Quality of Water from Rift Valley Lakes of Ethiopia for Livestock Drinking

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Abstract: Water from five rift valley lakes (Awassa, Beseka, Chamo, Langano and Shala) of Ethiopia was sampled at the inlets, sites influenced by human activity and livestock drinking sites. Quality of water was evaluated based on physicochemical and microbiological properties, while suitability of the water for livestock drinking was evaluated by comparing the results with maximum levels which are safe if present in livestock drinking water. There was no difference in water quality parameters ($P>0.05$) among sampling sites but it varied among the lakes ($P<0.01$). Comparison of the measured parameters with guidelines shows that levels of magnesium, calcium, nitrate, nitrite and zinc in water of all lakes, temperature, alkalinity, salinity, potassium, chloride and bicarbonate in more than 80% of the samples (except Lake Shala) and pH and sodium in 60% of the samples were below the maximum permissible levels in livestock drinking water. Nevertheless, levels of iron, cadmium and total *coliform* count in all the samples, and chromium, copper and manganese in 93% of the samples were beyond the safe limits. Although consumption of water with relatively high concentrations of chemicals for short term may not affect animal performance, the high concentrations of toxic elements need due attention, since human health could be affected through residues in animal products. Based on this result, the lakes except Shala, can be considered safe drinking water sources for livestock. However, to make a concrete conclusion, it is necessary to undertake detail analysis of the lake water at different seasons including other quality parameters that are not included in the present study and to evaluate long term effects of drinking the water on different species, breeds and classes of livestock.

Keywords: *Livestock drinking water, Microbiological properties, Physicochemical properties, Rift valley lakes, Water quality*

Introduction

Water is a key factor in ensuring efficient animal production. As in most tropical countries, in Ethiopia, livestock generally use surface water from rivers and lakes to meet their water requirement (Engdasew, 2013; Kebede *et al*., 2013; Tenalem, 2005). Lakes are one of the water sources in the country, where majority of them (about 10 major lakes) are found in the main Ethiopian rift valley. However, climate change in terms of uncertain rainfall and increased temperature may reduce groundwater recharge and river flow, thus availability (Araujo *et al*., 2010; Rango *et al*., 2012). Due to the increased temperature, water level lowers due to evaporation and the ions become concentrated and deteriorate water quality (TDS, 2014; Kebede *et al*., 2013). The suitability of water for consumption depends on physicochemical and microbial properties (Gerard, 2016; Engdasew, 2013; Andrew, 2009; MAF, 2004). The quality of water is also influenced by geological features of an area or the anthropogenic activities in the vicinity of the water sources (Beede, 2012). For safe consumption, the composition of drinking water for livestock should be in accordance with relevant guidelines for drinking water quality. Even if literature is sparse, there are some reports available (Higgins *et al*., 2008; Beede, 2006; ANZECC and ARMCANZ, 2000) concerning the effects of quality on the acceptability of drinking water, animal performance and the risk of producing residues in animal products.

Availability of lake water in Ethiopia for livestock is of great importance, particularly when considering reduction in water table due to climate change and during dry seasons. However, there is relatively little information concerning water quality for livestock drinking (Kebede *et al*., 2013) but, lake water quality for livestock usage in Ethiopia has not been studied. The aim of this study was therefore, to determine quality of lake water in relation to livestock drinking based on physicochemical and microbiological parameters. The results of this study will provide information necessary for the development of appropriate management strategies to ensure improved drinking water quality for livestock.

Materials and Methods

Description of the Study Area

The study was conducted in five Ethiopian rift valley lakes including lakes Langano, Shala, Awassa, Chamo and Beseka (Fig. 1) that are known to be brackish or saline. Lake Shala and Beseka are salt lakes, while Langano, Awasa and Chamo are brackish water lakes (Mulugeta *et al*., 2016; Helmut and Worku, 2015). The rift valley experiences seasonal rainfalls and the

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seasonality sometimes causes great fluctuations in size, salinity, alkalinity and other chemical variables in the individual lakes (Rango *et al*., 2012). The locations of the studied lakes were recorded using GPS and presented in Table 1.

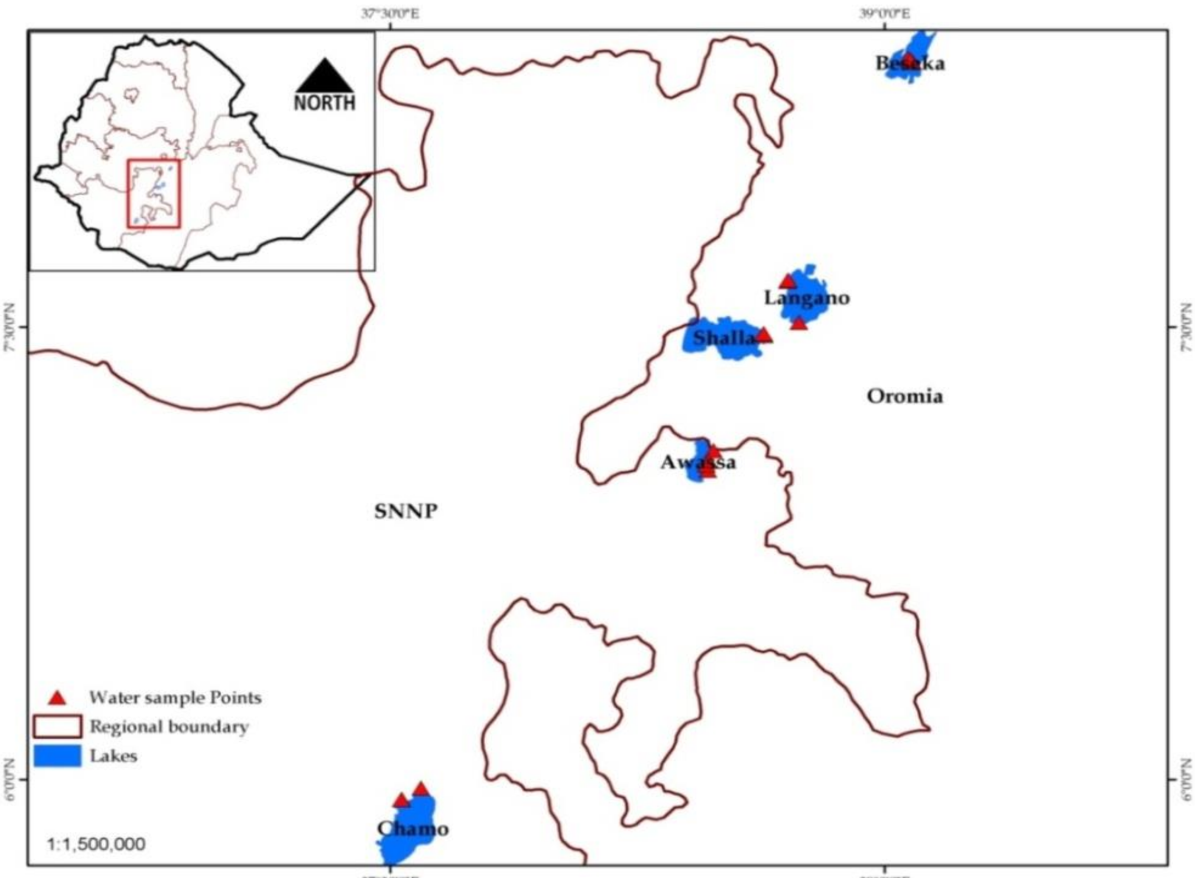

Figure 1. Map of the study area.

Water Sampling

Sampling sites were selected based on various uses and location. The first site represent inlet to the lake, the second one was a site influenced by human activity and the third one was used for livestock drinking. The number of samples collected from each sampling sites and lakes (Table 1) varied depending on accessibility of the sampling sites. Water samples were collected during November 2016 from the surface (at 0.5m) and at a 1m depth from three sampling sites of each lake using half liter clean plastic bottles. Surface samples were taken from all sampling sites in duplicate (as microbial quality is evaluated only from the surface samples) whereas samples at the 1m depth were taken only from sites influenced by human activity and livestock drinking sites.

Table 1. Geographical situations of points of sampling and number of samples (N) from the lakes

Lakes	Geographical locations			N in sampling sites			Total sample
	Altitude (m)	Longitude (N)	Latitude (E)	I	H	D	
Awassa	1685	038°46.924´	07°05.383´	1	4	2	7
Beseka	1585	038°71.787´	07°60.629´	1	3	3	7
Chamo	952	039°91.698´	08°89.233´	1	2	2	5
Langano	1110	037°55.423´	05°94.541´	1	2	2	5
Shala	1553	038°63.411´	07°47.490´	1	2	2	5

I= Inlets; H= Influenced by human activity; D= Livestock drinking sites.

Laboratory Analyses of Water Samples

The assessed parameters were selected based on their importance for health and palatability aspects of water for livestock use (Beede, 2012; Beede, 2006) where the selection was limited by available logistics and laboratory facilities. Laboratory analyses of the water samples were conducted following appropriate procedures (APHA, 1998) described in Table 2. Temperature, electrical conductivity (EC) and pH were measured immediately after samples were collected. Amounts of total dissolved solids (TDS) was calculated as EC*0.64 (Davis, 2016). Physicochemical parameters that include alkalinity, hardness, sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), nitrate (NO_3^-), nitrite (NO_2^-), iron (Fe), phosphate (PO_4^{3-}), chromium (Cr), cadmium (Cd), copper (Cu), manganese (Mn) and zinc (Zn) were determined at Haramaya University Chemistry Laboratory, while microbial quality was determined based on the total *coliform* count (TCC) at Hawassa University Dairy Laboratory.

Table 2. Methods used for determination of water quality parameters

Parameters	Methods
Temperature, electrical conductivity and pH	pH and conductivity meters
Turbidity	Nephelometric
Hardness, alkalinity, chloride and bicarbonate	Titration
Sodium and potassium	Flame atomic absorption
Nitrate, nitrite and phosphate	UV-Vis spectroscopy
Calcium	Atomic absorption
Magnesium, iron, cadmium, chromium, copper, manganese and zinc	Atomic absorption
Total *coliform*s	Most probable number (MPN)

The suitability of the water sources for livestock consumption was evaluated by comparing the results against guideline values of drinking water set for livestock (Davis, 2016; Socha *et al*., 2003; Higgins *et al*., 2008).

Statistical Analysis

Data were subjected to ANOVA considering lake, sampling site and their interaction (SAS, 2008). Means were separated by least significant difference (LSD) test when the F-test declare the existence of significance ($P<0.05$).

Results and Discussion

Quality of water was similar among the different sampling sites ($P>0.05$; Table 3) but, there were differences among the lakes ($P<0.01$; Table 4).

Physicochemical Properties of Lake Water

Physical properties: Physical parameters of water generally determine the suitability and palatability of water for livestock drinking (Araujo *et al*., 2010; Umar *et al*., 2014). Salinity is one of the physical properties of water that provides a measure of the total inorganic substances dissolved in water (Ontario, 2006). Lake Shala was the highest in water salinity followed by Lake Beseka. Comparable salinity values (mg TDS/l) of 1020 in Lakes Chamo (Zinabu *et al*., 2002) and 1411 in Langano (Tenalem, 2005) were reported. But in contrary, higher values of 904 in Lakes Awassa (Tenalem, 2005) and 4138 in Beseka (Megersa, 2017); and lower values of 778 in Lake Chamo (Tenalem, 2005) and 14564 in Shala (Zinabu *et al*., 2002) have been noted. Similarly, the pH values are comparable with previous study reports of 8.75 and 8.95 for Lakes Awassa and Langano (Ababu, 2005) and of 9.1, 8.9 and 9.6 for Lakes Beseka, Chamo and Shala (Tenalem, 2005).

Based on Engdasew (2013), Lakes Beseka, Chamo and Langano were categorized as brackish and slightly saline, while Lake Shala as saline and highly saline, respectively; and Lake Awassa as fresh water. Tenalem (2005) placed all the lakes in the same way as in the current study. Helmut and Worku (2015) also placed Lakes Beseka and Shala in a similar category, but Lake Awassa differently as brackish water lake. Hardness is expressed as the sum of calcium and magnesium and reported in equivalent amounts of calcium carbonate (MAF, 2004; Andrew, 2009). Lake Chamo is categorized as slightly hard based on EPA (2001); and this might be due to high levels of Ca and Mg ions as these ions are involved in hardness.

Livestock prefer drinking water at or below body temperature and they typically prefer water at temperatures between 16 and 18 °C (Higgins *et al*., 2008; Gerard, 2016). When the water temperature is above 25 °C, water consumption rises due to the initiation of sweating and increased respiration and above 30°C, they tend to drink more often (Davis, 2016). Comparison between the measured physical parameters with the maximum permissible levels in livestock drinking water (Table 4) revealed that the physical parameters in all lakes, except Lake Shala, were below the guidelines recommended for livestock. Salinity, alkalinity and pH of Lake Shala were above the limit recommended for livestock drinking water (Higgins *et al*., 2008; Davis, 2016). Consumption of water with excessive alkalinity and pH can cause poor feed conversion, and reduced water and feed intake (Andrew, 2009; Davis, 2016). Drinking saline water has been reported to reduce feed intake, increase water requirement, depress growth and affect body composition (MAF, 2004; Gerard, 2016). In accordance, because of high alkalinity, the use of Lake Shala for drinking purpose has been reported to be impossible (Mulugeta *et al*., 2016).

Chemical composition of lake water: Chemical composition of water is a quality indicator and refers to the ionic composition, excess nutrients, and toxic compounds present.

Ionic composition of lake water: Water contains many inorganic salts that are essential for animal health. Sodium ion is widely distributed in sources of water and commonly in association with sulphate or chloride ions (Marx and Jaikaran, 2007; Andrew, 2009) while Cl^- is present in small amounts in drinking water (Ontario, 2006).

Table 3. Effect of sampling sites on quality of lake water (mean)

Items	*P-values*	Values		Sampling sites			SEM
		Minimum	Maximum	I	H	D	
Physical properties							
Temperature, °C	0.180	23.1	29.0	26.5	25.0	25.7	0.311
Alkalinity, mg/l	0.982	210	5940	1481	1280	1366	369.3
Total hardness, mg/l	0.821	30.0	140	64.0	56.9	65.5	6.228
Turbidity, NTU	0.812	3.17	27.5	12.2	10.4	12.3	1.374
pH	0.805	8.21	9.62	8.83	8.84	8.95	0.086
Total dissolved solids, mg/l	0.953	458	15142	3989	3257	3833	981.7
Ionic composition							
Sodium, mg/l	0.973	103	1987	570	498	515	105.1
Potassium, mg/l	0.968	7.36	130	32.5	29.2	33.7	8.003
Magnesium, mg/l	0.791	0.06	14.1	5.35	6.44	4.71	1.117
Calcium, mg/l	0.783	1.30	7.10	4.98	4.78	4.35	0.340
Chloride, mg/l	0.960	24.9	1661	420	370	438	104.9
Bicarbonate, mg/l	0.931	10.0	1390	326	348	314	89.26
Excess nutrients							
Nitrate, mg/l	0.544	1.42	10.0	5.74	4.70	5.88	0.503
Nitrite, mg/l	0.114	1.57	7.86	5.70	3.87	3.88	0.333
Phosphate, mg/l	0.728	6.13	14.6	9.47	9.01	9.77	0.422
Iron, mg/l	0.950	3.00	10.0	5.82	5.74	6.02	0.383
Toxic compounds							
Cadmium, mg/l	0.969	0.320	1.80	0.832	0.797	0.84	0.078
Chromium, mg/l	0.452	0.800	3.20	1.60	1.97	1.91	0.102
Copper, mg/l	0.980	0.571	6.91	3.51	3.44	3.62	0.373
Manganese, mg/l	0.790	0.481	1.44	1.12	1.00	1.07	0.060
Zinc, mg/l	0.768	0.611	1.75	1.49	1.37	1.51	0.088
Microbial quality							
Total *coliform*, MPN/100 ml	0.115	7.00	240	19.2	96.1	37.5	16.18

I= Inlets; H= Influenced by human activity; D= Livestock drinking sites; SEM= Standard error of means.

The highest values of all ions, except Ca^{2+} and Mg^{2+}, were in water of Lake Shala; highest Ca^{2+} in waters of Lakes Awassa and Chamo; and Mg^{2+} in water of Lake Awassa. Variation among the lakes may arise from the influence of geological features, or anthropogenic activities (Beede, 2012). Comparable values (mg/l) of Na^+ in water of Lake Awassa (161) and Cl^- in water of Lake Chamo (111) but higher value of Mg^{2+} in waters of Lakes Langano and Shala (2.28 and 1.0) and higher K^+ and Ca^{2+} concentrations in waters of Lakes Awassa (37.2 and 8.4) and Chamo (21.8 and 27.4) have been reported earlier by Zinabu *et al.* (2002). The Na^+ in waters of Lakes Chamo and Beseka (265 and 480 mg/l), Ca^{2+} in waters of Lakes Awassa and Langano (7.0 and 4.5 mg/l) and Mg^{2+} in water of Lake Langano (2.0 mg/l) are comparable but values (mg/l) of Na^+ in waters of Lakes Awassa and Langano (225 and 390) and HCO_3^- values in waters of Lakes Awassa and Beseka (384 and 2074) are lower than the results reported by Tenalem (2005). The levels of K^+, Ca^{2+} and Mg^{2+} in water of Lake Beseka (82.2, 6.81 and 2.73 mg/l) indicated in Megersa (2017) were higher than those observed in the present finding.

Considering the ions, Mg^{2+} and Ca^{2+} concentrations of all the sampled waters, K^+, Cl^- and HCO_3^- of all waters except those sampled from Lake Shala and Na^+ of water sampled from Lakes Awassa and Langano were below the maximum permissible levels in drinking water of livestock (Table 4). Drinking water high in Na^+ may disturb acid-base balance and reduce water palatability that can decrease water intake (Andrew, 2009). Intake of high K^+ and Mg^{2+} in water is not a health concern (Ontario, 2006). However, very high level of Mg^{2+} may cause scouring and diarrhea, decrease feed intake and performance (ANZECC and ARMCANZ, 2000; Beede, 2006). Excess Ca^{2+} intake in drinking water is a potential risk of metabolic disorders, particularly in high producing animals and a risk associated with skeletal disorders have been reported (Andrew, 2009). Consumption of excess Cl^- for a prolonged period may decrease microbial population in ruminants leading to reduction in performance (Greg, 2014). In general, consumption of ions in water over acceptable levels may cause problems including toxicity, electrolyte and acid-base balance, and reduce water intake, feed intake and performance (Umar *et al.*, 2014).

Based on the ionic compositions, the present lakes were found to be a Na^+-Cl^--HCO_3^- type, like other findings (Tenalem, 2005; Shimelis, 2006). Concentrations of total inorganic ions dissolved in water and particularly alkali metals may contribute to salinity and alkalinity levels, respectively (Looper and Walder, 2002; Ontario, 2006; Andrew, 2009). Figure 2 shows that Lake Shala, which exhibited the highest salinity and alkalinity levels, has again the highest concentrations of Na^+, K^+, Cl^- and HCO_3^- while concentrations of Mg^{2+} and Ca^{2+} were lower.

Table 4. Results of lake water quality (mean, mg/l) and their comparison with guidelines

Items	*P-values*	Lakes					SEM	Guidelines[2]	Above guidelines (% from 29 samples)
		Awassa	Beseka	Chamo	Langano	Shala			
Temperature, ˚C	<0.001	24.0[c]	27.8[a]	24.6[c]	26.6[b]	25.2[bc]	0.25	27.0**	20
Alkalinity	<0.001	219[e]	774[b]	456[c]	377[d]	5590[a]	17.09	1000***	20
Total hardness	<0.001	59.2[b]	41.1[c]	126[a]	32.5[c]	62.5[b]	3.379		
pH	<0.001	8.36[d]	9.16[b]	8.92[c]	8.39[d]	9.58[a]	0.048	6.0-9.0***	40
Total dissolved solids	<0.001	513[d]	2214[b]	1004[c]	1139[c]	14941[a]	66.41	10000**	20
Sodium	<0.001	113[d]	453[b]	297[c]	201[cd]	1721[a]	40.36	300*	53
Potassium	<0.001	12.3[c]	15.5[b]	8.96[d]	10.3[c]	123[a]	0.527	20*	20
Magnesium	<0.001	13.1[a]	0.312[d]	11.5[b]	1.86[c]	0.101[d]	0.162	100*	0.0
Calcium	<0.001	5.80[a]	1.89[c]	6.27[a]	4.23[b]	4.58[b]	0.265	200*	0.0
Chloride	<0.001	30.2[e]	307[b]	108[d]	159[c]	1586[a]	10.05	300*	27
Bicarbonate	<0.001	27.5[c]	109[b]	102[b]	55.0c	1315[a]	12.71	1000*	20
Nitrate	<0.001	2.60[e]	5.53[c]	9.30[a]	3.24[d]	7.32[b]	0.29	44***	0.0
Nitrite	<0.001	2.29[b]	4.37[a]	5.69[a]	5.56[a]	5.17[a]	0.297	10***	0.0
Iron	<0.001	3.15[d]	6.05[b]	5.19[c]	9.12[a]	6.48[b]	0.216	1.0*	100
Cadmium	<0.001	0.470[d]	0.791[c]	0.473[d]	0.953[b]	1.54[a]	0.059	0.05**	100
Chromium	0.004	2.48[a]	1.80[b]	1.37[b]	1.80[b]	1.47[b]	0.163	1.0***	93
Copper	<0.001	1.08[e]	3.48[c]	1.96[d]	5.46[b]	6.35[a]	0.143	1.0***	93
Manganese	<0.001	0.516[b]	1.22[a]	1.24[a]	1.20[a]	1.23[a]	0.044	0.5*	93
Zinc	<0.001	0.619[d]	1.71[b]	1.74[a]	1.66[c]	1.70[b]	0.01	25*	0.0
Total *coliform* (MPN/100 ml)	0.912	52.25	70.4	89.3	87.7	44	46.28	5.0*	100

SEM= Standard error of means; [2], ** and *** = Socha et al., 2003, Higgins et al., 2008; and Davis, 2016, respectively.*

As evaporation is the only way for water outflows in terminal lakes (like Beseka and Shala), the resulted high concentrations of solutes elevate the salinity and alkalinity (Shimelis, 2006). The contribution of ions for salinity and alkalinity is further confirmed by a significant and positive correlation of Na^+, K^+, Cl^- and HCO_3^- and negative correlation of Ca^{2+} and Mg^{2+} with salinity and alkalinity (Table 5). The negative correlation of Ca^{2+} and Mg^{2+} with salinity and alkalinity could be due to the removal of these ions from solution under highly alkaline and saline conditions (Rango *et al.*, 2012).

Excess nutrients in lake water: Among nutrients that are found in water NO_3^-, NO_2^-, Fe and PO_4^{3-} were measured. Nitrate and NO_2^- are oxidized forms of nitrogen that occur in water (Ontario, 2006). Runoff are important contributors of phosphorus while iron may present as a result of anaerobic decay in sediments (EPA, 2001; Ontario, 2006). Though nutrients are important for animal, excess consumption of some nutrient may affect health and productivity (Greg, 2014). Both NO_3^- and NO_2^- can cause toxicity, but relatively high concentration of phosphorus and iron are not considered problematic (Jim, 2008; Beede, 2012). Concentration of iron above the aesthetic objective result in reducing water intake (Marx and Jaikaran, 2007; Andrew, 2009).

Toxic elements in lake water: among the metal elements that determine drinking water quality, Cd, Cr, Cu, Mn and Zn were measured in this study. Water of Lake Awassa recorded lower values of Cu, Mn, Zn and higher value of Cr. Concentrations of Zn in all water samples (Table 4) were below the maximum permissible levels in livestock drinking water; but the levels of Cd in all the collected samples, Cr, Cu and Mn in 93% of the samples were beyond the safe levels (Socha *et al.*, 2003; Higgins *et al.*, 2008; Davis, 2016). From these elements, levels of Cd, Cr and Cu cannot be exceeded the guideline values in safe drinking water, but Mn has only aesthetic effect (Andrew, 2009) where the taste of drinking water is generally considered offensive (Marx and Jaikaran, 2007). In fact, metal elements are not present in elevated concentrations in natural waters (Ontario, 2006) but higher concentrations might result from industrial processes around the lakes (ANZECC and ARMCANZ, 2000).

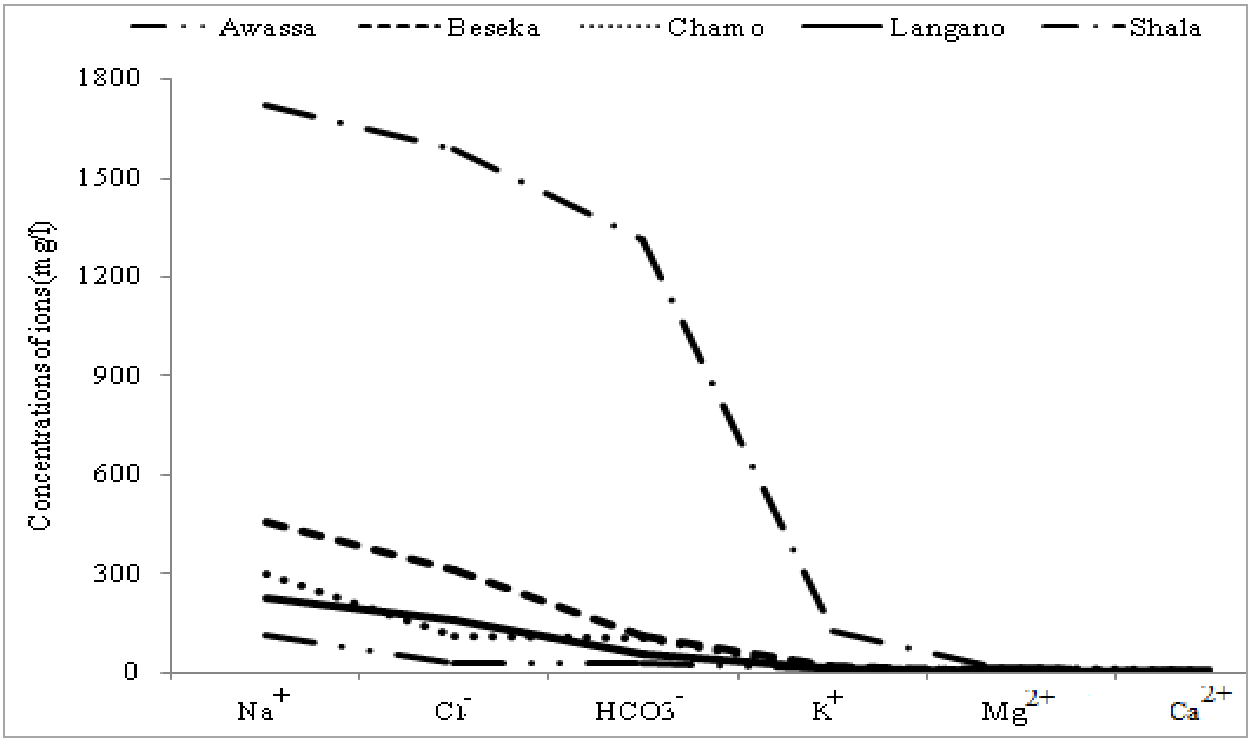

Figure 2. Major ions concentrations in the studied lakes.

Intake of toxic substances for short period of time may not cause any measurable effect on growth, production or reproduction, though it may increase susceptibility to disease (Marx and Jaikaran, 2007). In general, consumption of water with concentrations above the recommended ranges may have direct effects on performance and may have a risk to produce residues in animal products (Gerard, 2016).

Microbial Contamination in Lake Water

Microbial quality in drinking water is important as there are many pathogens that can be transmitted to livestock. The risk of contamination particularly in surface water is greatest as livestock have direct access (Umar *et al.*, 2014; Davis, 2016). Microorganisms of interest in drinking water include *Escherichia coli*, *streptococci* and algae (Looper and Waldner, 2002). The total *coliform* group is a large collection of different kinds of bacteria, which include fecal and other bacteria with similar properties. Their presence in water gives an indication of the general level of microbiological contamination (EPA, 2001). They are generally harmless however, under certain conditions; their populations can explode and may create problems for livestock (Gap water quality, 2013).

The total *coliform* count (TCC) was not affected by both sampling sites and lakes (P>0.05). The TCC in drinking water is indicated to be less than 5/100 ml (Socha *et al.*, 2003) and 100/100ml for livestock in general (Andrew, 2009). Accordingly, all the collected waters were beyond the safe limits suggested by Socha *et al.* (2003) but, based on the guideline of Andrew (2009), all the samples were safe. There is evidence that livestock can tolerate relatively high bacterial loadings in drinking water (MAF, 2004).

Table 5. Simple correlation matrix of water quality parameters (mg/l)

Parameters	EC	Alkalinity	Na^+	K^+	Cl^-	HCO_3^-	Mg^{2+}
Sodium (Na^+)	0.995**	0.995**					
Potassium (K^+)	0.997**	0.997**	0.99*				
Chloride (Cl^-)	0.998**	0.997**	0.997**	0.99**			
Bicarbonate (HCO_3^-)	0.998**	0.999**	0.991**	0.997**	0.99**		
Magnesium (Mg^{2+})	-0.53ns	-0.51ns	-0.55ns	-0.48ns	-0.57ns	-0.48ns	
Calcium (Ca^{2+})	-0.07ns	-0.05ns	-0.11ns	-0.02ns	-0.12ns	-0.02ns	0.8ns

EC= Electrical conductivity in µS/cm.= P<0.05; **= P<0.01; ***= P<0.001; and ns = Non-significant.*

Conclusion

Quality status of water of the rift valley lakes in Ethiopia for livestock consumption was assessed. Water quality parameters, except total *coliform* count, were different among lakes, but sampling site had no influence on water quality. Comparison with maximum levels recommended in drinking water for livestock shows that concentrations of Mg^{2+}, Ca^{2+}, NO_3^-, NO_2^-

and Zn in water of all the lakes were within the limits but alkalinity, pH, salinity, and concentrations of sodium, potassium, chloride and bicarbonate ions in Lake Shala were above the guideline values. While in all other lakes, except the levels of iron, heavy metals and total *coliform* count, most quality parameters were within the limits. Even for the parameters observed above the maximum tolerable values, intake for short term may not cause any measurable effect on growth, production or reproduction. Thus, the water from the lakes in general can be considered safe to livestock drinking. However, higher concentrations of cadmium, chromium and copper observed in lakes need due attention. Hence, it is necessary to identify potential sources of these contaminants through detail analysis of the water at different seasons. Besides, as information on effects of these compounds on livestock is not well documented and the effect on long term consumption is also lacking, it is necessary to undertake experiment to clearly define the effects of consumption (both short term and long term) of these water sources on different species, breeds and classes of livestock.

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Conflict of Interests

The authors declare that they have no competing interests.

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