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*Original Research Paper*

# Hydrogeochemical analysis and evaluation of water quality in Lake Chala catchment area, Kenya

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**Lake Chala is a transboundary fresh water resource with no surface water inflow or outflow and is located in the southwestern part of Kenya on the Kenya-Tanzania border. The lake catchment area is bound by longitudes $37^0$ 41' E and $37^0$ 43' E and latitudes $3^0$ 18' S and $3^0$ 20' S. The Lake has a surface area of 4.2 $km^2$ and lies within a surface catchment area of about 16.23 $km^2$, which falls within a semiarid region frequently facing severe water scarcity especially during periods of prolonged drought. The major economic activities in this area are agriculture, horticulture and animal husbandry which account for about 75-80% of household income. Due to reliance on rain fed agriculture, water scarcity has often had negative impact on the people and there is need to tap the lake water for irrigation purposes. As such, water samples were collected on the Kenya and Tanzania sides from eleven (11) sites in March 2011 and subjected to analysis for chemical characteristics. Ten of the water samples show that the type of water that predominates in the study area is Ca-Mg-$HCO_3$ type, while one water sample from a shallow well is a Ca-Mg-chloride type based on hydro-chemical facies. The suitability of water for irrigation has been evaluated based on sodium percent; residual sodium carbonate, sodium adsorption ratio and salinity hazard and are therefore suitable for irrigation purposes.**

**Keywords:** Water quality, chemical characters, chemical classification, Lake Chala, Kenya.

## INTRODUCTION

Water in Kenya, like elsewhere in the world, is a crucial resource with great implications for economic development since the country relies heavily on agricultural production. However, with an increasing population and expanding industrial sector, demand for water is constantly rising and this poses the challenge of managing the meager available water resources in a sustainable way in order to meet the country's demand (Kithiia, 2012). Kenya is currently classified as a net water deficit country. It has been estimated that Kenya has 19,500 million $m^3$ of renewable surface water and 619 million $m^3$ ground water potential, while total annual demand is estimated to be 3,874 M $m^3$ in 2000 but expanding very rapidly (NEMA, 2003). Accessibility to potable water is relatively low in the country estimated at 45% with 33% in the rural areas. Low access to portable water resources is exacerbated by its poor distribution and variable quality of water sources due to perennial overdrafts and industrial pollution which is affecting the water quality.

The capacity for water resources to meet the various needs has been over-stressed and this has led to its scarcity. Various reasons can be advanced for this and they relate to population increase, climate change,

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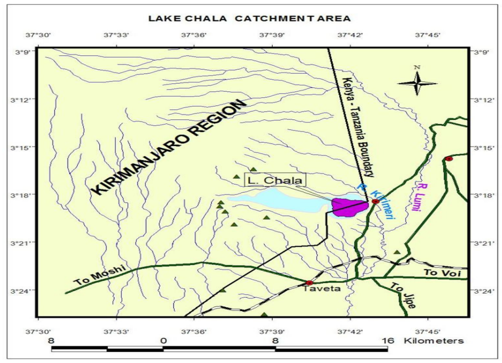


**Figure 1** Location of the study area within Lake Chala catchment

environmental degradation, weak and inadequate institutional capacities, and the growing poverty levels in the country. The rapid population increase has subjected the limited available water resources to a lot of pressure in efforts to meet the various needs. Climatic variability and change has also significantly altered the rainfall patterns and amounts, thereby affecting the replenishment rate of water bodies (Kithiia, 2012). These, coupled with wanton environmental degradation (especially in the main water catchments), changing land use patterns, wastage, misuse and pollution, the water problem has become even more critical. This is evidenced by the drying up of rivers, sedimentation and receding or dwindling lake levels (Ashley et al., 2004; Olaka et al., 2010), siltation of dams such that they cannot hold the expected capacities, and degradation of water qualities in many sources (UN-Water, 2007).

In view of the discussion in the preceding paragraphs, water quality analysis is one of the most important aspects in water studies. Hydro chemical analysis and subsequently water quality evaluation often reveals quality of water that is suitable for domestic consumption, agriculture and industrial purposes, as well as aiding in management of the water resource. Furthermore, it is possible to understand the change in water quality due to rockwater interaction or anthropogenic influence. Water often consists of seven major chemical ions which include cations $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$ and anions $Cl^{-}$, $HCO_3^{-}$ $SO_4^{2-}$. In addition, other ions include $Fe^{3+}$, $Pb^{2+}$, $Mn^{2+}$, $Cr^{2+}$, $Zn^{2+}$, $Cd^{2+}$, $NO_3^{-}$, $NO_2^{-}$, $Cl^{-}$, and $F^{-}$. Other parameters include pH, Colour, Turbidity, Free Carbon Dioxide and Total Dissolved Solid. These chemical parameters play a significant role in classifying and assessing water quality. Apart from $Pb^{2+}$, $Cr^{2+}$, $Zn^{2+}$ and $Cd^{2+}$, all the other ions and parameters were analyzed in water samples from Lake Chala and environs. Considering the individual and paired ionic concentration, certain indices are proposed to find out the alkali hazards. Residual sodium carbonate (RSC) can be used as a criterion for finding the suitability of irrigation waters. It was observed that the criteria used in the classification of waters for a particular purpose considering the individual concentration may not find its suitability for other purposes and better results can be obtained only by considering the combined chemistry of all the ions rather than individual or paired ionic characters (Handa, 1964, 1965; Hem, 1985). Chemical classification also throws light on the concentration of various predominant cations, anions and their interrelationships. A number of techniques and methods have been developed to interpret the chemical data.

Zaporozec (1972) has summarized the various modes of data representation and discussed their possible uses. Presentation of chemical analysis data in graphical form makes understanding of complex water resource systems simpler and quicker. Methods of representing the chemistry of water like Collin's bar diagram (Hem, 1985), radiating vectors (Maucha, 1949), and parallel and horizontal axes (Stiff, 1940) have been used in many parts of the world to show the proportion of ionic concentration in individual samples.

The main objective of the present work therefore is to study critically and discuss the major ion chemistry of surface and groundwater of Lake Chala and surrounding environs using methods proposed by Piper (1944), Wilcox (1948, 1955), Eaton (1950), Todd and Mays (2005), Fetter (2001) and Back and Hanshaw (1965) among others.

## The Study Area

Lake Chala catchment area is located in the southwestern part of Kenya between Longitude $37^0$ 30' 00" and $37^0$ 46' 30" East and Latitudes $3^0$ 9' 00" and $3^0$ 25' 30" South (Figure 1). The catchment area straddles Kenya and Tanzania and the lake is located about 9.65 km North of Taveta town. It forms a trans-boundary water resource which is shared between Kenya and Tanzania (Figures 1 and 2). The lake is a crater lake formed from a paroxysmal volcanic outburst (CPK 1955) and has a surface area of 4.2 $km^2$ within a surface catchment area of about 16.23 $km^2$. According to CPK (1955), the inner walls of the lake are inclined at an angle of approximately $45^0$ and the depth is estimated to be about 91.44 meters. The lake is enclosed by a ridge with a surface elevation of 952 meters above sea level (masl) while the elevation

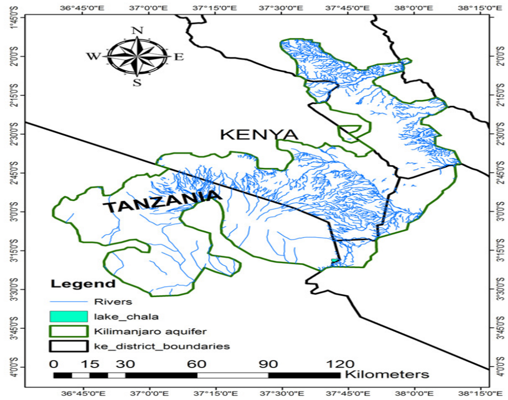


**Figure 2** Extent of Kilimanjaro aquifer across the Kenya-Tanzania border (Modified from Grossmann, 2008)

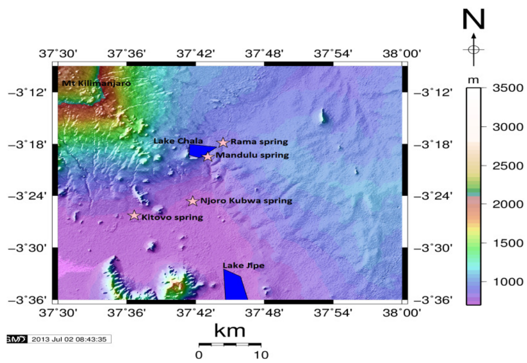


**Figure 3** Springs within Lake Chala catchment area

of the water level is 854 masl. This translates to a vertical descent of about 98 m from the ridge surface to the lake water level. The hydrogeology of Lake Chala catchment area is defined by the Kilimanjaro aquifer delineated by Grossmann (2008). The aquifer is comprised of volcanic pyroclastics and volcanic alluvium deposits, which occur at the base of Mt Kilimanjaro and extend across the Kenyan-Tanzanian border (Figure 2). These deposits form basins which extend outward from the mountain and are limited by the surrounding Precambrian basement rocks. Occurrence of groundwater in the surrounding basement plains is limited to faults, fractures and small parts of weathered zones and also to the bottom layers of wide alluvial valleys which are recharged by natural flood spreading (Grossmann, 2008). The basement rocks are an aquaclude for a large regional groundwater flow system emanating from Kilimanjaro, which extends into the volcanic alluvium at the base of the mountain and forms major aquifers. These basins are filled by alluvium deposits composed of sand, gravel and clay, with calcerous deposits, some lava and pyroclastic volcanic rocks (Grossmann, 2008). Water from the regional groundwater flow systems within the volcano reaches the aquifers and high yielding springs at the base of the mountain in two ways: by diffuse flow and by concentrated flow. Three major geological features determine the formation of springs for the Kilimanjaro aquifer, these include, in-fills of paleo-valleys, fault zones in fractured rocks, and lateral aquifers characterized by porous rocks or sedimentary materials (Mpanda and Yanda, 2001 c.f. Grossmann, 2008). However, aquifers of the first two types have a limited spatial extent, and springs emerge from them at isolated points. Lateral aquifers, on the other hand, are often extensive and are characterised by series of springs and swamps (Figure 3). Lake Chala is part of the extensive Kilimanjaro aquifer and although it does not have a visible inlet or outlet its recharge and discharge is strongly linked to the volcanic pyroclastics and volcanic alluvium deposits which allow percolation through the faults, fractures and weathered zones.

## METHODOLOGY

Eleven water samples were collected from Lake Chala, boreholes, shallow wells, springs and Lumi river, with two samples being collected from the lake on the Kenyan and Tanzanian sides as shown in Figure 4 and Table 1. The sampling was carried out in March 3, 2011 and the sample collection and chemical description was conducted in line with the field sampling procedure for

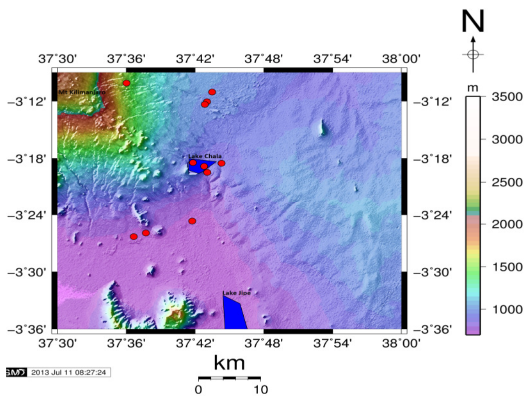


**Figure 4** Water sampling locations within Lake Chala catchment area

**Table 1** Water sampling locations and sample types from Lake Chala catchment area

| Longitude (East) | Latitude (South) | Location | Water sample type |
|---|---|---|---|
| 37.713042 | 3.313751 | Lake Chala (Kenya) | Lake |
| 37.696938 | 3.307386 | Lake Chala (Tanzania) | Lake |
| 37.724691 | 3.184299 | Njukini Primary School | Borehole |
| 37.714002 | 3.205722 | Bishop Njenga Secondary School | Borehole |
| 37.738646 | 3.308755 | Mutinda well | Shallow well |
| 37.628269 | 3.431884 | Reate well | Shallow well |
| 37.717570 | 3.324420 | Mandulu spring | Spring |
| 37.695960 | 3.410960 | Njoro Kubwa spring | Spring |
| 37.610664 | 3.438353 | Kitovo spring | Spring |
| 37.600170 | 3.168635 | Lumi river (Tanzania) | River |
| 37.717454 | 3.201204 | Lumi river (Kenya) | River |

Texas Water Development Board (Boghici, 2003). The water samples were collected using pre-cleaned plastic containers, which were first rinsed with distilled water. Samples for analysis of cations were filtered through a 0.45 µm filter. Each sampling bottle was then totally filled with the respective water sample and carefully closed tightly for dispatch to the central water testing laboratory of the Ministry of Water and Irrigation for analysis of chemical characters. Chemical analyses were carried out in order to determine the major ionic concentrations, outlined in the introductory section, of the water samples collected from different locations using the standard procedure recommended by American Public Health Association, APHA (1999). Such analytical data can be used for the classification of water for utilitarian purposes and for ascertaining various factors upon which the chemical characteristics of the water depend. pH, conductivity (Eh) and total alkalinity were determined at the time of sampling so as to avoid the effect of dissociation especially of carbon dioxide during the holding time that may cause analytical errors and thereby significantly affect the total alkalinity. In addition, since alkalinity is controlled by dissolution or degassing of carbon dioxide, this is likely to shift the source of alkalinity. Consequently, total alkalinity as $CaCO_3$ – bicarbonate test procedure and Phenolphthalein alkalinity as $CaCO_3$ – carbonate test procedure were used to measure alkalinity.

## RESULTS AND DISCUSSION

The maximum and minimum concentrations of the major ions present in water from Lake Chala and surrounding environs are presented in table 2. The Piper (1944) tri-linear diagram has been used to infer hydrogeochemical facies of the water in Lake Chala and surrounding environs. According to Fetter (2001), the trilinear diagram includes two triangles, one for plotting the percentage composition of the major cations and the other for plotting the percentage composition of the major anions. In these triangles, $Na^+$ and $K^+$ are grouped together while $CO_3^{2-}$ and $HCO^-$ are likewise grouped together. The cation and anion fields for each of the respective water samples are then combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of the hydro-chemical facies to describe water sources that differ in their chemical composition (Fetter, 2001) as well as to represent water-type categories (Back and Hanshaw, 1965) that form the basis for one common classification scheme for natural water. Evolution pathways or mixing of different sources of water can also be illustrated by this diagram. Consequently, piper tri-linear diagrams are useful in bringing out chemical

**Table 2** Maximum and minimum concentrations of major ions in water samples from Lake Chala catchment area

| Ions | Concentration (mg/l) | |
|---|---|---|
| | Minimum | Maximum |
| $Na^+$ | 5.5 | 109.0 |
| $K^+$ | 0.0 | 0.6 |
| $Ca^{2+}$ | 6.4 | 76.8 |
| $Mg^{2+}$ | 2.43 | 41.3 |
| $CO_3^{2-}$ | 0.0 | 282.0 |
| $HCO_3^-$ | 0.0 | 190.0 |
| $Cl^-$ | 3.0 | 205.0 |
| $SO_4^{2-}$ | 0.3 | 16.9 |
| Total hardness | 26.0 | 362.0 |
| Total Dissolved Solids (TDS) | 47.43 | 746.5 |

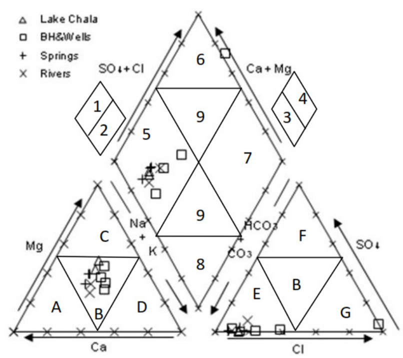


**Figure 5** Water sample compositions plotted on piper tri-linear diagram

relationships among water samples in more definite terms than with other possible plotting methods.

Chemical data of the water samples from the study area has been grouped into four groups and represented by plotting them on a Piper tri-linear diagram in Figure 5. The four groups include Lake Chala, Boreholes and Wells, Springs and Rivers. The regions delineated by letters in Figure 5 show the major-ion percentages as follows: A-Calcium type; B-No dominant ion type; C-Magnesium type; D-Sodium and potassium type; E-Bicarbonate type; F-Sulphate type; and G-Chloride type. Hence from figure 5, no cation is dominant in the water samples, while for anions, ten samples are of bicarbonate type and only one sample is of chloride type. The hydrochemical facies of the water samples from Lake Chala catchment area is deduced from the diamond shaped field of the piper tri-linear diagram (according to subdivisions suggested by Back and Hanshaw, 1965) where the various facies are classified on the basis of numbers 1-9 as follows: 1- Alkali earth metals (Ca+Mg) exceed alkali metals (Na+K); 2-Alkali metals exceed alkali earth metals; 3-Weak acids ($CO_3$+$HCO_3$) exceed strong acids ($SO_4$+Cl); 4-Strong acids exceed weak acids; 5-Magnesium bicarbonate type; 6-Calcium chloride type; 7-Sodium chloride type; 8-Sodium bicarbonate type; and 9-Mixed type where no cation-anion exceeds 50%. Upon this basis, the hydrochemical facies of ten water samples from Lake Chala catchment area is of calcium-magnesium bicarbonate type and only one sample is of calcium-magnesium chloride type. The calcium-magnesium chloride type water was from an open well which apparently has the highest concentrations of Ca (76.8 mg/l), Mg (41.3 mg/l), Na (109 mg/l), $CO_3$ (282 mg/l), Cl (205 mg/l), $SO_4$ (16.9 mg/l), total hardness (382 mg/l) and total dissolved solids (746.5 mg/l) in the study area.

The presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate causes hardness in water. Even though hard water is beneficial to health and has no known adverse effects, some evidence indicates its role in heart disease (Schroeder, 1960). Hard water is unsuitable for domestic use since it requires more soap for effective cleaning, forms scum and curd, causes yellowing of fabrics, toughens vegetables cooked in the water and forms scales in boilers, water heaters, pipes and cooking utensils. On the other hand, naturally too soft water may be corrosive. In Lake Chala catchment area, the total hardness varies between 26 to 362 mg/l. According to Adams (2001), the hardness of good quality water should not exceed 270 mg/l. In Lake Chala catchment area, the total hardness of water from the open well discussed in the preceding paragraph is the only one which exceeds the 270 mg/l threshold. According to the hardness classification by Sawyer and McCarty (1967), three samples fall under soft, hard and

**Table 3** Classification of water based on sodium percentage (After Wilcox, 1995)

| Sodium (%) | Water class |
|---|---|
| <20% | Excellent |
| 20 - 40 | Good |
| 40 - 60 | Permissible |
| 60 - 80 | Doubtful |
| >80 | Unsuitable |

**Table 4** Salinity hazard water quality classes based on electrical conductance (After Sadashivaiah et al. 2008)

| Salinity hazard class | EC (µS/cm) | Remark on quality |
|---|---|---|
| Class 1 | 100 – 250 | Excellent |
| Class 2 | 251 – 750 | Good |
| Class 3 | 751 – 2000 | Permissible |
| Class 4 | 2001 – 3000 | Doubtful |
| Class 5 | > 3000 | Unsuitable |

very hard classes, while eight samples fall under moderately hard class.

The suitability of water for irrigation purposes is dependent on its mineral constituents. Several criteria for judging its suitability have been proposed by Wilcox (1955), Eaton (1950). These criteria include (i) Total salt concentration as measured by electrical conductivity, (ii) Relative proportion of sodium as expressed by SAR to other principal cations, (iii) Bicarbonate, and (iv) Boron. According to Wilcox (1955), the United States Salinity Laboratory of the Department of Agriculture adopted certain techniques on the basis of which the suitability of water for agriculture is intended. The sodium content in irrigation waters is then expressed as percent sodium (also known as sodium percentage and soluble-sodium percentage) which can be determined using the equation by Todd and Mays (2005) as follows:- $\%Na = ((Na^+ + K^+)^* 100) / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$ where the concentrations of ionic species are in milliequivalents per liter (meq/l).

Wilcox (1955) has classified water meant for irrigation purpose on the basis of the percentage of sodium as shown in table 3. The sodium percentage in water from Lake Chala catchment area varies between 24.65% - 39.65%. From table 3, the water is hereby classified as good for irrigation purpose.

Residual Sodium Carbonate (RSC) is another factor which determines the suitability of water for irrigation purpose. RSC is attributed to increase in sodium carbonate in waters having high concentration of bicarbonate due to precipitation of calcium and magnesium salts as the water in soil becomes more concentrated in sodium carbonate. RSC is calculated using the equation: $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$ where the concentrations of ionic species are in milliequivalents per liter (meq/l). According to Wilcox (1955), water having more than 2.5 meq/l of RSC is unsuitable for irrigation purposes. The RSC of ten water samples from Lake Chala catchment area are less than zero varying between -2.72 and -0.09 where else one water sample from a shallow well has an RSC value of 1.91. Based on the RSC values, the sampled water sources in Lake Chala catchment area including Lake Chala are excellent for irrigation purposes and no hazard is likely since the negative RSC values from ten water sources indicates that sodium buildup is unlikely as sufficient calcium and magnesium are in excess of what can be precipitated as carbonates, with consequent removal of calcium and magnesium from the irrigation water leaving the sodium carbonate to accumulate.

The suitability of water for irrigation purposes can also be determined by the sodium hazard or Sodium Adsorption Ratio (SAR). SAR is calculated using the equation (Todd and Mays, 2005; Richards, 1954 c.f. Fetter, 2001) $SAR = Na^+ / ((Ca^{2+} + Mg^{2+})/2)^{½}$ where all ionic concentrations are expressed in milliequivalents per liter (meq/l). Wilcox (1955) has classified water for irrigation purposes with respect to SAR as excellent if SAR<10 and unsuitable if SAR>26. Intermediate range of SAR varies between 10 - <18 (good) and 18 - <26 (doubtful). Upon this basis, the SAR values of water in Lake Chala catchment varies between 0.5 (minimum) to 2.5 (maximum) and is therefore excellent for irrigation purposes.

Water may also be classified on the basis of specific conductance (EC) which is dependent on the total concentration of soluble salts or salinity hazard (Hoffman et al., 1980; Longenecker and Lyerly, 1974). The classification of water in Lake Chala catchment based on salinity hazard is shown in table 4. The water falls under three classes of salinity hazard. Two water samples from Lake Chala on the Kenyan and Tanzanian sides have EC values of 382 and 383 µS/cm. In addition, two samples from two boreholes, one sample from a well and two samples from two springs have EC values of 266 and 400 µS/cm, 577 µS/cm, and 235 and 394 µS/cm respectively. Two river samples and a further one spring sample have EC values of 76.5, 224 and 235 µS/cm respectively. Out of the eleven water samples, only one sample from a shallow well has an EC value of 1204 µS/cm. From the classification of water on the basis of salinity hazard in table 4, ten water sources fall under classes 1 and 2 and are therefore considered as good to excellent for irrigation purposes. Water sample from the shallow well where the EC value exceeds 1000 µS/cm falls under class 3 and is hereby considered as being of permissible quality for irrigation purposes.

## CONCLUSIONS

Based on the hydrochemical facies, the type of water that predominates in Lake Chala catchment area is Ca-Mg-$HCO_3$. One shallow well, however, has Ca-Mg-Cl type of water. The suitability of water for irrigation purposes has been determined in this study on the basis of %Na, RSC, SAR and salinity hazard. This, however, is an empirical conclusion since in addition to water quality, other factors like soil type, crop type, crop pattern, rainfall frequency, recharge and climate among others play an important role in determining the suitability of the water. Based on this classification, unsuitable water for irrigation purposes may be suitable if the soils are well drained. The suitability of water for irrigation in Lake Chala catchment area as evaluated based on %Na, RSC, SAR and salinity hazard is good with respect to %Na, excellent with respect to RSC and SAR values and, good to excellent with respect to salinity hazard, apart from only one water sample from a shallow well. The water is therefore suitable for irrigation purposes.

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