PHYSICAL MORPHOMETRIC CHARACTERISTICS AND CAPACITY CURVES OF ABAYA AND CHAMO LAKES

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ABSTRACT

The purpose of the study undertaken in this paper is aimed at investigating the Abaya and Chamo lakes, which are not previously studied in any meaningful detail regarding their water resources capacity. The paper discusses the bathymetry survey undertaken and the resulting morphomoteric characteristics derived as a result. The background lake map has been digitised and surveyed data has been also developed as digital values. The digital values have been interpolated and grids of the elevation surface have been generated. From the digital values elevation area and elevation volume curves (capacity curves) of the two Lakes, which can describe the water resources capacity of the lakes body, have been developed. Furthermore, immediate application of the result as a continuation of the study is highlighted in the paper.

GENERAL DESCRIPTION OF THE LAKE AND THE DRAINAGE SYSTEM

The **Abaya and Chamo lakes** belong to the Ethiopian rift lakes system, which in turn is the component of African Eastern Rift Valley. In east Africa the drainage pattern began to change following upward movements and volcanic activity in Miocene times, starting 25 Million years ago. A wide stretch of land from Eriteria to the Zambezi has been lifted more than 1,000 meters since the Miocene. The two edges have been raised further, forming two great rift valleys. Tectonic activities in and near these valleys formed series of splits in the earth's crust of which some are more than 1000 meters deep and have filled with water. In this way the Abaya and Chamo lakes as well as the other rift valley lakes (excluding Lake Victoria) has been formed.

The Abaya and Chamo Lakes are components of the Ethiopian Rift Valley Lakes Basin (ERVLB). The ERVLB comprises of 8 natural lakes and their tributaries see Fig. 1. The Figure is digital line graph created for this study. The Abaya-Chamo

drainage sub-Basin (ACB) comprises mainly the two lakes, Lake Abaya & Chamo, and rivers and streams which are Gelana, Bilate, Gidabo, Hare, Baso, Amesa & other small brooks and streams entering the Abaya lake. Outflow from Abaya with Kulfo and other streams Sile, Argoba/Wezeka and other intermittent streams are entering to Chamo and an overflow from Chamo through Metenafesha joins Sermale river to join Sagan river, which intern ends up in Lake Chew-Bahir at border of Ethiopia with Kenya. The level difference between the two lakes is about 61m. Fig. 2 shows the boundary maps of the two lakes under investigation.

Morphometry is the measurement of the form characteristics of lakes and lakes basins. The three dimensional form of a lake basin and several aspects of the lake dependent on kind of topography in which it is formed, physical means by which the lake come in to existence and the conditions and events in the lake & drainage basin since its formation, Chow [1]. For the two Lakes, the most important standard general and morphometric parameters of lakes labelled according to Chow [1], for are investigated in this paper. Field data collection work under the umbrella of the ACB research has been undertaken. The methodologies of data collection in the field survey work, analysis of data and derived results are presented in the following sections.

THE NEED FOR BATHYMETRY SURVEY OF THE TWO LAKES

The bathymetry data for Abaya & Chamo Lake is not readily available, and only lake Ziway has bathymetry data in Ethiopian RVLB Lakes, [4]. The absence of such data has hindered various useful studies and planning which would have facilitated the water resources development of the drainage area and the lake body itself. Such deficiency can be observable in the studies of, [4], [3] and others, where assumption of simple trapezoidal lake bodies has been adopted. Earlier approximate depth contours of Lake Margarita
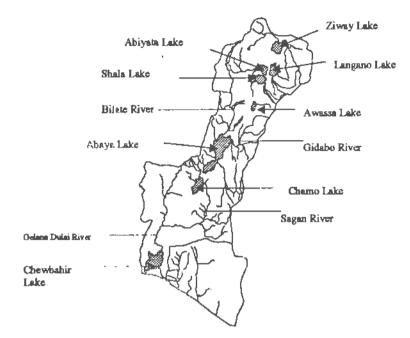
Figure 1 Southern Rift valley Lakes Basin of Ethiopia
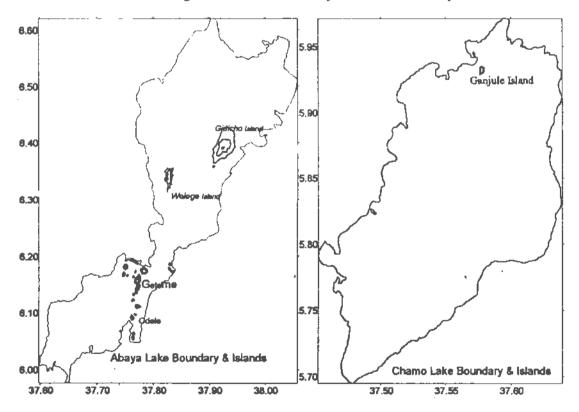

Figure 2 Digitized Boundary Maps of Abaya and Chamo Lakes with their Islands
(Long. & Lat. Degrees Coordinate)

(Lake Abaya) has been sketched by Morandini, G. in 1941 as reported in Riedel [6] with few measured points. Thus, for various future and as an objective of the wider study of ACB, bathymetry data of Abaya and Chamo Lakes have been collected and results are presented.

The bathymetry survey of the Abaya as well as the Chamo Lake has been carried out in the first half of 1998. Short description of the equipment and methods used, data of the survey work, results and conclusions on the data collection have been contained in this document. Full document of the undertaken study is provided in Ref. [8].

EQUIPMENT AND METHODS USED

The equipment used in the study includes Boat, Echo sounder, Global Positioning System (GPS) and accessories. For details on accuracy of the equipment, capacity, needed modifications and etc., see Ref. [8]. An optimal methodology has been set out in the field based on the first two days of reconnaissance work. The required parameters are depth and corresponding location. The method of measurement described as follows:

i.   *GPS setting*: The GPS was set, and important parameters, which includes, latitude and longitude, travelled distance, orientation, have been set to be displayed.

ii. *Echosounder setting*: The setting is carried out according to the operating manual and adjusted to display shallow water depth both graphically and digitally.

iii. *Echosounder calibration*: the Echosounder is set and the boat was taken in to the position where sufficient depth is available for calibration. Actual depth is measured and the Echo sounder is adjusted to read the measured depth at the point, which ensures the calibration. Calibration value for sound speed in Abaya Lake of 1500m/s and 1550m/s for Chamo Lake provided good result. For possible errors of measurements refer limitations section 7 below.

iv. *Measurement*: During the measurement first approximate orientation are chosen based on pre selected marks. While travelling in the selected orientation a quickly changing co-

ordinate is pre-registered at intervals of 0.1minutes latitude or longitude distance (about 180m), the corresponding longitude or latitude respectively registered. At the same time the corresponding depth from the display of the echo sounder have been registered.

However, near banks, and where there were sudden depth variations, records were taken at shorter intervals.

THE DATABASE, ADJUSTMENT OF DATA & DIGITAL DATA GENERATION

The Database

The survey data includes 20 days survey work of Abaya Lake in the period 25.02 to 29.04 1998 and 9 days survey work of the Chamo Lake in the period 1.05 to 31.05.1998. The data includes date of measurement, sound speed taken for measurement and details of equipment as well as data from the measuring equipment, i.e. latitude, longitude in degrees and minutes and depths were recorded, including peculiar remarks. In total, 4050 depth data points for Abaya and 2400 depth data points for Chamo have been captured. These data have been compiled and included in Ref. [8]. The data routes and captured points are indicated in Fig. 3 below.

Adjustment of Data

As can be seen in Fig. 4 below, the water level in the bathymetry survey period is not constant. The collected data should be adjusted using a reference value of water level to provide computations referenced to a common level. In order to adjust all bathymetry data, a common date of the maximum lake level, which corresponds to the date of investigation, is chosen and the other day's data are adjusted to this chosen date. For Abaya Lake this date corresponds to March 10, 1998 and for that of Chamo it corresponds to May 31, 1998.

However, as the datum of these particular dates corresponding to the datum above sea level are not known it is difficult to fix the values corresponding to standard values. This would have been easily carried out, had there been a reference bench mark around the Lakes or had the gauging stations of Ministry of Water Resources (MOWR) have exact references associated to their measurements or to the gauge locations.
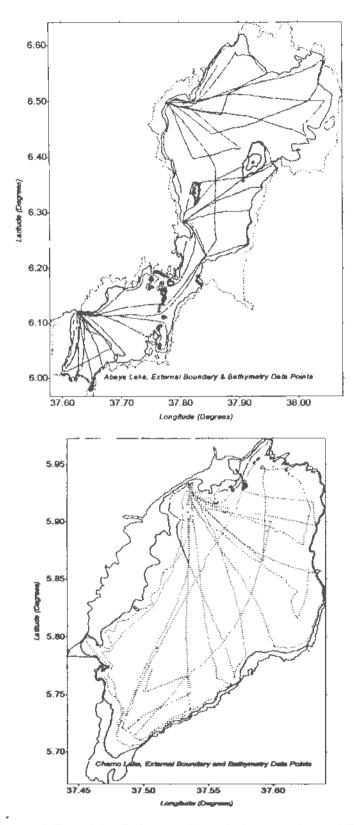
Figure 3   Abaya and Chamo lakes Bathymetry Survey Points, Boundary and Captured External Contour Line

The temporally adjusted and corrected lake water levels and depth data can be mapped on top of digitised background Ethiopian Mapping Authority (EMA) map. In order to use the existing maps as background maps common reference should be found for the map and the lake level during investigation. A trial search procedure has been developed for the two Lakes which can be shortly described as follows:

to sediment deposition process, the boundary can also be further modified if new lake boundary map can be obtainable. Such new boundaries can be derived from satellite maps produced during or near the investigation periods.
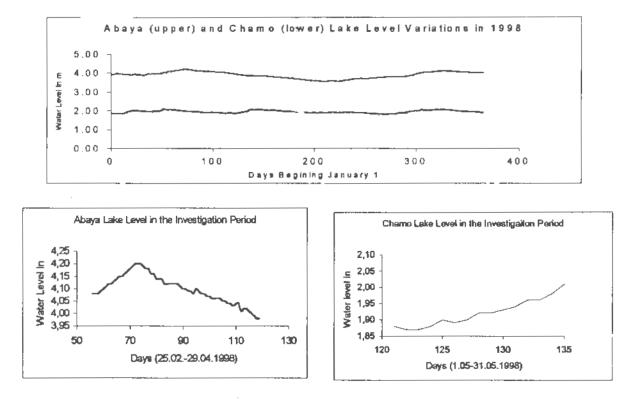

Figure 4   Abaya and Chamo Lakes Water Level Variations During Investigation

Abaya Lake: The Abaya Lake level reached the highest recorded level in 1998 due to effect of El-Ninô, which caused heavy rainfall and runoff in southern Ethiopia in the same year. Thus, the existing map boundary is in the inundated area as a result of extreme lake water level. Procedures, that are described in the subsequent sections and used to produce grids and to compute area and volume, are employed to find the flooding extent beyond the map boundary and the boundary depth relative to the bathymetry data, by trial and error. The trial and error procedures are explained in Seleshi (8). As a result the boundary of Lake Abaya corresponding to EMA map of level 1169m a.m.s.l. is fixed to depth of 2.0m. As the EMA (constructed 1972) maps boundary is vulnerable to change due

Chamo Lake: Unlike Abaya, the Chamo Lake has not been regenerated to the levels in 1960 and 1970s from the recent impact of El-Ninô. Digitised existing EMA map of 1:50.000 scale is corresponding to the dry land, when compared with the water level in the investigating period. This is mainly because the Lake has no substantial tributaries, and despite highest water level in the Abaya Lake this hasn't produced overflow to enter in to the Chamo Lake, which is a largest inflow factor to regulate the Chamo Lake level. Thus grid values have been generated using only surveyed data and elevation area curve, developed from the survey is extrapolated to set the Chamo Lake map boundary of level 1110m according to EMA. This corresponds to a level of 2.75m above Chamo water level relative to May 31, 1998 stage.

Data Interpolation and Digital Data Generation

The spatial coverage of the survey can be considered as sampling values. To obtain regular grid data for the entire surface of the lakes the data have to be interpolated. Having superimposed the digitised background map and digital data the scattered data have been interpolated to create grid data, using various interpolation techniques and the various results compared. The interpolated grid data are used to create contour maps and to derive various morphometric parameters of interest and maps of the lakes.

Gridding is the process of using original data points (observations) in an XYZ data file to generate calculated data points on a regularly spaced grid. Interpolation schemes estimate the value of the surface at locations where no original data exists, based on the known data values (observations). Thus the grid is used to generate the contour map or surface plot. The various grid methods include: Inverse Distance, Kriging , Minimum Curvature, Nearest Neighbour, Polynomial Regression, Radial

Basis Functions, Shepard's method, Triangulation with Linear Interpolation. Having tested these methods with the collected data, the last method, i.e., Triangulation with Linear Interpolation has been chosen to derive end results in this study. This method is fast with all data sets. When small data sets are used Triangulation generates distinct triangular facets between data points. One advantage of Triangulation is that, with enough data, it can preserve break lines defined in a data file. The comparison of various methods is carried out with the help of surfer graphic software.

COMPUTATION OF LAKE PARAMETERS

Morphometric Characteristics and Contour Maps

The most important parameters of morphometry; area (A), maximum effective length (L_{me}), maximum width (W_{me}), mean width (W), shoreline (L) and depth (d) are summarized in Table1. The values are with respect to the reference datums discussed above. Contour Maps are provided in Figures 5a and 5b below.

Table 1: Summary Morphometric Characteristics of Abaya and Chamo Lakes

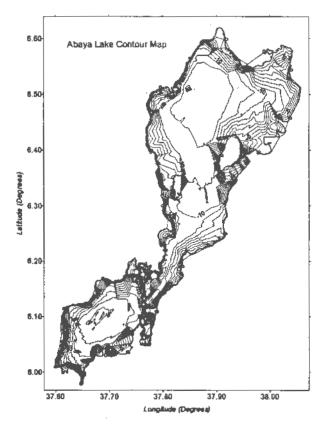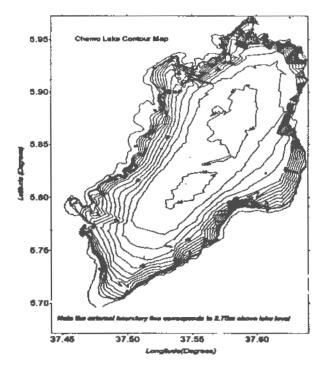| Parameter	Lake	
	Abaya	Chamo
Altitude (m)	1169	1110 (NMSA 1:50,000 maps)
Basin area, including lakes (km^2)	16,328.52	18599.8 (with Abaya Contribution)
A, including Islands (km^2)	1139.786	316.7274
L_{me} (km)	79.2 b/n 5°58.5N & 37°39'E ~ 6°35'N & 38°02'E	33.5, b/n 5°42'N & 37°39'E to 5°58'N & 37°36'E
W_{me} (km)	27.1, $\perp$ to L	15.5, $\perp$ to L
W (km)	14.13	10.1
d_{max}, m	24.5, around the islands	14.2, near the middle
d, m	8.61	10.23
Shore line (km)	268.78	108.1
Volume, m^3	9.818591×10^9	3.241693×10^9

Figure 5 (a) Abya Lake Contour

Figure 5 (b) Chamo Lake Depth Contour Map

Elevation-Area Curve of Abaya and Chamo Lakes

Based on the previous discussions, the processed data is related to a reference lake level and used for computation of elevation-area relationships of the two lakes. For various elevation points based on generated grid, planar and surface areas can be computed. The surface area considers slope and elevation in to effect to compute the area, while the planar are computes the projected 2 dimensional plan water area parallel to the water surface. The planar areas are summarised in Table 2 and the curves are plotted in Figs. 6(a) and 6(b) for Abaya and Chamo Lakes respectively. The fitted elevation-area polynomial curves, which are shown on the Figures, and related to depths are given by:

Abaya Lake

$$A = 0.0198\ d^5 - 0.06662\ d^4 + 7.7116\ d^{3\,2}$$
$$- 39.7666\ d + 31.023\ d + 1133.4 ;$$
$$R^2 = 0.9995 \tag{1}$$

Where d is depth below zero water lake level measured positive downwards and A is area in km^2. R^2 is coefficient of determination. Zero lake level corresponds to 1171m a.m.s.l.

Chamo Lake

$$A = -0.002\ d^5 + 0.044\ d^4 - 0.2906\ d^3$$
$$- 0.1991\ d^2 - 4.5943\ d + 316.69 ;$$
$$R^2 = 0.9993 \tag{2}$$

Where d is depth below zero water lake level measured positive downwards and A is area in km^2. Zero lake level corresponds to 1107.25m a.m.s.l. Similarly, a number of other equations can be developed using the tabular result in Table 2.

Elevation Volume Curves
Based on the derived elevation-area curve and depth, elevation-volume can be computed using various methods, which are briefly described below[6]:

i   Average area or trapezoidal method
$$V = h \frac{A1 + A2}{2} \tag{3}$$

ii.   Simpson's rule method
$$V = h \frac{A1 + 4A2 + A3}{3} \tag{4}$$

iii. Simpson's 3/8 rule method

$$V = h\left[\frac{3}{8}A1 + \frac{9}{8}A2 + \frac{9}{8}A3 + \frac{3}{8}A4\right] \quad (5)$$

where

   h is depth magnitude between
   .   interpolation points

   $A1, A2, A3, A4$ are planar areas at
                  interpolation points.

The above three methods are used to determine volumes in this study. The difference in the volume calculations by the three different methods also gives a qualitative measure of the accuracy of the volume calculations. If the three volume calculations are reasonably close together the true volume is close to these values. If the three values differ significantly, a new denser grid file is produced and the volume calculations are performed again.

The relative error for the volume results can be estimated by comparing the results of the three methods. Then the relative error can be given as a percentage of the average volume. The relative error can be estimated using the following formula:

$$RE = \frac{(LR - SR)}{Aver}100 \quad (6)$$

where RE is the relative error
LR is the largest result from the three methods
SR is the smallest result from the three methods
$Aver$ is the average of the three methods

Based on the above discussions values have been computed and tabular as well as plotted results are presented in Table 2 and Figs. 7(a) and 7(b) for Abaya Lake & Chamo Lakes respectively. The fitted volume curves for the two lakes are given by Eqs. 7 and 8 as:

Abaya Lake

$$V = -1 \times 10^{-5}d^5 + 0.0005\ d^4 - 0.0057\ d^3$$
$$+ 0.0516\ d^2 - 1.2242\ d + 9.842\ ;$$
$$R^2 = 1 \quad (7)$$

where d is depth of water in m, measured from lake level 1171m a.m.s.l., positive downwards.

Chamo Lake

$$V = 2 \times 10^{-6}d^5 - 3 \times 10^{-5}d^4 - 0.0003\ d^3$$
$$+ 0.0031\ d^2 - 0.319\ d + 3.2419\ ;$$
$$R^2 = 1 \quad (8)$$

Where d is depth of water in m, measured from lake level 1107.25m a.m.s.l., positive downwards.

A number of other equations can be fitted described with the data provided below in Table 2. 3-dimensional stacked maps of contour and surface plots can also be generated from the digital maps, and see Ref. [8] for such maps.

Table 2: Abaya and Chamo Lakes Capacity Curves Summary Table

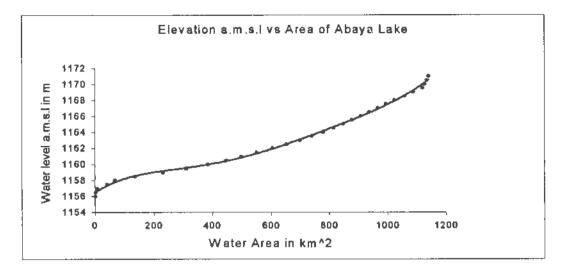| Abaya Lake Capacity Curve Data				Chamo Lake Capacity Curve Data			
Depth (m)	Level a.m.s.l	A (km^2)	V (km^3)	Depth (m)	Level a.m.s.l	A (km^2)	V (km^3)
0	1171	1139.786	9.818591	-2.75	1110	334.9209	4.136699
0.5	1170.5	1133.252	9.250334	-2.5	1109.75	332.6729	4.05328
1	1170	1126.449	8.685393	-2	1109.25	329.4012	3.887765
1.5	1169.5	1119.066	8.123975	-1.5	1108.75	326.181	3.723865
2	1169	1087.462	7.566691	-1	1108.25	322.9976	3.561558
2.5	1168.5	1059.014	7.030376	-0.5	1107.75	319.8447	3.400842
3	1168	1023.684	6.50802	0	1107.25	316.7274	3.241693
3.5	1167.5	994.2173	6.003793	0.5	1106.75	313.6382	3.0841
4	1167	966.122	5.513684	1	1106.25	310.5723	2.928049
4.5	1166.5	937.4431	5.037777	1.5	1105.75	307.526	2.773517
5	1166	907.98	4.576356	2	1105.25	304.3241	2.620527
5.5	1165.5	878.89	4.129553	2.5	1104.75	299.9028	2.469459
6	1165	847.1784	3.697981	3	1104.25	295.1472	2.320682
6.5	1164.5	814.92	3.282422	3.5	1103.75	290.3585	2.174291
7	1164	779.6216	2.883623	4	1103.25	285.3287	2.030362
7.5	1163.5	741.2171	2.503187	4.5	1102.75	280.0637	1.889004
8	1163	699.6	2.142924	5	1102.25	274.5478	1.75034
8.5	1162.5	654.609	1.804265	5.5	1101.75	268.3927	1.614553
9	1162	605.1638	1.48918	6	1101.25	262.0135	1.481962
9.5	1161.5	551.6791	1.199686	6.5	1100.75	255.6527	1.352554
10	1161	498.8134	0.937915	7	1100.25	248.9295	1.226379
10.5	1160.5	446.6181	0.700869	7.5	1099.75	241.4141	1.103771
11	1160	385.1694	0.49359	8	1099.25	233.5681	0.98501
11.5	1159.5	310.4609	0.318682	8.5	1098.75	225.5972	0.870215
12	1159	230.2644	0.182559	9	1098.25	217.0398	0.759515
12.5	1158.5	134.9559	0.088668	9.5	1097.75	208.131	0.653219
13	1158	67.57643	0.0431	10	1097.25	198.8365	0.551441
13.5	1157.5	41.86267	0.015008	10.5	1096.75	188.1499	0.454612
14	1157	8.218282	0.003349	11	1096.25	175.2752	0.363675
14.5	1156.5	-2.385709	0.001073	11.5	1095.75	161.1198	0.279553
15	1156	0.69405	0.000327	12	1095.25	146.389	0.202635
				12.5	1094.75	129.1542	0.133607
				13	1094.25	104.5254	0.07459
				13.5	1093.75	73.87478	0.030032
				14	1093.25	26.2	0.003006

Figure 6 (a)   Area Curve of Abaya Lake
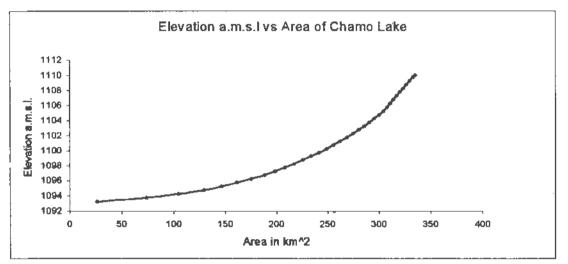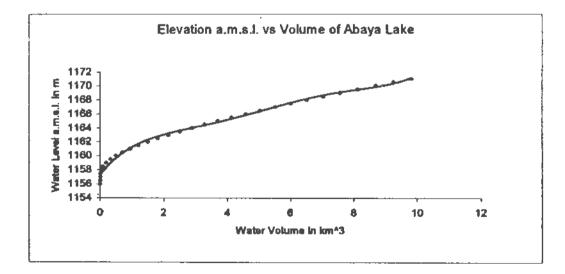

Figure 6 (b)   Area Curve of Chamo Lake

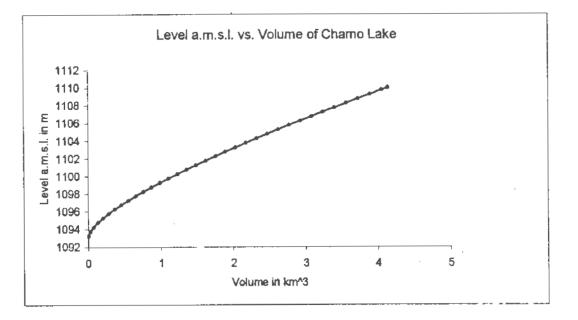Figure 7 (a) Volume Curve of Abaya Lake

Figure 7 (b) Volume Curve of Chamo Lake

APPLICATIONS AND LIMITATIONS

The data and generated result have various use &
applications. Among others, the following are some
of these applications:

- water resource quantity assessment of the lakes
- computation of water balance model for the
  lakes and entire drainage area
- assessment of project development impact on
  the lakes
- limnology and water quality study of the lakes
- hydrological/hydraulic study of the two lakes
  and their drainage system
- fishery, tourism and agricultural development
  using the lakes.

One of the most important applications of the
derived result is in water balance model of the
lakes, such model helps among others to assess the
impact of basin's water resources development
activity on the lakes.

The water balance equation can be written, from
continuity equation at any time, which is governed
by the conditions that the water volume is not
constant. The continuity equation intern governed
by conservation of matter, which described by
equilibrium between added water volume/depth,
lost water volume/depth and change in
volume/depth as:

$$Q_{in} - Q_{out} + P - E - \Delta S \pm \delta = 0 \qquad (9)$$

where Q_{in} = surface and subsurface inflow
        Q_{out} = surface and subsurface outflow
        P = Precipitation
        E = Evaporation
        ΔS = Change in storage
        δ = Eerror term

The water balance is usually computed for seasonal
or annual means. In ideal situation variables of the
water balance equation are computed separately,
and providing closed result. In practice however,
the computation leads to a discrepancy or residual
error, and the equation includes error term
described by δ. Geographic Information System
(GIS) supported investigation is undergoing to
develop the water balance models of the two lakes
by the authors.

The surveyed data and result are not without
limitations. The following are the most important
limitations and users should be aware of these
limitations.

- The accuracy of echo sounder is limited to
  0.1m. The best equipment available on market
  is not used for the survey work, because of
  limitation of cost.

- It is known that sound speed in water varies depending factors like salinity of the water, temperature of the lake. These factors and variations are not taken in to account. The near shore calibration values for the Abaya lake gives sound speed of 1500m/s and for Chamo lake 1550m/s. However, it is possible that these values, differ slightly as one goes to the middle of the lakes where there are deeper depths and having temperature variations & stratification. In deep lakes these parameters should be considered very well.
- The GPS's positional reading accuracy is in the order of possible error of 10 to 15 meters. Indeed the accuracy is more than sufficient for the intended aim in this study. Furthermore it is proved that in short spatial distances variation of Lake Water depth is insignificant.
- Latest available maps, which are used as a background map, are according to NMSA 1972, 1:50,000 and 1:250,000 scales. Other large-scale background base maps are not available for the study. Satellite imagery obtained in recent years could have provided better boundary maps.

CONCLUSION

The Abaya and Chamo Lakes water depth and bottom profiles have been surveyed and combined with base map to develop digital data at sampled points. These sampled data have been interpolated to provide regular grid from which various physical morphometric parameters, such as depth-area, depth-volume and other general parameters have been developed. These parameters, in addition to providing useful facts, can be utilised for various water related and resource management and environmental impact studies.

ACKNOWLEDGMENTS

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