

Diagnosing the Suitability of Lake Water for Domestic and Agricultural Uses: A Case Study in Eastern Ethiopia

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Abstract: Lake Adele is one of the lakes giving incomparable economic benefits in Eastern Hararghe zone. It is being used for irrigation and water supply purposes, especially for animals. However, the lake water quality has not yet been analyzed even though it is traditionally believed that it has quality problems. This research was, thus, undertaken to evaluate the quality, identify the origin, and analyze the hydro-chemical composition of the lake water. Three water samples were collected from the lake by a grab sampling method. Samples were analyzed for six physicochemical parameters (temperature, EC, TDS, TA, pH, and turbidity), major cations and anions, minor anions and trace metals using standard procedures. The laboratory measurements were weighed against the local and global standards. The results of the analysis revealed that the lake water has exceedingly intolerable levels of certain physical and chemical parameters. The GW-Chart software was also used to produce the piper diagram that can graphically show the origin and geochemical composition of the lake water, which revealed that the origin of the lake is deep groundwater with a major geochemical composition of sodium bicarbonate. It is concluded that the lake water has particularly excess turbidity and dangerous levels of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3), and lead (Pb) that would make it unsafe to use for drinking as well as excess levels of salinity, pH, and Sodium Adsorption Ratio (SAR) that would make it unfit to use for irrigation.

Keywords: Domestic use; Irrigation; Lake Adele; Major Ions; Origin and Geochemical Composition; Water Quality

1. Introduction

Water is the most important substance for human and other lives (Ranjan, 2012; Tiwari and Ranga, 2012). Chemically, pure-water, which contains atoms of various isotopes of hydrogen and oxygen, is recognized as a complex substance; i.e., water is not found in a chemically pure form. It contains other minerals in a solution form that conduct an electric current. Moreover, the different uses of water also need other necessary chemicals to be found in water. Drinking water, for example, should contain several electrolytes including Ca, Cl, F, Mg, Na, K which are very crucial for different functions in the human body (e.g., absorption and digestion functions) (WHO, 2011).

The interaction of water with the landscape components during the process of the hydrologic cycle, the anthropogenic activities like agricultural practices and mining, and some other natural and manmade causes are the primary factors that affect the hydro-chemical composition of water (Setegn, 2012). Due to this fact, natural water is composed of complex groups of gases, minerals and organic substances, and suspended colloidal matters. It is, therefore, considered as a dynamic chemical system. Thus, the need for water may either be associated with the quality or availability in different parts of the universe, especially in the developing countries (WHO, 2011).

The process of water quality analysis is, therefore, very important for the assessment of current water quality in

comparison with the universal standards, and prediction of future quality conditions of water bodies (USEPA, 2012; WHO, 2011). In general, information on the physicochemical composition of water is very crucial to solving the problems associated with the different uses of water (Shishaye and Nagari, 2016; USEPA, 2012; WHO, 2011).

Water quality analysis is usually conducted based on certain parameters according to the harmfulness index (Liu *et al.*, 2014). The quality standards of the different parameters in water used by different countries are known as one of the following: quality criteria, maximum allowable levels, maximum contaminant limits, and maximum contaminant standards (Shishaye and Nagari, 2016; Liu *et al.*, 2014; USEPA, 2012).

The concentration standards of the different parameters may vary from region to region and from country to country, even though their variations may be small (Shishaye and Nagari, 2016). For example, Americans use the water quality standards designed by USEPA; while, European countries use the European health based water quality standards (USEPA, 2012; Liu *et al.*, 2014). However, most of the countries in Africa use the drinking water quality standards designed by WHO, even though some countries use their own drinking water standards designed based on the WHO standards. Accordingly, Ethiopia has its own water quality standards called “Ethiopian Health Based Water Quality Standards” designed based on the WHO



standards (EMH, 2011). However, the quality of most of the groundwater and surface water resources in the country have not yet been measured and characterized well. In fact, tropical lakes are known to have very essential significances for regional economies and biodiversity conservations (Branchu *et al.*, 2010). Some of the lakes in Ethiopia are also giving similar benefits. However, their productivity, ecology, physicochemical characteristics and their water levels are being affected by different factors. Some of the factors are climate change, overexploitation, geological processes, and some other limnological changes (Liu *et al.*, 2014; Olana, 2014). The area/formation where the lake water comes from is also one of the factors affecting the quality of some lakes, e.g. Lake Beseka (Shishaye, 2017). Therefore, water quality analysis/characterization and comparisons with the national and international standards are very crucial to design effective and long lasting surface water management strategies and increase productive uses of water bodies.

Similarly, Lake Adele provides incomparable economic benefits for the nearby communities (Belay, 2006). The nearby communities are using it as an irrigation water supply. Furthermore, it is also under use for water supply purposes, especially for animals. However, because of quality problems, the lake water is not being used for drinking (Belay, 2006). Nevertheless, the levels of the contaminants and other hydrochemical parameters are not exactly known, for there has been no hydrochemical analysis conducted within the lake water so far, even though its quality problem can be easily detected with the naked eyes.

The general objective of this research was, thus, to elucidate the physical properties and chemical compositions of Lake Adele water. More specifically, the research was aimed at identifying the hydro-geochemical composition and origin of the lake water, comparing the concentrations of the measured parameters with the local and universal standards, and determining the suitability of the lake water for different uses.

2. Material and Methods

2.1. Description of the Study Area

Lake Adele is located in Eastern Haraghe Zone, Oromia Regional State, Ethiopia. It has a length of about 3.2 kilometers and width of 1.15 km (measured from Google Earth). It is located at the latitude and longitude coordinates of 9.425833 and 41.950833, respectively. It is characterized by “Woina-Dega (Subtropical)” agro-climatic zone that receives a mean annual rainfall of 775.9 mm. The monthly rainfall in the site is greater than 100 mm from April to September, except in June, which is 48.4 mm. The wettest month is August, with a mean rainfall of 151.9 mm. The daily temperature of the site varies from 10 °C - 25 °C.

Lake Adele is one of the wintering areas for aquatic Palearctic wintering birds. Different wintering birds are commonly seen in the shallow parts of the lake. Lake Adele could thus be suitable for bird watching, for it is larger than

the other two lakes in the area, i.e., the now vanished Lake Haramaya and Lake Finkile (Fig. 1).

Physiographically, the lake watershed as a whole is part of the Harar Plateau areas, which is the upper part of Wabi Shebele Basin. Three major stratigraphic units including the Precambrian crystalline basement (mainly granite), Mesozoic sedimentary rocks (sandstone and limestone) and Quaternary sediments from old to young characterize it (Kebede, 2013). The Precambrian basement complex includes the high-grade metamorphic gneisses and migmatites, and the intrusive granites.

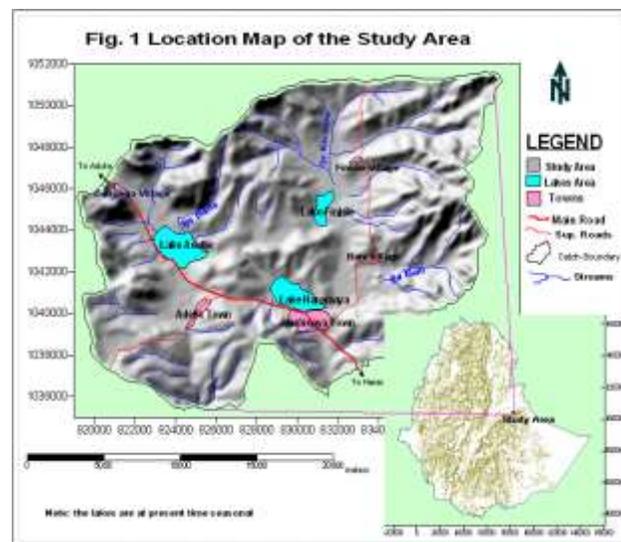


Figure 1. Adele - Haramaya Dry lakes Catchment, modified from Belay (2006)

2.2. Laboratory Measurements

2.2.1. Glassware and Instruments

Instruments like an electronic analytical balance with 0.001 sensitivity (AFP, ADAM), Polyethylene bottles, a mercury thermometer (0-100 °C), Digital (pH, conductivity and Temperature) meter (MAX Electronics, India), volumetric pipettes (1, 5 and 10 mL), burette (50 mL), measuring cylinder (10, 25 and 50 mL), micropipette (0–50 µL), borosilicate beakers (100, 250 mL), lab hot plate, volumetric flasks (50, 100, 250 and 1000 mL), Whatman filter paper (No. 42), fume hood, serological water bath (Bluefic), funnels, capped glass bottles (50 mL), flame atomic absorption spectrophotometer (210VGP, Buck scientific), flame photometer (JENWAY), and UV-Vis Spectrophotometer were used during the laboratory measurements of the lake water chemistry.

2.2.2. Chemicals and Reagents

HNO₃ (65–68%, High-tech Healthcare, India), H₂SO₄ (98.0%, High-tech Healthcare, India), HCl (35–38%, High-tech Healthcare, India), prepared stock standard solutions (1000 ppm), Disodium salt of EDTA (99.5%, BDH chemicals Ltd Poole England, AR), EBT (99.5%, Fluka, Switzerland), Na₂CO₃ anhydrous (99.9%, High-tech

Healthcare, India), CaCO_3 (99.5%, BDH chemicals Ltd Poole England, AR), AgNO_3 (99%, High-tech Healthcare, India), BaCl_2 (99%, Fluka, Switzerland), Isopropyl alcohol (High-tech Healthcare, India), Na_2SO_4 (High-tech Healthcare, India), glycerol (High-tech Healthcare, India) and distilled water were the chemicals and reagents used in this experiment.

2.2.3. Cleaning of Glassware and Apparatus

All the glassware and apparatus used in the entire analyses of all the parameters were washed with tap water and detergent, except in case of PO_4^{3-} in which chromic acid was used. Then, they were rinsed using distilled water and soaked with 10% (v/v) HNO_3 solution for 24 hrs. They were also rinsed with distilled water, and eventually air-dried. The containers used for sampling were also rinsed with sample water prior to actual sample collection (APHA, 1999).

2.2.4. Water Sampling, Preservation and Transportation

Representative water samples were collected by a grab sampling technique from the three different sampling sites within the lake (North, South, and Eastern sides) into 1 L capacity polyethylene bottles. Three bottles of the water samples were taken from each sampling site based on the types of parameters to be determined and their pretreatment requirements, in which case the first bottle was treated with 1.5 mL of conc. HNO_3 to $\text{pH} < 2$ for major and trace metal analysis and the second bottle was preserved for other physicochemical parameters at a temperature of 4 °C. The water samples were stored in an ice-box and transported later to the laboratory for analysis.

2.2.5. Preparation of Reagents

All reagents were prepared based on the procedures given in the Standard Methods; e.g., '4500-P E. Ascorbic Acid Method' for phosphate, '4500- NO_3^- B. Ultraviolet Spectrophotometric Screening Method' for nitrate, '4500-Cl⁻ B. Argentometric Method' for chloride, '2340 C. EDTA Titrimetric Method' for hardness, '4500- NO_2^- B. Colorimetric Method' for nitrite and '4500- NH_3 C. Titrimetric Method' for NH_3 , 'Section 2320 B. Titration Method for alkalinity (HCO_3^- alkalinity and CO_3^{2-} alkalinity) and '4500- SO_4^{2-} E. Turbidimetric Method' for SO_4^{2-} (APHA, 1999).

2.2.6. Preparation of Stock and Working Standard Solutions

The stock standard solutions of each of the metals of interest were prepared at the concentrations of 1000 mg L⁻¹. Accordingly, 1000 mg L⁻¹ solution was prepared for each parameter by dissolving 2.5 g CaCO_3 for Ca, 2.563 g $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ for Mg, 1.23 g AlCl_3 for Al, 1.75 g $\text{Fe}(\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ for Fe, 0.72 g KMnO_4 for Mn, 1.1 g $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ for Zn, 0.45 g $\text{CdCl}_2 \cdot 2\text{H}_2\text{O}$ for Cd, 0.4 g $\text{Pb}(\text{NO}_3)_2$ for Pb, 1.92 g $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ for Cr, 1 g $\text{Co}(\text{NO}_3)_2$ for Co, 1.23 g $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ for Ni, 0.635 g

NaCl dried at 140 °C for Na, 0.477 g KCl dried at 110 °C for K in 1 L distilled water and diluting to 250 mL in all cases.

Moreover, 1000 mg L⁻¹ solution was also prepared by dissolving 1.479 g Na_2SO_4 (anhydrous) in 1 L distilled water and diluting it to 1000 mL of the stock standard solution of SO_4^{2-} . For NO_3^- , 1000 mg L⁻¹ solution was prepared by dissolving 0.18045 g KNO_3 (dried at 105 °C for 24 h) in 1 L distilled water and diluting to 250 mL according to '4500- NO_3^- B.3b Ultraviolet Spectrophotometric Screening Method' of APHA (1999). For PO_4^{3-} , 1000 mg L⁻¹ solution was prepared by dissolving 1.097 g KH_2PO_4 in 1 L distilled water and diluting to 250 mL according to 'Section 4500-P.C.3e' of APHA (1999). For NO_2^- , 250 mg L⁻¹ solution was prepared by dissolving 0.308 g NaNO_2 in distilled water and diluting it to 250 mL according to '4500- NO_2^- B. Colorimetric Method' of APHA (1999). For F^- , 100 mg/L solution was prepared by dissolving 0.05525 g NaF in distilled water and diluting it to 250 mL according to '4500- F^- C Ion-Selective Electrode Method' of APHA (1999).

The working intermediate standard solutions, 100 mg/L for metals, 10 mg/L for PO_4^{3-} and F^- , and 50 mg/L for NO_3^- , NO_2^- and SO_4^{2-} were prepared by diluting 10 mL (metals, F^-), 1 mL (PO_4^{3-}), 20 mL (NO_2^-) and 5 mL (NO_3^- , SO_4^{2-}), respectively, of the respective individual stock standard solutions with distilled water to a 100 mL volume.

2.2.7. Calibration of the Standard Solutions

The instruments used in this analysis were calibrated using the calibration standard solutions with respect to the analyte concentrations. Standard solutions of each analyte of six points (including calibration blank for metals, PO_4^{3-} , NO_3^- , NO_2^-), five points (including calibration blank for SO_4^{2-}) and four points (for F^-) were prepared from their respective working intermediate standard solutions. These calibration standard concentrations were within the working linear range of the instrument used for analysis. Beginning with the blank and working toward the highest standard, the solutions were aspirated, the readings were recorded, and the linearity was checked with the linear regression of excel software 2007 and a visual inspection of the line. The prepared calibration standard solutions for each analytes are shown in Table 1.

2.2.8. Preparation of Blanks

A solution of distilled water and 2% (v/v) HNO_3 , distilled water treated with 1 mL of 8.3% (v/v) HCl , distilled water treated with 4 mL of ammonium molybdate solution and 0.5 mL of stannous chloride reagent, distilled water plus 5 mL of conditioning reagent (prepared from Isopropyl alcohol, Na_2SO_4 , NaCl , conc HCl and Glycerol) and distilled water plus 5 mL conc. H_2SO_4 were, respectively, used as calibration blanks for metals, NO_3^- , PO_4^{3-} , SO_4^{2-} and NO_2^- determination. Furthermore, a solution of 3 drops of Erichrome Black T (EBT) and distilled water, distilled water plus 3 drops of 0.1% methyl red indicator were used,

respectively, as a blank for the determination of hardness, alkalinity, chloride and ammonia in the sample.

Table 1. Prepared calibration standard solutions: blank (S₀), standard 1 (S₁), standard 2 (S₂), standard 3 (S₃), standard 4 (S₄), and standard 5 (S₅) for each analyte.

Analytes	Calibration Standard Solutions (mg/L)					
	S ₀	S ₁	S ₂	S ₃	S ₄	S ₅
Na	0	5	10	15	20	25
K	0	5	10	15	20	25
Mg	0	0.5	1	5	10	15
Ca	0	0.5	1	5	10	15
Fe	0	0.2	0.4	0.6	0.8	1.0
Zn	0	0.2	0.4	0.6	0.8	1.0
Mn	0	0.2	0.4	0.6	0.8	1.0
Al	0	0.5	1	5	10	15
Cd	0	0.2	0.4	0.6	0.8	1.0
Cr	0	0.2	0.4	0.6	0.8	1.0
Co	0	0.2	0.4	0.6	0.8	1.0
Pb	0	0.2	0.4	0.6	0.8	1.0
Ni	0	0.2	0.4	0.6	0.8	1.0
NO ₃ ⁻	0	2.5	5	10	15	20
PO ₄ ³⁻	0	0.4	0.8	1.2	1.6	2
NO ₂ ⁻	0	5	10	15	20	25
SO ₄ ²⁻	0	2.5	5	7.5	10	-
F ⁻	-	0.01	0.02	0.03	0.04	-

Note: The reason for the use of different calibration standard concentrations for the different species is the detection limit of the instrument used in this work.

2.2.9. Sample Analyses

Duplicate analyses were carried out on the samples for the determinations of the amounts of physicochemical (pH, EC, Turbidity, total hardness, Total alkalinity, Organic carbon, TDS, TS, Ca²⁺ hardness, Mg²⁺ hardness, HCO₃⁻ alkalinity, CO₃²⁻ alkalinity), the concentrations of major and trace metals (Na, K, Mg, Ca, Fe, Zn, Cu, Mn, Cd, Cr, Pb, Al, Co, Ni) and inorganic nonmetals (NO₃⁻, PO₄³⁻, NO₂⁻, SO₄²⁻, NH₃, F⁻, Cl⁻).

2.2.10. In situ Sample Analysis

Temperature: A mercury thermometer (0-100°C) was used to measure the temperature of the lake water. Readings were therefore made by immersing this instrument long enough into the water to allow complete equilibration (APHA, 1999).

Classical Methods of Analyses: The parameters including hardness (Ca²⁺ and Mg²⁺ hardness, EDTA Titrimetric Method 'Section 2340 C'), chloride (Argentometric Method 'Section 4500-Cl⁻ B'), alkalinity (HCO₃⁻ alkalinity and CO₃²⁻ alkalinity, 'Section 2320 B. Titration Method'), organic carbon (5310 B. High-Temperature Combustion Method), NH₃ (4500-NH₃ C. Titrimetric Method), and TDS (2540 C. TDS Dried at 180 °C Method) were determined following the procedures reported by APHA (1999).

Instrumental Methods of Analyses: pH was measured using a pH-meter according to '4500-H⁺ B. Electrometric Method' of APHA (1999). The pH-meter was calibrated, before measuring pH of the water samples, using a buffer solution of pH 4.0 and 7.0. In this case, the buffer solution was prepared by dissolving one buffer tablet in a 100 mL volume of distilled water.

Electrical Conductivity (EC) was also measured with a conductivity meter. The EC meter was calibrated using 0.01 M KCl solution according to manufacturer's instruction manual. Similarly, turbidity was also measured with turbidimeter. The turbidimeter was calibrated according to the procedures given in '2130 B. Nephelometric Method' of APHA (1999).

UV-Vis spectrophotometer was used for the determination of PO₄³⁻ (at 880 nm, 4500-P E. Ascorbic Acid Method), NO₂⁻ (at 543 nm, 4500-NO₂⁻ B. Colorimetric Method) and SO₄²⁻ (at 420 nm, 4500-SO₄²⁻ E. Turbidimetric Method). Determination of NO₃⁻ was made by UV absorption at 220 nm according to '4500-NO₃⁻ B. Ultraviolet Spectrophotometric Screening Method' of the standard method of APHA (1999) for which the measurement made at 275 nm was used to correct the NO₃⁻ value.

The major and trace metals were determined with flame atomic absorption spectrophotometer (FAAS). The FAAS was calibrated using a blank and five series of working standard solutions of each metal. Finally, Ion Selective Electrode Method was used for the determination of F⁻. The ion selective-meter was calibrated with four series of working standard solutions of fluoride according to 'section 4500-F⁻ C' of APHA (1999).

Software Packages: The software used in this paper was the GW_chart. This software was used to identify the origin and geochemical composition of water resources. Accordingly, the origin and geochemical composition of the lake water were identified using the piper diagram produced based on the laboratory measurements.

3. Results and Discussion

Physico-chemical Analysis: The mean values of the physicochemical parameters were obtained from duplicate analyses of the lake water samples and the results (mean ± SD) are given in Tables 2-4.

Temperature: Temperature is one of the essential parameters in water because of its influence on water chemistry. The rate of chemical reactions increases with the increase in water temperature (Shishaye and Nagari, 2016). Similarly, the average temperature value of Lake Adele water was found to be 23.6 °C, which is beyond the maximum recommended values for drinking purposes (15 °C). This is, therefore, an indicator of high chemical reactions within the lake water.

pH: The pH levels of the three samples taken from the lake were measured in duplicate and the average of

measurements was found to be 8.17, showing a slightly basic reaction. The mean pH value of the lake water is in fact within the allowable pH limits for drinking water quality, which is 6.5 - 8.5 (WHO, 2011). However, apparently, it is gradually getting closer to the maximum tolerable level.

Electrical Conductivity (EC): The mean EC value of the study area was found to be 1447.6 $\mu\text{S}/\text{cm}$, which is beyond the values given in the EPA guidelines for drinking and irrigation water quality (EPA, 2003). In general, the mean EC value measured in the area indicates that Lake Adele water is at its maximum level in terms of irrigation water quality whereas it cannot be used for drinking purposes, for it is beyond the maximum contaminant level of drinking water standards.

Total Dissolved Solids (TDS): The measured TDS levels in Lake Adele have a mean value of 990 mg/L. This is by far beyond the maximum contaminant limit, 500 mg/L (WHO, 2011). Thus, this maximum TDS level indicates that Lake Adele has palatability problems.

Total Alkalinity (TA): The TA values in this study were measured due to methyl orange alkalinity (pH 4.5), for the phenolphthalein alkalinity expected at pH 8.3 in all samples were zero. Therefore, the observed alkalinity was due to HCO_3^- . The TA value of the lake water was, thus, found to be 425 ± 7.07 mg/L, which is similar to the HCO_3^- alkalinity, and it is greater than the maximum permissible value for drinking water (Ethiopia, 2011). In this case, this high level of bicarbonate alkalinity could be the major controlling factor for the Ca and Mg ions concentrations in the lake water.

Total Hardness (TH): The mean value of TH of the lake water was found to be 205 mg/L, which is greater than the maximum drinking water quality standards (WHO, 2011). This shows that the water of the lake needs to be treated before using it for drinking purpose. TH is the sum effect of Ca^{2+} hardness and Mg^{2+} hardness. In this study, the mean values of Ca^{2+} and Mg^{2+} hardness were found to be 82 mg/L and 123 mg/L, respectively.

Turbidity: The mean value of turbidity of the lake water was found to be 43 NTU. According to WHO (1997), the median turbidity should be ideally below 1 NTU and turbidity in excess of 5 NTU is not recommended for drinking purposes. Accordingly, the mean turbidity value measured in Lake Adele was found to be beyond the maximum contaminant limit.

Organic carbon (OC): The mean value of organic carbon content in the lake water was found to be 333.34 mg/L. It indicates that the amount of organic molecules measured as carbon present in the water of the lake is high, which is

beyond the maximum contaminant standards set by EPA (2003).

Major Chemicals (Inorganic nonmetals)

The concentrations of inorganic nonmetals were also obtained from duplicate analyses of the samples and the results (mean \pm SD) are given in Table 3.

Sulphate (SO_4^{2-}): SO_4^{2-} is a major anion that could be found in natural waters. In water, SO_4^{2-} is expected to come from atmospheric deposition, industrial runoff, and natural sources such as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and anhydrite (CaSO_4) (Maiti, 2004; Saadeh, 2012). The mean level of SO_4^{2-} ion in this study was measured to be 0.19 mg/L, which is less than the taste threshold value, 250 mg/L (WHO, 2011).

Chloride (Cl): According to this study, the mean Cl⁻ concentration in the lake water was found to be 105 mg/L. It is a level which is by far below the maximum contaminant level, 250 mg/L (WHO, 2011).

Nitrate (NO_3^-): Nitrate concentrations in excess of 45 mg/L as NO_3^- or 10 mg/L as $\text{NO}_3\text{-N}$ could cause a disease called Methemoglobinemia (WHO, 2011). The average concentration of nitrate in the water source under consideration (measured as $\text{NO}_3\text{-N}$) was found to be 18.1 mg/L. The obtained result is above the maximum recommended value for drinking water supply, 10 mg $\text{NO}_3\text{-N}$ /L (WHO, 2011). This high level of nitrate in the lake could be due to the application of inorganic nitrogen fertilizers in the farms within the lake watershed.

Phosphate (PO_4^{3-}): The level of PO_4^{3-} in the study area was found to be 0.04 mg/L. In fact, there is no guideline that lists criteria for the acceptable phosphorus levels in drinking water quality (Nollet, 2007). However, the level of PO_4^{3-} in the lake water can be considered low.

Nitrite (NO_2^-): The NO_2^- concentration in Lake Adele was found to be 30.67 mg/L. According to WHO (1997), the presence of nitrite in water may mainly result from excessive application of fertilizers. This justification is also true in this study area. Farmers in the lake watershed produce crops through irrigation using water from the Lake, such as vegetables, maize, sorghum, (*Katha edulis* Forsk.) etc. In this connection, fertilizer applications to farm lands may have increased the concentration of nitrite ion in the lake water through runoff during rainy seasons. As far as the comparison of the NO_2^- concentration of the lake with the universal standards is concerned, it was found to be far beyond the maximum contaminant standard, 0.1 mg/L (WHO, 1997).

Fluoride (F⁻): The maximum contaminant limit of fluoride ion in water is 1.5 mg/L (WHO, 1997; EPA, 2001). The F⁻ concentration in the investigated lake water was found to be

1.89±0.15 mg/L, which is a little beyond the maximum contaminant standard. Therefore, the lake water is not recommended for drinking purposes, unless it is treated well to remove the high level of F.

Ammonia (NH₃): Similar to nitrite, the concentration of NH₃ in the investigated lake was found to be far beyond the maximum contaminant standards. According to EPA (2001), the recommended maximum permissible value of ammonia for drinking water is 0.5 mg/L. However, the average concentration of NH₃ in Lake Adele was found to be 301 mg/L. Therefore, the lake water needs treatment with regard to ammonia removal.

Major and Trace Metals: The concentrations of major and trace metals were obtained from duplicate analyses of the samples and the results (mean ± SD) are given in Table 4.

Sodium (Na⁺): The Na ion concentration in the study area was found to be 185.65 mg/L. Though the value is large, it was found to be below the maximum contaminant level, 200 mg/L (WHO, 2011).

Potassium (K): From this study, the average concentration of K was found to be 0.99±0.22 mg/L. Potassium tends to be "fixed" in soils and there are no implications of toxicity with regard to potassium (EPA, 2001).

Calcium (Ca): The mean concentration of Ca in the investigated water source was also measured to be 11.15±1.47 mg/L and it is below the recommended maximum value for drinking water, 40 mg/L (WHO, 2011).

Magnesium (Mg): The mean level of Mg in the lake under consideration was found to be 14.74 mg/L. This value is well below the Ethiopian Ministry of Health and WHO drinking water quality standard, which is 150 mg/L (EMH, 2011; WHO, 2011).

Aluminum (Al): The determined concentration of Al in Lake Adele is 5 mg/L. According to EPA (2001), the recommended limit for Al in drinking water is 200 µg/L or 0.2 mg/L. However, the mean value of the Al concentration in Lake Adele is far beyond the contaminant standards. Therefore, the lake water needs treatment to minimize the levels of Al to the standard.

Iron (Fe): The obtained mean concentration of Fe in the lake water was 0.27 mg/L. The recommended maximum value for drinking water is 0.3 mg/L (WHO, 2011). Therefore, in comparison to the local and universal standards, the level of Fe in Lake Adele was found to be below the maximum contaminant level, even though it is very close to the maximum standard.

Zinc (Zn): The Zn concentration in the lake under consideration was found to be 0.01mg/L. This is below the

maximum limits for the quality of drinking water (WHO, 2011).

Manganese (Mn): Mean concentration of Mn in the lake water was found to be below the method detection limit (ND). It is, therefore, below the maximum recommended limit set for drinking water quality (WHO, 2011).

Cadmium (Cd): The level of Cd in the lake water was also found to be below the method detection limit. Therefore, this can show us that the measured level is below the USEPA Primary Drinking Water Standard (2012) and the Canadian Drinking Water Quality (2003) for Cd, which is < 0.005 mg/L. Therefore, there is no problem concerning Cd in the lake water.

Chromium (Cr): The mean Cr concentration in the studied water body was found to be 0.05 mg/L. This level of Cr shows a concentration below the maximum permissible value recommended for domestic water supply purposes (WHO, 2011).

Lead (Pb): According to EPA (2001), the recommended limit for Pb in drinking water is 10 µg/L. However, the concentration of Pb in the investigated water body was found to be 0.07 mg/L, which is far beyond the maximum tolerable level for drinking.

Nickel (Ni): The concentration of Ni in the lake under consideration was found to be below the method detection limit (ND), which is below the recommended limit for Ni in drinking water, 20 µg/L (EPA, 2001).

Cobalt (Co): From this study, the mean concentration of Co was found to be 0.02 mg/L. Co is rarely found in natural waters; accordingly, there are few recommendations as to its limitations (EPA, 2001).

Origin and Geochemical Composition of Lake Adele:

The origin of lake water could either be precipitation or groundwater. An aquifer can yield water to the surface of the earth in the form of spring due to the naturally applied pressure and the geological discontinuities within the formation/groundwater storages underneath. The spring water can, therefore, be accumulated in a localized area of land and can be called a lake. In this case, the geochemical composition of lake water is associated with its origin (Shishaye & Nagari, 2016).

A piper diagram is a very important tool to identify the origin and geochemical composition of water bodies (Fig. 2). There are different software used to simulate the origin and geochemical composition of water resources, taking the ionic concentration values of the major cations and anions as model inputs.

In this paper, the origin and geochemical composition of Lake Adele were simulated using the GW-chart software. The levels of six ion groups, i.e. calcium, magnesium and sodium plus potassium cations; sulfate, chloride and

carbonate plus hydrogen carbonate anions and the TDS values were considered in the plot. Accordingly, the origin of Lake Adele water was found to be deep groundwater with a major geochemical composition of sodium bicarbonate, i.e., deep groundwater influenced by ion exchange (Fig 3).

In general, the simulated values of the origin and geochemical composition of the lake water were found to be in line with the laboratory results. i.e, according to the laboratory results, the alkalinity level of the lake water was found to be high and the observed alkalinity was due to HCO_3^- . The TA value of the lake water was also found to be as equal as the HCO_3^- alkalinity, 425 ± 7.07 mg/L, which is beyond the maximum permissible values designed for drinking purposes. Therefore, this result indicates that the lake water contains high bicarbonate values as it is also shown in the piper diagram below (Fig. 3). The high values of HCO_3^- alkalinity can also react with the hydrogen ions from water and raise the pH levels of the lake water, which can be clearly seen in the study area. The major controlling factors for the high levels of bicarbonate and other related ions could, therefore, be the regional geology and weathering processes.

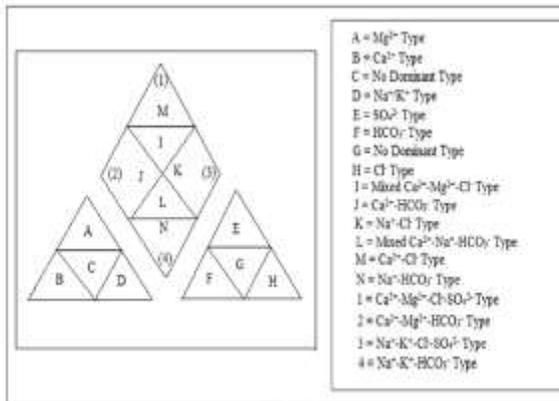


Figure 2. Reference trilinear diagram, modified from (Manoj *et al.*, 2013)

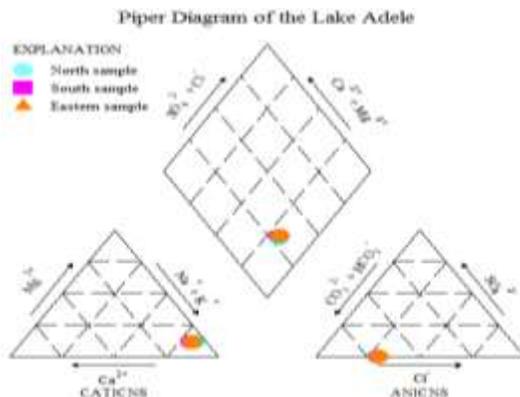


Figure 3. Piper Diagram of the Lake Adele

Suitability of the Lake Water for Irrigation: Irrigation water could either be from surface water or groundwater. However, regardless of the source, its quality needs to be within the international standards. Irrigation water quality can be determined through laboratory analysis and some analytical formulations. Some of the important factors used to determine irrigation water suitability are pH, salinity hazard, sodium hazard (Sodium Adsorption Ratio), and the percent sodium. The Lake Adele water was therefore analyzed for its suitability for irrigation purposes in terms of these factors.

Salinity and pH: In terms of salinity, Lake Adele was found to be very close to the maximum standard set by the WHO. The measured EC level was for example close to the maximum contaminant limit of salinity for irrigation purposes, $2000 \mu\text{S}/\text{cm}$ (Ayers and Westcot, 1994). Moreover, the pH level of the lake water was also found to be very close to the maximum standard for irrigation water, 8.5 (Ayers and Westcot, 1994). Therefore, using this lake water for irrigation purposes without any pre-treatment may cause a long-term problem of soil salinity and alkalinity.

Sodium Adsorption Ratio: As discussed above, sodium adsorption ratio (SAR) is also another factor used to evaluate irrigation water suitability. SAR can be calculated using the following formulae:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{(\text{Ca}^{2+} + \text{Mg}^{2+})}{2}}} \quad (1)$$

Where: Na^+ , Ca^{2+} and Mg^{2+} are in meq/L.

Accordingly, the SAR of the water in Lake Adele was calculated as:

$$\text{SAR} = \frac{16.9}{\sqrt{\frac{(0.56+1.23)}{2}}} = 18 \quad (2)$$

The result is showing that the SAR of the lake water is at its medium level of sodium hazard. A SAR value within the range of 10-18 may lead to amendments and leaching activities, for it has a medium level sodium hazard; while, $\text{SAR} > 18$ is not suitable for irrigation purposes (Ayers and Westcot, 1994). Therefore, Lake Adele is classified as unsuitable water for irrigation purposes. i.e., the lake water needs to be treated before being used for irrigation purposes.

However, farmers in the lake watershed are still using the lake water for agricultural purposes traditionally. Therefore, the concern of the use of this contaminated water for irrigation purposes is not only the decrease in productivity but also a long-term problem of soil salinity and sodicity, which will require additional investments for soil treatment.

Percent Sodium: Percent sodium (PS) is also another measure of water quality analysis for irrigation purposes. The equation used to calculate the percent sodium is:

$$PS = \frac{Na^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} * 100 \quad (3)$$

Where: Na^+ , Ca^{2+} , K^+ and Mg^{2+} are in meq/L.

The level of the PS of irrigation water should be less than 60 (Ayers and Westcot, 1994). However, the PS of the Lake Adele water was found to be **90.2%**, which is beyond the maximum recommended level for irrigation purposes. Therefore, Lake Adele also requires treatment to reduce the levels of PS, for it is not suitable in its current quality status.

Table 2. Mean \pm SD (in mg/L, °C, μ S/cm, NTU) values of physico-chemicals in the samples of Lake Adele Water in Eastern Ethiopia.

Parameter	T°	pH	EC	Turbidity	TH	Ca ²⁺ hardness	Mg ²⁺ hardness	TA	HCO ₃ ⁻ alkalinity	Organic carbon	TDS
Concentration	23.6°C	8.17 \pm 0.007	1477.6 \pm 0.00	43 \pm 4.24	205 \pm 7.1	82 \pm 2.83	123 \pm 4.24	425 \pm 7	425 \pm 7.1	333.34 \pm 9.4	990

Table 3. Mean \pm SD (in mg/L) values of major chemicals (inorganic nonmetals) in the samples.

Analytes	NO ₃ ⁻	NO ₂ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	Cl ⁻	F ⁻	NH ₃
Conc.	1.81 \pm 0.00001	30.67 \pm 1.89	0.04 \pm 0.003	0.19 \pm 0.02	105 \pm 3.54	1.89 \pm 0.15	301 \pm 9.9

Table 4. Mean \pm SD (in mg/L) values of major and trace metals in the samples.

Analyte	Na	K	Ca	Mg	Al	Fe	Zn	Mn	Cr	Co	Ni	Pb	Cd
Conc.	185.7 \pm 0.2	1 \pm 0.00	11.15 \pm 1.5	14.74 \pm 0.02	5 \pm 2.95	0.27 \pm 0.02	0.01 \pm 0.002	ND	0.05 \pm 0.006	0.02 \pm 0.003	ND	0.07 \pm 0.001	ND

4. Conclusion

This study has revealed that the origin of Lake Adele is deep groundwater with a major geochemical composition of sodium bicarbonate. The results of the hydro-chemical analyses demonstrated that the water of Lake Adele is contaminated by hazardous chemicals and rapidly deteriorating in quality making it dangerous to use for both domestic and irrigation purposes without treatment. This is because most of its key chemical constituents are beyond the tolerable limits of water quality standards as set by such international organizations such as the European Union, Australian Standards, WHO and USEPA. The levels of turbidity, nitrate (NO₃⁻), nitrite (NO₂⁻), ammonia (NH₃), and Lead (Pb) have been found to be too high to use the water for domestic purposes such as drinking and cooking. Salinity, pH, and Sodium Adsorption Ratio (SAR) of the water were also found to be beyond the tolerable levels of irrigation water quality standards. However, farmers in the study area have been intensely using the lake water for both drinking and irrigation purposes without any relevant treatment. This would predispose the farmers and other members of the community to the risk of health hazards due to direct consumption of the water as well as vegetables, khat, or other food produced through irrigation that contain too high levels of nitrate, nitrite, lead, and other heavy

metals. Therefore, policy makers and development agents need to create community awareness in the study area on the dangers of using the lake water for drinking as well as irrigation and make campaigns of sanitizing and treating it through judicious and sustainable utilization. Future research should focus on identifying sources of the contaminants to design a strategy for controlling them at their origins and promoting sustainable management of the Lake.

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