiyata is declining drastically due to large scale-water abstraction, decreased overflow from Ziway and increased evaporation. The significant association of the level of Lake Abiyata with evaporation seems to be realistic since the lake is closed topographically and is located at a terminal position in the CER.

The size of Lake Ziway is also reduced slightly due to abstraction of water for irrigation and the variation in discharge (about 16% of the lake level fluctuation is due to the variation in the river discharge). The lake level does not associate significantly to rainfall and evaporation indicating considerable anthropogenic contributions to the level fluctuation.

The size of Lake Langano is reduced slightly. The lake level is associated with rainfall and river discharge. About 61% of the lake level fluctuation is caused by the variation in both rainfall and discharge. This comparatively large value could imply relatively less (as compared to the other lakes in the CER) man-induced contributions to the fluctuation in the level of Lake Langano.

The lakes under consideration in order of decreasing magnitude of the degree of fluctuation are: Abiyata, Chamo, Hawassa, Ziway, Langano and Abaya.

4.2 Recommendations

- Concerned bodies need to work in harmony to manage water use in the Ethiopian Rift Valley lakes, particularly Abiyata and Chamo.
- Since Lake Abiyata is seriously affected, special attention is needed to replenish the water in the lake by controlling the use of water and save the lives of many endemic animals including the flora and fauna.
- Further studies need to be made on the Ethiopian Rift Lakes to accurately identify the prevailing factors that are causing lake water level fluctuations, especially in the Lake Abaya-Chamo Basin.
- Educations on the consequences of excess water use and on how to protect the water resources need to be given to some representatives of the community living around the lakes.

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