4. Methods

4.1. Meteorology

Two automatic meteorological stations were established at the western shoreline of Lake Abaya. Fura Station is located at 37.67^{o} Easting, 6.16^{o} Northing in 100 m distance to the shoreline, and Wajifo Station is located at 37.28^{O} Easting, 6.5^{O} Northing in 30 m distance to the shoreline.

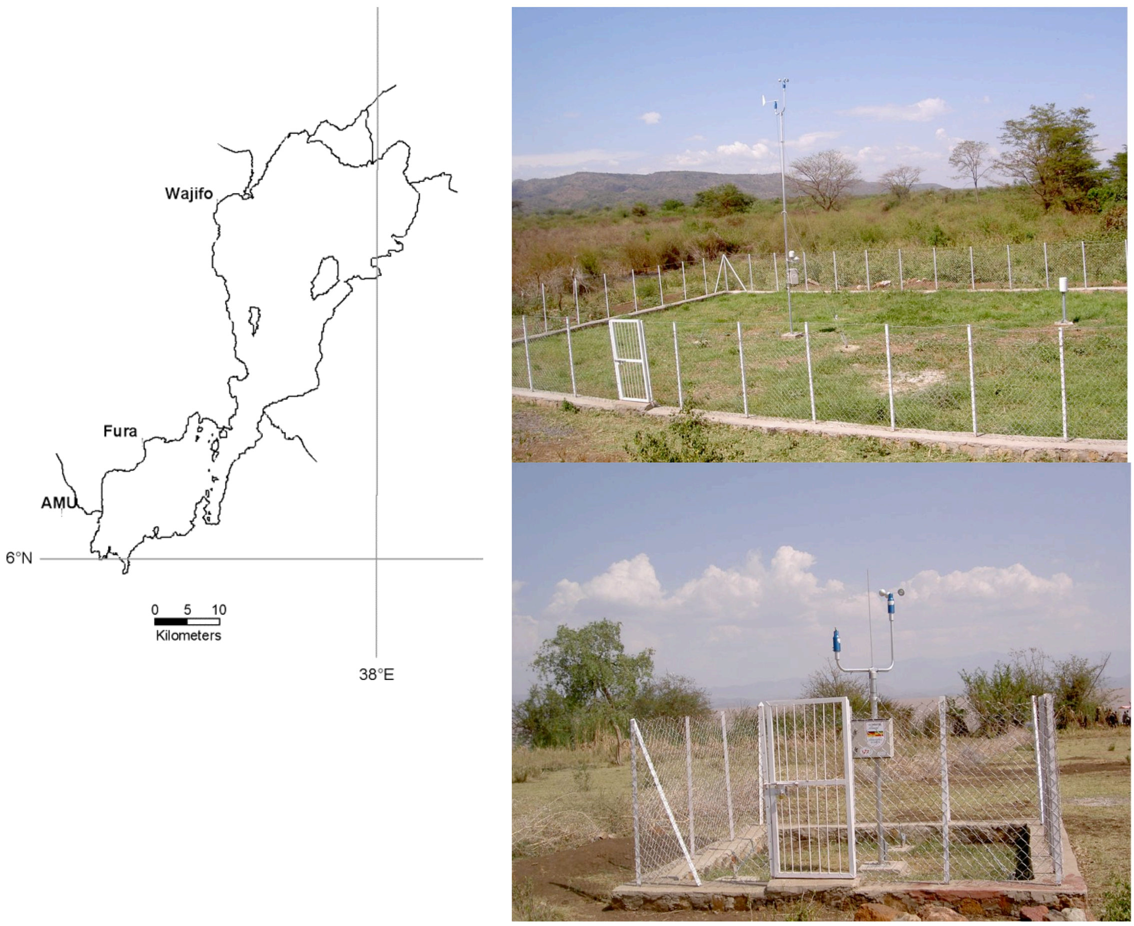

Figure 4.1. Left: Location map of meteorological stations and base site (AMU); Right: Wajifo (top) and Fura (bottom) stations.

The selection of the localities for the establishment of observational stations involved various meteorological and logistical problems. For instance, in order to simplify the meteorological complications, a straight coastline in a region of flat terrain is desirable (Fisher, 1960). Although the two selected sites do not fully satisfy these requirements, they offer some advantages that led to their selection. Only the western shoreline of Lake Abaya can be accessed for routine operation of the instruments. Relief at the stations is fairly flat enough to capture winds from all directions. In addition, locations are as close as possible to the shoreline, to the west of the longest transverse lengths and around the middle of the main basins in the south and north (Figure 4.1).

For the two sits selected for the meteorological stations there are some disadvantages which should be mentioned. The pronounced bend at Fura and indentation to the north of Wajifo in the coastline, and the presence of valley floor edges within few kilometres to the west of the stations certainly have some effect on the main features of the wind field resulting from differential heating at a lake shore.

The Fura station is located in the south basin, and records wind speed (measuring range: 0.5 – 35 m/s) and direction (angle of rotation: 0 359^{o}) at 2 m elevation from the ground surface using SEBA HYDROMETRIE sensors. Wajifo station is located in the north basin; it records wind data at 6 m elevation along with air temperature (resolution: 0.1^{o}C, accuracy: ±0.3^{o}C), atmospheric pressure (accuracy: 1% relative error), global radiation (spectral range: 0.3 – 3μm, temperature dependence: <0.15%/^{o}C), and rainfall using rain gauge with impulse output (resolution: 1 pulse = 0.1 mm precipitation, pick-up for data logger system and ball-beared tipping bucket). Both stations are equipped with data logger and the data were recorded as either two or five minute averages since 7th of February, 2004. In the present study data from 1 March 2004 through 28 February 2005 are used. Although the available data set is not sufficient for formal statistical analysis to investigate the general structure of the meteorological elements around the lake, it provides important information to capture local phenomena observed during the study period.

Various analyses were performed in order to understand the variation of wind field at different time scales along the western shoreline of Lake Abaya. The resultant values of the wind records were computed by adding and averaging the west and south components of the two or five minute interval wind observed at a given time. Diurnal variation of the wind is analyzed using half-hourly averages of 2 minute interval records of wind speed and direction. Frequency histogram was plotted to compare onset of lake-breeze at two stations. Hourly wind roses were obtained from the mean wind vector for each observation time at the stations to study the average variation of wind speed and direction over each hour of a day. The monthly wind statistics is presented using the monthly wind roses and speed class histograms. Periodicity analyses were performed to identify the most oscillatory components using the monthly spectra estimates from hourly average speed along dominant directions. The dominant directions were explored using wind direction histograms.

The tipping bucket data were converted to series of daily and monthly total and 1 minute, 5 minute, 10 minute and 1 hour rainfall intensities. Temperature variation at Wajifo Station is analyzed using hourly averages. The descriptive statistics together with frequency distribution histograms and plots of monthly averages over individual hours during the study period are used to observe closely diurnal and monthly variability of temperature. Interdiurnal variability was computed as the difference between either the daily mean or a fixed hour of a day and that of the next day to identify the variability of warming and cooling in each month during the study period. The monthly atmospheric pressure oscillations about the monthly means were plotted to illustrate the diurnal cycle of pressure changes as well as some atmospheric dynamics causes for extreme events.

4.2. Sedimentology

948 surficial sediments were collected from the Lake Abaya lake floor (Figure 4.2) using a Van Veen grab sampler type during the 2003–2004 field years from both south and north basins (Figure 4.3). Additional 238 samples were collected by Blumberg and Schütt (2006) in 2002 from the area around the Lake Abaya bottleneck connecting two basins. Sampling stations were geo-positioned using the topographical maps (scale 1:50,000) and Garmin III GPS. The water depth was recorded at each sampling locality using the markings on sampler line. For the fresh samples colour, grain size composition and odour were recorded.

In the Hydraulics and Water Quality laboratories of Arba Minch University the sediment samples were dried at 60^{o}C, disaggregated and stored. For further analysis samples were homogenized using an agata ball mill at Siegen University and at Freie University of Berlin. The geochemical and mineralogical analyses were carried out in the Geographic laboratories of Freie University of Berlin.

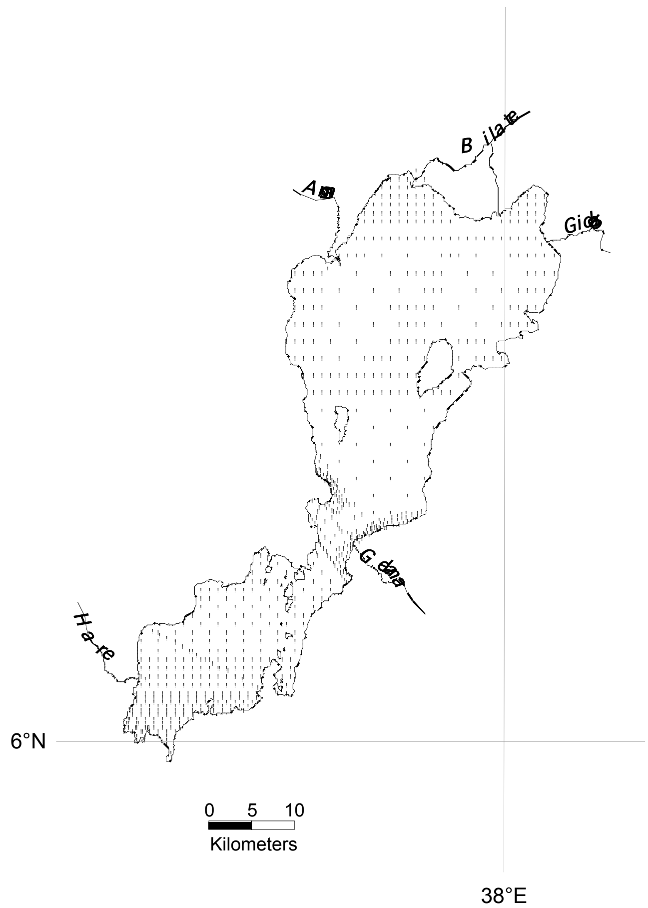

Figure 4.2. Location of sampling sites of Lake Abaya lake floor sediments.

The total carbon content (TC) was determined by burning 100 mg of grounded sample material in an oven under oxygen atmosphere at a temperature of 1000^{o}C. The released CO_2 changed the electrical conductivity of NaOH-solution in a special measuring cell

(WÖSTHOFF, CARMOGRAPH 6). For total inorganic carbon (TIC), 100 mg of sediment material was treated with 42.5% phosphoric acid at a temperature of 80^{o}C, and the released CO_2 was detected in the same manner (see above). The difference between TC and TIC represents the organic carbon content. The detection limit for all carbon measurements is 0.02 mass %.

X-ray diffraction analysis of 706 powder samples was undertaken to determine the mineral composition of the lake floor sediments from Lake Abaya using a Philips PW 1710 diffractometer connected with PC-APD (version 3.6g) with Ni – filtered copper Kα radiation. To produce reliable diffractogram each sample was tested for preparation error.

The determination and a semi-quantitative analysis of mineral composition of the lake floor sediments were carried out using Philips X'Pert HighScore analysis software. The position change of the major peaks of X-ray diffraction data, which may be inherent mainly due to sample preparation, affects the computed amount of mineral composition. The software feature to correct this computational error produces usually different results when 'allowing pattern shift' is turned on and off. To overcome this effect, the computed results of the percentage composition of identified minerals were compared with the major peak intensities of quartz, feldspar and calcite minerals.

Determination of clay minerals is not possible using X-ray powder analysis. Correspondingly, first the amount of the different minerals without clay minerals was calculated. Since X-ray diffraction failed to reveal the occurrence of other carbonates than calcite in the lake sediments, the inorganic carbon content (TIC) was used to calculate the calcite content (mass %). In comparison with the calcite content obtained by semi-quantitative analysis of X-ray diffraction data, a reducing factor is calculated. After using this factor to reduce the semi-quantitative values of the identified minerals, the difference between 100% and the sum of calculated minerals is taken as the amount of the clay minerals including also allophanes and organic matter.

Figure 4.3. Grab sampling of lake bed sediment from predefined sampling site.

In general, the diffraction patterns of samples from the central parts of Lake Abaya are extremely similar. This fact was also used to prove the correctness of the calculations.

All basic statistics on the percentage composition of minerals were carried out using SPSS. Kriging interpolation method in ARC GIS environment was used to estimate spatial distribution of water depth and percentage composition of minerals. This method is chosen because it represents better two ends in the spectrum of interpolation method. Plots of frequency distribution of percentage composition for main basins included to display relative distribution structure. Correlation analyses were used to investigate the influence of water depth on the spatial distribution of sediment texture and mineralogical composition. Average mineralogical compositions at deltas of major rivers were compared to identify the influence of drainage basins. The Ward method of cluster analysis with percent mineralogical compositions was used to group different lake sediment samples. The data are reported as mean percent of the sediment samples included in a cluster.

4.3. Water quality

The water quality data are categorized into two sets of parameters: (1) in situ parameters, measured with multiparameter sonde and Secchi disk, and (2) laboratory parameters. Parameters measured on site using portable multiparameter water quality measuring equipment of SEBA HYDROMETRIE include: pH (accuracy: ±0.1pH, resolution: 0.01pH); water temperature (accuracy: ±0.1^{o}C, resolution: 0.01^{o}C); conductivity (accuracy: ±1μS (0 – 200 μS), ±0.5μS (> 200 μS), resolution: 0.001 μS); dissolved oxygen (accuracy: ±0.5 vol. of measured range, resolution: 0.01mg/l); and redox (accuracy: ±10mV, resolution: 0.1mV). Laboratory parameters include concentrations of Total Suspended Solids (TSS) and Total Dissolved Solids (TDS).

Crosschecks between upcast/downcast near surface quality data of duplicate measurements were used to confirm accuracies suggested by the manufacturer as well as the sensors are operating properly. The quality sensors were calibrated frequently in the Water Quality Laboratory of Arba Minch University before going out in the field (SEBA HYDROMETRIE, 2004b) against company made fresh standards. The calibration process is supported by the calibration software SEBAConfig and infra-red (IrDA-Standard) interface to make wireless connection to a PC.

The primary criterion for the selection of sampling locations was an adequate spatial coverage to determine the effects of different parameters on water quality. Nine fixed monitoring stations were established where three types of sampling stations were defined (Figure 4.4): (1) in the sphere of influence to the major tributary rivers mouths (S2, S3, S7, S8, and S9), where freshwater and transported materials are delivered in large amount; (2) in the central part of the lake (S4 and S6), which are remote from transported materials delivery points to the lake; and (3) in the southern margin of the two sub-basins (S1 and S5) to identify any trend in water quality parameters along the longitudinal axis.

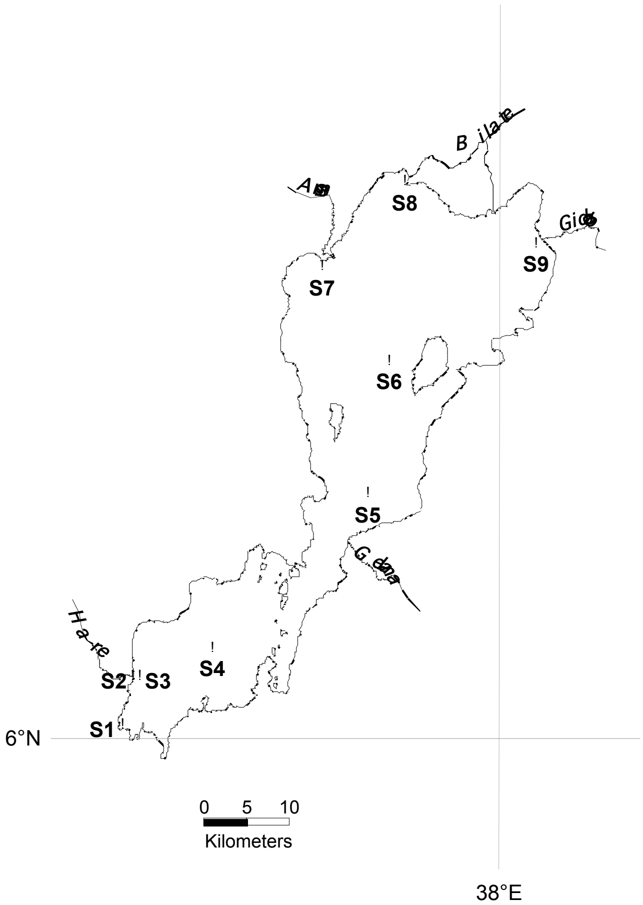

Figure 4.4. Location map of fixed monitoring stations.

The research vessel was anchored at each fixed station and parameters were measured and water samples were obtained from predefined sampling depths. All lake water samples were extracted using SEBA HYDROMETRIE grab sampler (Figure 4.4). Number of water quality measurements depended on the lake depth at the respective station. For shallow stations (depth ≤ 3m), parameters were measured at the surface (0.1m) and at 0.5m intervals working down to the bottom (0.5m, 1m, 1.5m, etc). For stations deeper than 3m, parameters were measured at the surface (0.1m), at 0.5 m, and 1.0 m, and at every meter thereafter until reaching 0.5m above the bottom. The measurements were recorded after the sonde readings were stabilized.

The Secchi disk transparency was obtained with a 20 cm metallic Secchi disk. The disk was lowered into the water over the shaded side of the boat to reduce problems of glare until it just disappeared from view and the depth was recorded. Then the disk was slowly retrieved to the point where it reappeared and the depth was recorded again. The mean of these two measurements was taken as the Secchi disk transparency.

The physical analyses conducted in the water quality laboratory of the Arba Minch University included determination of Total Suspended Solid (TSS) and Total Dissolved (TDS) concentrations. TSS concentration was determined gravimetrically by filtering a known volume of a well-mixed water sample and by differential weighing of the dried filters. 250 to 1000 ml were filtered through 55 mm diameter and ashless S & S Filter Paper. After filtration was complete, the filters were washed with 20ml distilled water and then dried for 12 hrs at 105°C. The residue was weighed in an analytical balance (precision = ±0.1 mg) to calculate the total concentration of suspended solids. The mass of total dissolved constituents in water (TDS) was determined by evaporating the filtrate at 180°C and weighing the residue.

Figure 4.5. Water sampling from fixed monitoring station.

Table 4.1 Regular field monitoring sessions for water sampling from fixed sampling station in Lake Abaya (March-October 2004). Figures indicated dates of the month when field samplings were conducted.

Bimonthly monitoring in the south basin								
Station ID	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
South basin								
S1	11, 26	14	11, 26	14, 26	12, 28	12, 27	25	12, 27
S2	11, 26	14		26	12, 28	12	25	12, 27
S3	11, 26	14	11, 26	14, 26	12, 28	12, 27	25	12, 27
S4	11, 26	14	11, 26	14, 26	12, 28	12, 27	25	12, 27
North Basin								
S5	20	19	19	21	19	20	21	21
S6	19	19	19	21	19	20	22	21
S7	20	19	19	21	20	20	22	22
S8	19	20	20		20			22
S9					20			22

Stratification patterns in Lake Abaya were shown by the contour plots of water quality profiles at fixed monitoring stations. The monthly and bi-monthly values of variables for all the fixed stations were described in terms of the mean values of depth profiles. The general spatial variation of water quality parameters for fixed stations was depicted based upon the overall average values for each fixed station. Seasonality of quality parameters variations were assessed by plots of mean values during the study period. The relationship between weather and water temperature was examined using plots of average values of 1 hour air temperature and top layer water temperature at the nearby fixed stations. The spatial distribution of water transparency was estimated by the mean Secchi values at fixed monitoring sites combined with single measurements taken from some sediment sampling locations

Statistical results to quantify the associations and differences between water quality parameters were evaluated with a two-tailed t-test, one-way ANOVA, Tukey's Multiple Comparison and correlations coefficients. Stations which have been monitored more frequently and profile measurements taken at more than one depth are included for analysis. The individual parameters were tested between fixed stations and data set. Statistics were computed in SPSS® v14.0.