

Effects of Solute Concentrations on Thermodynamic Properties of Lake Victoria Waters

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Abstract

Water helps support life processes and habitats of virtually all organisms. The rivers that flow into Lake Victoria harbor huge amount of solutes which affect its characteristic features and ecological equilibrium. This has affected the distribution of aquatic organisms and led to eutrophication and algal blooms and other invasive species such as water hyacinths. The present study focused on colligative properties (boiling point elevation, freezing point depression and vapor pressure deficit) of waters of Lake Victoria as key parameters in assessment of water quality. Water samples were obtained from five different sites along coastline of the Winam gulf and investigated of their solute properties. As control experiment, the effects of direct addition of selected cations sodium, potassium, calcium, zinc and lead on the samples from the five different sampling sites were also investigated. The samples were refrigerated and later heated for the purpose of determining the effect of salts on freezing point depression and boiling point elevation respectively. Temperature logging carried out using a digital thermometer throughout the experiments. The result obtained and subjected to Analysis of Variance revealed that cation concentrations had insignificant effect on vapor pressure deficit and other colligative properties of the waters. Maximum error barely exceeded 2% for the studied parameters was carried out to determine any significant differences. The results also indicated that cation concentrations were significantly different and direct addition of similar molar solute concentrations could significantly and differentially affect solute properties of the waters. These finding can support the production of policy formulation on management of waters of the lake.

Keywords: Lake Victoria, Boiling Point Elevation, Freezing Point Depression, Vapour Pressure Deficit

Introduction

Lake Victoria, the second largest freshwater lake in the world by surface area, is vulnerable to climate changes due to its great surface area, shallow depth and limited inflow from its inlets particularly Rivers Sondu Miriu, Nyando, Nzoia, Gucha and Kagera (Awange et al, 2013). The lake and its tributary rivers are a major biodiversity ecosystem, containing at least two hundred and thirty-four native fish species, one hundred and thirty-five native aquatic plant species, and fifty native freshwater mollusc species. Lake Victoria is a habitat of approximately five hundred fish species, most of which are haplochromine cichlids (Awange et al, 2013).

Lake Victoria is increasingly under threat from unsustainable land conversion and the intensification of agriculture. Studies have shown that land use has significantly impacted on freshwater biodiversity due to direct discharge of farm fertilizers and chemicals (So and Jn, 2016). There is also direct discharge of raw sewage into the waters and domestic and industrial wastes. The raw sewage increases eutrophication, which sustains the water hyacinth (Awange et al, 2013; Auchterlonie et al, 2021; Gophen, M, 2015; Mwita, 2014). High population growth is driving the expansion of agriculture, urbanization, and freshwater abstractions.

Lake Victoria is affected by a complex mixture of processes and driving factors including pollution and river inflows (Akurut et al, 2017). Seasonal variations also affect solute concentration of the water. Earlier research on its water quality indicates that pH, colour, turbidity, total suspended solids, biological oxygen demand, phosphate, nitrates and coliforms are significantly high ($p < 0.001$) in the wet season. In the dry season, temperature, electrical conductivity, total dissolved solids, heavy metals, chloride and ammonia are significantly high ($p < 0.001$). There is also high level of pollutants in wet season due to storm water run offs carrying a higher load of contaminants while in dry season it is likely due to the increased solubility of ions as a consequence of the elevated water temperature and low pH [2]. In this study, samples were collected during both dry and wet seasons.

Sediment quality is one good indicator of water column pollution where it tends to concentrate the heavy metals and other organic pollutants (Ustaoğlu & Tepe, 2019). The metals are effective pollutants and have drastic environmental impact on all organisms. They can get into food chains and in aquatic organisms to the level that affects their physiological state (Jiwan & Kalamdhad, 2011). Sediments have an impact on ecological quality and / or quantity. Hence, sediment monitoring can partially address the basic physiochemical properties of sediments and the geomorphological processes within a water system including the operating floodplains, wetlands and coastal zones (Schweizer, 2018).

Colligative properties particularly boiling point elevation (ΔT_b), freezing point depression (ΔT_f) and pressure deficit (ΔT_p) affect all chemical processes such as growth, reproduction, metabolism and mobility of organisms in an aquatic ecosystem (Williams et al, 2015). This implies that the organisms survive within a particular range of temperatures. Extreme fluctuations in temperature may compromise the tolerance ratio and ability of most organisms to survive (Férard & Blaise, 2013). Coral species, for example, live within a relatively narrow temperature range, and positive or negative temperature deviations of only a few degrees can induce bleaching (Camp et al, 2018; Hoegh-Guldberg, 1990). Increased water temperatures can promote the growth of harmful algal blooms, including toxic cyanobacteria. These blooms can release harmful toxins into water, posing risks to both aquatic organisms and human health. Changes in water

temperature can disrupt food chains and ecological interactions. Elevated temperature observed for Lake Victoria could partially and hypothetically result from increased air temperature, increased air moisture, decreased wind speeds, or decreased atmospheric pressure (Lehman, 1998).

The quality of water is also dependent on variations on its thermodynamic properties. This is because these properties affect several other parameters and can change the physical and chemical properties of water (Luoma, 1983; Rahbari et al, 2021). Hence, these properties (conductivity and salinity, oxidation reduction potential, pH, dissolved oxygen and other dissolved gas concentrations, metabolic rates and photosynthesis production, density and compound toxicity) must be factored in when determining water quality

Materials and Methods

Area of Study

Sampling was conducted at the shores of Lake Victoria from the Kenyan side. The sample sites were the river mouths of the rivers Kisiani, Nyamasaria, Sondu and Kibos pouring their waters into the lake.

Sampling

Purposeful sampling was done in Six (6) locations. The samples sites (locations) were marked along the river mouths of Sondu Miriu, Nyamasaria, Kisiani and Kibos. Three samples of 500ml of water were collected from every location from a depth of 5-10m deep and packed in plastic bottles. They were labeled from as S1 to S6, based on the sample site, and were stored in a refrigerator. Low concentrated Solutions of the lake water were prepared on a daily basis. All tests were conducted at Kenya Marine Fisheries and Research Institute(KEMFRI), Kisumu Branch adjacent to Lake Victoria. Freezing point (f.p)and boiling point (b.p) determinations were achieved through the use of A SAMSUNG refrigerator (Model SR-L727EV) and a HACH heater (Model 240vac). Temperature logging was done throughout the experiments by use og A HACH digital thermometer (Model 444500). Determination of the electrical conductivity (EC) and total dissolved solids (TDS) were achieved by use of WTW Multi-meter (Model Profiline 197i). Other data were accessed from the Kenya National Meteorological Department.

Water analyses

Water Analysis

5ml of conc. HNO_3 was added into 50ml of the water sample in a beaker and the solution slowly boiled in a hot plate until the volume reduced to 10-20 ml. The solution was filtered out into a 50ml volumetric flask, and the filter paper washed three times with deionised water. The mixture was diluted with distilled water to 50ml mark, and the resulting solution subjected to AAS (Atomic Absorption Spectrometry) analyses. All samples underwent the same treatment before being analyzed by AAS. Three standards were identified and used for calibration of the curve for analysis, for each element. pH readings were directly read after calibration of the pH meter.

Freezing Point Temperature

A Vernier computer interface had a Temperature Probe connected to it. For data collection, a file “17 Freezing Ocean Water” from the *Earth Science with Vernier* folder was opened in the computer. A 400 ml-beaker was $\frac{1}{3}$ filled with ice, and 100 ml of water added. 5 ml of fresh water was measured into a test tube. Using a utility clamp, the test tube was fastened to a ring stand above a water bath. The Probe was dipped into water inside the test tube. Data collection was done. The test tube was then lowered into the ice-water bath and 5 spoons of salt were added into the mixture with constant stirring. Continuously, the Probe was slightly moved out, but kept in, of the mixture in the first 10 minutes of data collection. After 10 minutes, the movement of the probe was completely stopped and mixture allowed to freeze to ice. Observations were made and recorded as the water froze. Data collection took 15 minutes. To determine the freezing temperature of fresh water, analysis was done on the flat part of the curve on the displayed graph.

Boiling Point Elevation

Apparatus for determination of b.p were assembled. The thermometer was set up in a manner that the temperatures above 100°C could easily be read. The thermometer was suspended in the middle of the liquid being heated to avoid direct contact with the bottom of the beaker above the burner flame. 100ml of the samples (S1 to S6) were separately and accurately measured and subjected to the same procedure. By use of a graduated cylinder, 100mL of distilled pure water was measured into a 250 beaker and gently heated to boil. As the water was boiling gently, its temperature was determined. After turning off flame, 100ml of S1 was slowly and carefully added into a 250ml beaker and then heated to a gentle boil. The b.p was determined and recorded. The procedure was repeated for the rest of the samples.

Vapor Pressure Deficit

A 125 ml suction flask was fitted with a rubber stopper with two holes. A pressure sensor was connected into one hole using plastic tube. Through the other hole, one end of a piece of straight glass tubing was connected with a Teflon stopcock. The outside diameter of the tubing was 8 mm and was fitted with a stopcock midway along its 30 cm length. The tubing was used to introduce the sample into the flask. A filter paper was placed in a dry flask to absorb the liquid and facilitate the achievement of equilibrium. After the rubber stopper was fitted tightly into the flask, stopcock was started. The side arm of the flask was connected to a house vacuum port, an aspirator and vacuum pump using a walled-rubber tubing. The flask was partially evacuated until the pressure sensor read nearly 10 kPa. The rubber tubing was closed with a pinch clamp. A flask was made to stand in a beaker containing ice and water acting as a constant temperature bath and allowed to stand for some time to come to thermal equilibrium. After attainment of constant temperature and pressure (the former at or near 0°C), the values were recorded. Approximately 2 ml of the liquid was transferred to the sample delivery –tube using a pipette. The liquid was introduced by opening the stopcock which was closed before the liquid level could drop below the stopcock. Air was allowed into the system. The pressure and corresponding temperature values were recorded after the former attained stability or became constant. The temperature of the water bath increased to about 10°C, and when the temperature and pressure stabilized, their values were read and recorded. The procedure was repeated at different temperature and pressure readings at roughly 20°C, 30°C, 40°C and 50°C. The apparatus was disassembled, the filter paper removed and the flask cleaned and dried. The apparatus was then ready for a

repeat trial on original liquid or for a series of measurements on a new sample. In processing data, it was realized that there was some air in the flask before the experiment was started. Consequently, the pressure that was read after introducing liquid sample was the sum of the pressure of the air originally present and the vapor pressure of the sample.

It was firstly assumed that the pressure of the air remains constant at all temperatures and was equal to the pressure measured at 0°C before the introduction of the unknown. The assumption and raw data assisted to determine the vapor pressure for each temperature at which a measurement was made. The data was recorded in a spreadsheet and a plot of vapor pressure versus absolute temperature was obtained using graphing program. The $\ln p$ and $1/T$ for each set of measurements was determined to enable in data analysis. These variables were plotted to examine the relationship specified in equation, fitting the data with the best straight line. The equation of the line yielded the slope, from which the heat of vaporization was determined. This also helped to calculate the temperature at which the vapor pressure equals 1 atmosphere (normal b.p). Knowledge on the properties of ideal gases was applied in calculating the pressure of the air at each temperature, and obtain more accurate values for vapor pressure. Using the results, a plot of P versus T and $\ln p$ vs. $1/T$ and the equation of the straight line determined, the heat of vaporization and the normal b.p were obtained.

Presentation Of Data

Data obtained from this research study were presented in the form of tables, graphs, equations phase diagrams and further subjected to statistical analysis.

Results and Discussion

P^H of the Samples

The P^H of water samples from five locations in the inner Winam gulf represented in the bar graph below (figure 1). The wet season was found to be acidic at 6.42 ± 0.11 exhibiting little variability, hence showing high stability. Similarly, the P^H values of the samples during the dry season had a mean of 6.53 ± 0.28 indicating slightly higher variability relative to that of the wet season.

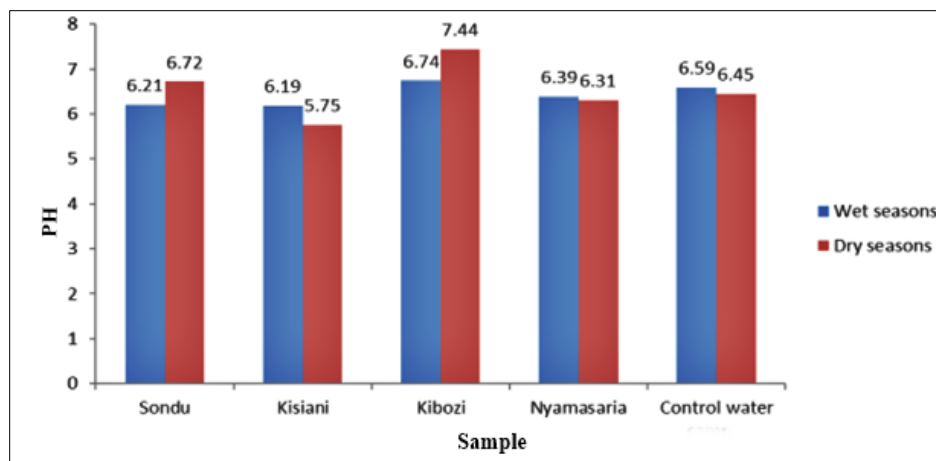


Figure 1: Bar graph of pH values

The P^H values during both seasons, ranged from 6.21 to 6.59. As indicated earlier, P^H influences solubility and toxicity heavy metals in the water. The majority of aquatic creatures prefer a pH range between 6.5 - 9.0, which is either slightly acidic or slightly alkaline, though few can survive outside of the range. However, during the dry season the water at Kisiani river mouth was more acidic as indicated by recorded minimum P^H value of 5.75 whereas the upper section was slightly alkaline with a mean P^H 7.44 (Table1).

Table 1: Descriptive statistics of cations for both wet and dry seasons

	N	Ran.	Min.	Max.	Mean		Std. Dev.	Var.
	Stat	Stat	Stat	Stat	Stat	Std. Error	Stat	Stat
Wet Season	5	0.550	6.190	6.740	6.42400	.107033	0.239332	0.057
Dry Season	5	1.690	5.750	7.440	6.53400	.276344	0.617924	0.382

Key: Ran. – Range; Std. Dev. Standard deviation; Var.- Variance; Stat- Statistics; Min.- Minimum; Max- Maximum;

Concentrations of Selected Cations in Samples

The cation concentrations of samples (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Zn^{2+} and Pb^{2+}) are recorded in Table 2. The results revealed that K^+ was the most dominant followed by Na^+ at all sampling locations during the wet season.

Table 2: Descriptive statistics of cations for wet season

	N	Ran.	Min.	Max.	Mean		Std. Dev.	Var.
	Stat	Stat.	Stat.	Stat.	Stat.	Std. Error	Stat.	Stat.
Na^+	5	148.000	28.0	176.000	86.40000	27.027370	60.435037	3652.394
K^+	5	1012.50	31.500	1044.000	266.50000	195.149894	436.368429	190417.41
Ca^{2+}	5	9.400	4.200	13.600	8.06600	2.076942	4.644182	21.568
Mg^{2+}	5	21.05	10.85	31.90	18.3800	3.77924	8.45064	71.413
zn^{2+}	5	21.25	2.25	23.50	9.5400	3.62772	8.11183	65.802
Pb^{2+}	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The concentrations of the remaining cations, Ca^{2+} , Mg^{2+} and Zn^{2+} were found to be relatively lower and varied from site to site. Pb^{2+} cation occurred at undetectable amounts at different sampling locations. The variability of the Na^+ , K^+ , Ca^{2+} , Mg^{2+} and Zn^{2+} cations was significant in all cases because it was greater than 30%. In this case, the most Na^+ was dominant, followed by K^+ in all sampling locations Table 3.

Table 3: Descriptive statistics of cations for dry season

	N	Ran.	Min.	Max.	Mean		Std. Dev.	Var.
	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Error	Stat.	Stat.
Na^+	5	145.05	15.200	160.250	60.1600	26.00995	58.16000	3382.59
K^+	5	105.800	6.200	112.000	49.18000	18.708912	41.834400	1750.117
Ca^{2+}	5	10.140	5.360	15.500	10.13200	1.705762	3.814200	14.548
Mg^{2+}	5	30.56	2.59	33.15	15.0880	5.23382	11.70317	136.964
zn^{2+}	5	21.46	0.04	21.50	8.7980	3.55661	7.95283	63.248
Pb^{2+}	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00

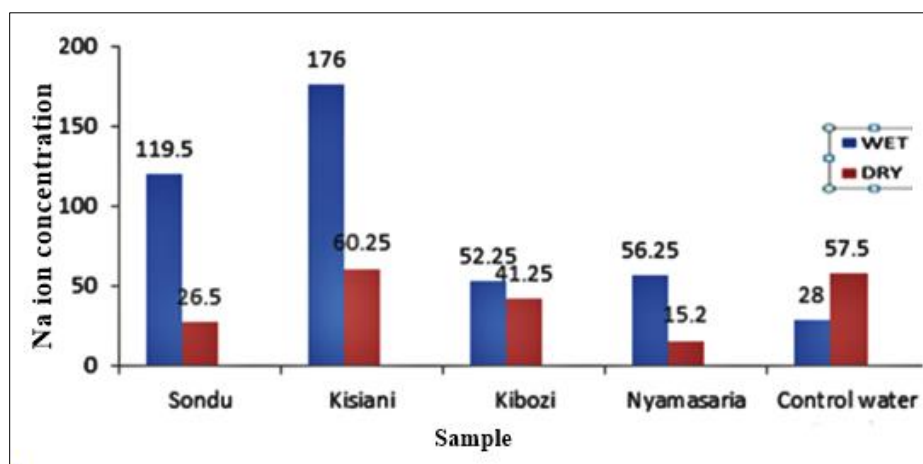


Figure 2: Sodium ions concentrations (ppm)

The results from figure 2 indicate that concentrations of sodium ions during the wet season range from 28ppm – 176ppm whereas, during the dry seasons the concentrations range from 15.2ppm – 60.25ppm. The range was higher during the wet season, 148, as compared to the dry season, 45.05. This difference could have been attributed to by various factors for instance, more of the metal ions dissolved and were washed into the lake, much of the fertilizers used by farmers in the highlands contained sodium ions as part of the ingredients and therefore, much of the ions must have been leached and washed to into the lake hence higher concentrations.

Conversely, during the dry season, less of the activities, particularly farming would have taken place hence lower amounts of the Na^+ ions concentrations were recorded in all the samples. On the contrary, during the

dry spell, all the samples from the different river mouths exhibited fewer amounts of Na^+ ions except from the control sample with 57.5ppm of Na^+ ions compared to 28ppm Na^+ ions during the wet season.

Similar results were detected in southwestern Nigeria where results show that only sodium ions ranged between 15.86 ± 2.290 for the dry and 21.10 ± 0.154 , this is in line with results from Lake Victoria since the dry season seemed to have had low concentrations.

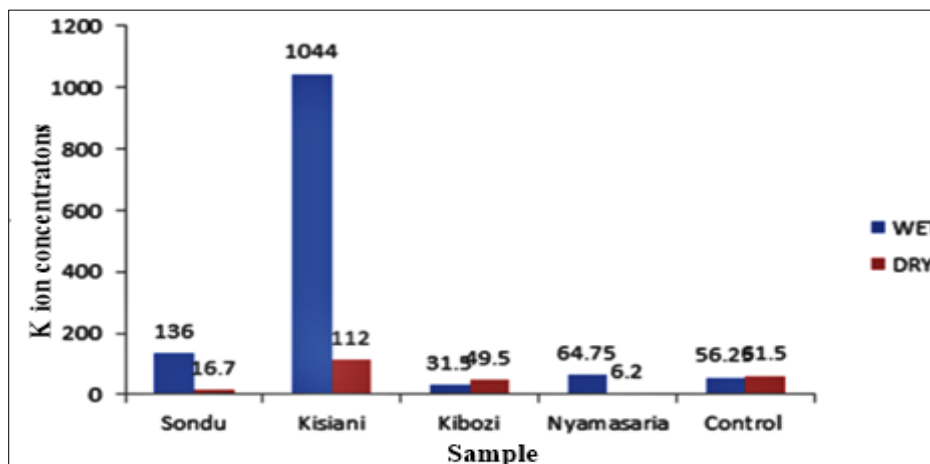


Figure 3: Potassium ions concentrations during wet and dry seasons (ppm).

Potassium ions concentrations of the water samples taken from different river mouths were higher during the wet season than during the dry season. Water sample from Kisiani river mouth exhibited highest concentration (1044ppm) while that from Kibos river mouth had the lowest concentration (31.5ppm). Water samples from Nyamasaria river- mouth exhibited the lowest amount of K^+ ions concentrations of 6.2ppm while water from Kisiani river mouth exhibited the highest K^+ ions concentrations of 112ppm during the dry season.

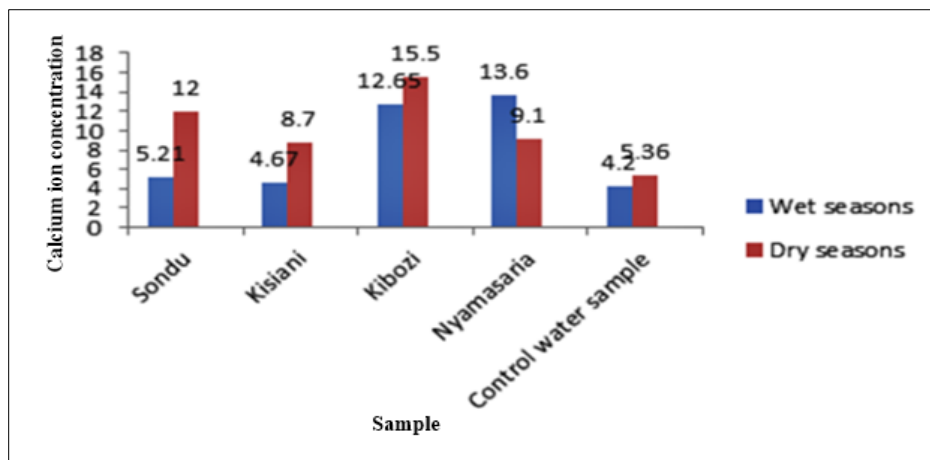


Figure 4: Calcium ions concentrations in wet and dry seasons (in ppm).

All samples displayed higher concentrations of Calcium ions during the dry season except for Nyamasaria with 9.1ppm as compared to 13.6ppm in the wet season. This is in agreement with Amoo and Komolafe, 2018 that did research in Nigeria and got 33.22mg/l. However, this was a little higher compared to these results despite it being high; this could be due to the difference in terrain and soil.

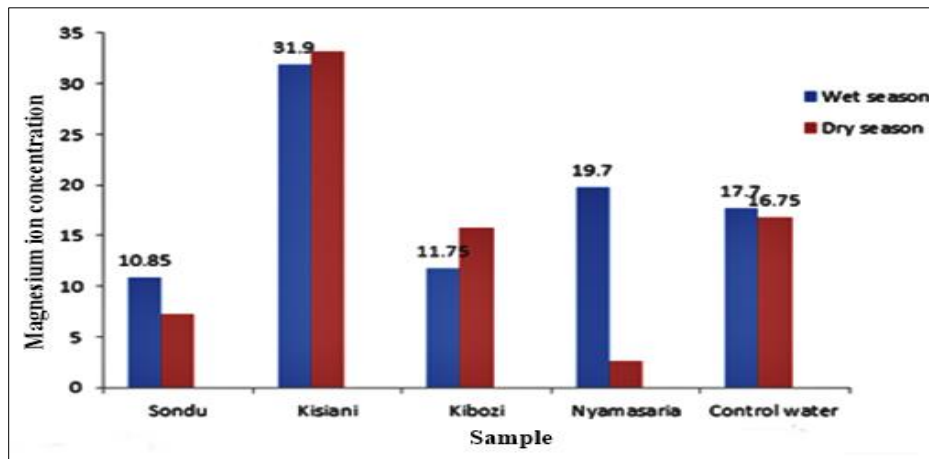


Figure 5: Magnesium ions concentrations in wet seasons and dry seasons (in ppm)

All samples displayed higher concentrations of magnesium ions during the wet season except for Kibos water sample with 11.7 ppm as compared to 15.75ppm in the dry season. Similar results were experienced in studies in North Nigeria where magnesium ions were detected in the range of 2.75mg/l which though low were found to be within the range found in this study.

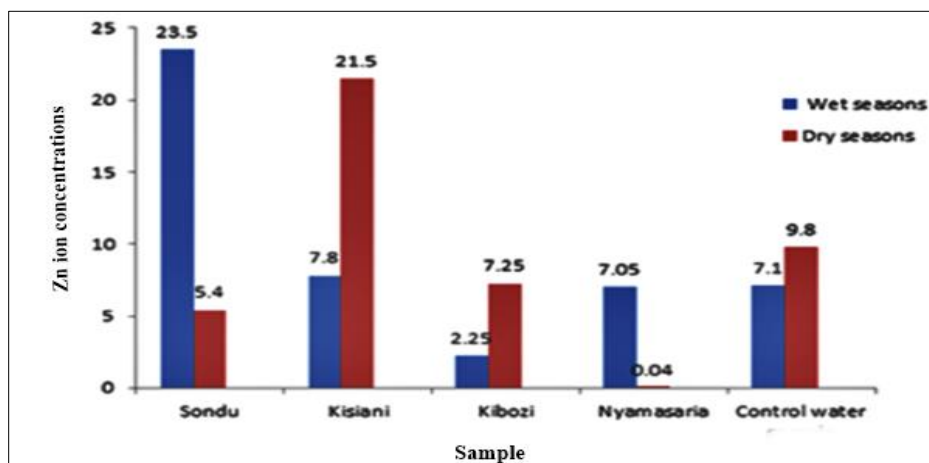


Figure 6: Zinc ions concentration (ppm) in wet and dry seasons.

Most samples displayed higher concentrations of Zn^{2+} ions during the dry season except for Sondu Miriu and Nyamasaria water samples with 5.4ppm and 0.04ppm as compared to 22.5ppm and 7.05ppm in the wet season respectively.

Boiling Point and Vapor Pressure

Table 4 presents the descriptive statistics for b.p (K) and VP (mmHg) particularly during the wet season. The results revealed that with introduction of sodium chloride in water, there is an elevation of b.p from 370K to 372K which was about 2K while, that of vapor pressure was elevated from 657.60 mmHg to 733.20 mmHg as shown in the results. The results on boiling point elevation could be as a result of introduction of the sodium chloride which upon dissolution of the salt causes molar coefficient of the water to increase therefore leading to increment of the b.p.

Table 4: Descriptive Statistics for b.p (K) and VP (mmHg) for the wet season

	N	Ran	Min	Max	Mean	Std. Error	Std. Dev	Var.
	Stat.	Stat.	Stat.	Stat.	Stat.		Stat.	Stat.
1	9	2.00	370.00	372.00	371.0000	0.23570	0.70711	.500
2	9	4.00	372.00	376.00	374.5556	0.37680	1.13039	1.278
3	9	75.60	657.60	733.20	704.7333	7.80621	23.41864	548.432
4	9	111.90	733.20	845.10	803.6667	10.50583	31.51750	993.352

Key: 1- BP before addition of NaCl(K); 2 - BP after addition of NaCl(K); 3 - VP before addition of NaCl(K); 4 - VP after addition of NaCl(K); Ran – Range; Min – Minimum; Max – maximum; Std. Dev – standard deviation; Var. – Variance; Stat. – Statistics

Similar studies from on the extremes of the Urmia Lake in Iran show showed that the b.p may undergo an elevation of about 5.1 °K in dry period and 2.7 °K in the wet season while the results from this study indicated an increment of about 2K in the wet season. This concurs with this results though results in the dry season don't match since the ones from Urmia lake indicate a higher elevation of about 5.1K compared to about 2K during the dry season, this could be due to the environment and the nature of the lake (Urmia is a salt Lake whereas Lake Victoria is a Fresh water lake (Kokyaet.al., 2011)).

According to Bromley *et.al.* 1970. The boiling point elevation calculated using:

$$\text{BPE} = AS^2 + BS$$

Where:

$$A = -4.584 \times 10^{-4} t^2 + 2.823 \times 10^{-1} t + 17.95$$

$$B = 1.536 \times 10^{-4} t^2 + 5.267 \times 10^{-1} t + 6.56$$

Validity: BPE in (K); $0 \leq t \leq 200$ °C; $0 \leq S \leq 0.12$ kg/kg

Accuracy: ± 0.018 K as it changes with temperature and salinity

From the above data calculation, the boiling point elevation increases with temperature and salinity. It has a maximum value of 3.6 K that concurs with these studies from Lake Victoria. The vapor pressure deficit upon addition of NaCl salt was 98.9334 from the result mean vapor pressures. This could be due to the addition of the different concentrations of salts, different terrains of sampling points based on disposal of their localities and economic activities. However, dissimilar results were experienced in Urmia Lake in Iran where the deficit was 21.22mmHg during the wet season whereas, the book or calculated value is 20.97mmHg, this could be due to the nature of the Lake Urmia being a Salt Lake therefore less economic activities. However, the extreme temperatures experienced could equally play a role in over saturating the water body.

Determination of Boiling Point During the Wet Season

The temperature, b.p and vapor pressure characteristics of water from different sampling sites are presented in table.5. In situ temperature ranged from 296K at Kibos river mouth to 297.5K at Sondu River mouth during the wet season, while it ranged from 295.5K atNyamasaria river mouth to298K at Kisiani river mouth. The differences are attributed to the different times of the day when the temperatures were measured at the different sampling sites. Table 5 presents the results for the determination of ΔT (K) (Boiling point elevation),during the wet season. After the water samples were subjected to and attained a room temperature of 296K, their b.p ranged from 370K at Nyamasaria river mouth to372KatKisiani river mouth against the control of 370K .Hence, there was a Maximum ΔT between the BP of the control and that of the water sample with highest BP. This is attributed by the amount of dissolved salts in different water samples.

Table 5: Determination of ΔT (K) (Boiling point elevation), during the wet season.

Sample	T0	$\frac{1}{T0}$	T1	$\frac{1}{T1}$	VP0	InP0	VP1	InP1
Distilled H2O	370	0.002710	372	0.002688	657.6	6.489	733.2	6.597
Sondu 1	371	0.002695	376	0.002660	707.3	6.561	845.1	6.739
2	371	0.002695	375	0.002667	707.3	6.561	815.9	6.704
Nyamasaria 1	371	0.002695	375	0.002667	707.3	6.525	815.9	6.704
2	370	0.002702	375	0.002667	682.1	6.597	815.9	6.704
Kibos 1	372	0.002688	374	0.002674	733.2	6.561	787.6	6.668
2	371	0.002695	375	0.002667	707.3	6.561	815.9	6.704
Kisiani 1	371	0.002695	374	0.002667	707.3	6.561	787.6	6.668
2	372	0.002688	375	0.002674	733.2	6.597	815.9	6.704

Key: T_0 -Normal Bp (K); $\frac{1}{T_0}$ - Normal Bp (K); T_1 - Bp (K) on addition of NaCl;

$\frac{1}{T_1}$ - Bp On addition NaCl; VP_0 - at Normal Bp (mmHg); InP_0 - at Normal Bp; VP_1 - Bp on addition of NaCl(P_1) (mmHg); InP_0 - at Bp on addition of NaCl.; 1 – Unfiltered; 2 – Filtered

Determination of Boiling Point during the Dry Season

Table 6: ΔT (BP elevation), (K), Determination during the dry season

Sample	T0	$\frac{1}{T0}$	T1	$\frac{1}{T1}$	VP0	InP0	VP1	InP1
Distilled H2O	371	0.002710	372	0.002688	707.3	6.489	733.2	6.597
Sondu 1	372	0.002695	377	0.002653	733.2	6.561	875.1	6.774
2	372	0.002695	375	0.002667	733.2	6.561	815.9	6.704
Nyamasaria 1	372	0.002695	376	0.0026595	733.2	6.525	845.1	6.740
2	372	0.002702	377	0.002653	733.2	6.597	875.1	6.704
Kibos 1	371	0.002688	376	0.0026595	707.3	6.561	845.1	6.740
2	372	0.002695	375	0.002667	733.2	6.561	815.9	6.704
Kisiani 1	372	0.002695	376	0.002667	733.2	6.561	845.1	6.740
2	372	0.002688	375	0.002667	733.2	6.597	845.1	6.740

Key: T_0 - Normal Bp (K); $\frac{1}{T_0}$ - Normal Bp (K); T_1 - Bp (K) on addition of NaCl;
 $\frac{1}{T_1}$ - Bp On addition NaCl; VP_0 - at Normal Bp (mmHg); InP_0 - at Normal Bp; VP_1 - Bp on addition of NaCl(P_1) (mmHg); InP_0 - at Bp on addition of NaCl.; 1 – Unfiltered; 2 – Filtered

After the water, samples were subjected to heat and attained a room temperature of 298K, their b.p ranged from 371K at Kibos river mouth to 372K at Kisiani, Nyamasaria and Sondu River mouths against the control of 371K. Hence, there was a Maximum ΔT between the BP of the control and that of the water sample with highest BP. This is could have been attributed to the number of dissolved salts in different water samples.

Temperature and Vapor Pressure Differences in the Wet Season

The temperature and vapor pressure value differences during the wet season are tabulated below (table 7).

Table 7: Temperature and vapor pressure differences during the wet season.

NO.	Sample	BP(K)	BP(K)(NaCl)	$\Delta T(K)$	VP(NaCl)(mmHg)	VP (mmHg)	$\Delta P(K)$
1	H2O (control)	370	371	1.0	657.6	733.2	75.6
2	Sondu 1	371	372	1.0	707.3	845.1	187.5
3	2	371	372	1.0	707.3	815.9	158.3
4	Nyamasaria 1	371	374	3.0	707.3	815.9	158.3
5	2	370	372	2.0	707.3	815.9	158.3
6	Kibos 1	371	372	1.0	682.1	786.6	129.9
7	2	371	372	1.0	707.3	786.6	129.9
8	Kisiani 1	371	372	1.0	707.3	815.9	158.3
9	2	371	372	1.0	707.3	815.9	158.3

Key: 1- Filtered; 2 –Unfiltered

The differences in ΔT and ΔP before and after addition of NaCl to water from different sampling sites are presented in the table 7 during the wet season. The majority of the sampling sites had ΔT of 1.0K while the samples from Nyamasaria river mouth had 3.0K and 2.0K respectively, for filtered and unfiltered water samples respectively. The observed differences after addition of NaCl were attributed to the chemical composition of water at different sampling points. The vapor pressure differences ΔP , before and after adding NaCl to water from different sampling sites (table 6) indicated that the lowest was 129.9mmHg from Kibos river mouth while the highest ΔP was 187.5mmHg from Sondu River mouth. The differences in vapor pressure were large and could reflect the differences of dissolved salt at different sampling sites. The

differences in temperature $\Delta T(K)$ and vapor pressure $\Delta P(\text{mmHg})$ before and after addition of NaCl to water from different sampling locations are recorded in table 8.

Table 8: Temperature and vapor pressure differences sites during the dry season.

NO.	Sample	BP0(K)	BP1(K)	$\Delta T(K)$	VP0	VP1	$\Delta P(K)$
1	H2O (control)	372	374	2.0	733.2	845.1	111.9
2	Sondu 1	376	378	2.0	845.1	887.3	42.2
3	2	375	378	4.0	815.1	860.1	45.0
4	Nyamasaria 1	375	377	2.0	815.9	859.3	33.4
5	2	375	376	1.0	787.6	860.1	72.5
6	Kibos 1	375	375	1.0	815.9	857.9	42.0
7	2	374	377	3.0	787.6	860.1	44.2
8	Kisiani 1	375	378	3.0	815.9	860.1	44.2
9	2	375	378	3.0	787.6	887.5	99.9

Key: BP₀-Before addition of NaCl; BP₁ - After addition of NaCl; VP₀ - Before addition of NaCl(mmHg); VP₁ - After addition of NaCl(mmHg)

The observed changes in temperature, $\Delta T(K)$ of water samples during the dry season had a wider range from 1- 4K compared to 1- 3K during the wet season. The changes in vapor pressure, ΔP during the wet season were much smaller than the dry season. They ranged from 33.4mmHg water sample for unfiltered Nyamasaria river mouth water to 99.9mmHg for unfiltered Kisiani river mouth water. These differences are attributed to the chemical composition of the water sample during the dry season.

Determination of Vapor Pressure Deficit (ΔP) During the Wet and Dry Season

The vapor pressure deficits after adding NaCl to water from different sampling sites are presented in table 9. The deficits are not the same in all sampling sites. The values were in the range of -2.45mmHg to -1.5mmHg. This variation was attributed to the chemical composition of the samples, especially in the wet season.

Determination of Vapor Pressure Deficit (ΔP) During the Wet Season

Table 9: Vapor pressure deficit (ΔP) determination for the samples during the wet season.

Sample Name	BP(K)	VP0	VP1	$\Delta P = P_{H_2O} - P_{H_2O}$
Control (H2O)	369	637.60	635.70	-1.95
Sondu 1	371	760.00	757.70	-2.30
2	370	815.90	813.50	-2.45
Nyamasaria 1	371	815.90	813.50	-2.40
2	370	760.00	757.70	-2.30
Kibos 1	372	733.20	731.00	-2.20
2	371	707.30	705.20	-2.10
Kisiani 1	371	760.00	757.70	-2.30
2	371	733.20	731.70	-1.50

Key: VP₀- Vapor pressure of Normal H₂O (mmHg); VP₁-Vapor pressure of H₂O over NaCl (aq)

Table 10 presents the descriptive statistics analysis of ΔP , for the samples from different sampling sites during the wet season and their b.p before and after addition of NaCl.

Table 10: Descriptive statistics of vapor deficit (ΔP) of the sample during the wet season

	N	Range	Min	Max	Mean		Std. Dev.	Var.
	Stat.	Stat.	Stat.	Stat.	Stat.	Std.Error	Stat.	Stat.
VP0(mmHg)	9	3.00	369.00	372.00	370.6667	.28868	.86603	.750
VP1(mmHg)	9	178.30	637.60	815.90	747.0111	18.22954	54.68861	2990.844
BP(K)	9	177.80	635.70	813.50	744.8556	18.17034	54.51101	2971.450
$\Delta P = VP_1 - VP_0$	9	0.95	-2.45	-1.50	-2.1667	0.09754	.29262	0.086

Key: VP₀-Vapor pressure sample before addition of NaCl (aq); VP₁-Vapor pressure of sample after addition of NaCl (aq)

Determination of vapor pressure deficit (ΔP) during the dry season

The vapor pressure deficit(ΔP) before and after adding NaCl to the samples obtained during the dry season are recorded in table 10. Vapor pressure deficit (ΔP); range from -3.4 mmHg from Kibos river mouth to -2.3mmHg for Sondu river mouth. There is a slight difference between the vapor pressure deficit of the wet and dry season as reflected in tables 9 and 10 respectively. The variations are attributed to the chemical composition of the different samples and the various catchment areas.

Table 11: Vapor pressure deficit (ΔP) determination of the different samples during the dry season.

Sample Name	BP(K)	VP0	VP1	$\Delta P = VP_1 - VP_0$
Control (H ₂ O)	372	733.2	731.0	-2.2
Sondu;	1	374	787.6	-2.4
	2	373	760.0	-2.3
Nyamasaria	1	374	787.6	-2.4
	2	373	760.0	-2.3
Kibos;	1	385	1094.1	-3.4
	2	372	787.6	-2.4
Kisiani;	1	374	787.6	-2.4
	2	375	815.9	-2.5

Table12 shows the descriptive statistics of vapor pressure deficit (ΔP) determination of the different samples during the dry season and their b.p before and after addition of NaCl. Vapor pressure deficits (ΔP) had a range of 1.20mmHg with minimum and maximum deficits being -3.40 and -2.20mmHg respectively. Unfiltered water sample from Kibos river mouth recorded the lowest VP deficit while the control water sample recorded the highest deficit. The differences in vapor pressure deficits (ΔP), of water samples from

the different sites are attributed to the chemical composition of the samples and the season with which they were collected.

Table 12: Descriptive statistics on Vapor pressure deficit (ΔP) during the dry season

	N	Rang	Min.	Max.	Mean		Std. Dev.	Var.
	Stat	Stat	Stat	Stat	Stat	Std..Error	Stat	Stat
BP (K)	9	13.00	372.0	385.0	374.667	1.333	4.00000	16.000
VPO(mmHg)	9	360.9	733.2	1094.1	812.622	36.053	108.1614	11698.8
VP1(mmHg)	9	359.70	731.00	1090.70	810.1444	35.93505	107.80515	11621.9
$\Delta P = VP1 - VPO$	9	1.20	-3.40	-2.20	-2.4778	0.11876	0.35629	0.127

From the results in table 12 above it is evident that the mole fraction of the Lake Victoria waters is less than the mole fraction of pure water. Further, the vapor pressures of the samples indicated significant deviation at the same b.p with respect to distilled water i.e

$$\Delta P_{\text{solvent}} = P_{\text{solvent}} - P^{\circ}_{\text{solvent}} = VP_1 - VP_0$$

$$\text{Where, } P_{\text{solvent}} < P^{\circ}_{\text{solvent}},$$

$$\Delta P_{\text{solvent}} \text{ is negative}$$

Hence, vapor pressure deficit is proportional to the mole fraction of solute.

Determination of Freezing Point Depression, ΔT_f (K)

The freezing points before and after addition of NaCl and the ΔT_f for the different samples collected from different sites during the wet season are presented in table 13. An unfiltered water sample from Sondu River mouth, registered the lowest f.p of 269.5K. Whereas water samples from Nyamasaria, Kibos and Kisiani river mouths registered a similar f.p of 272K before the addition of NaCl. On addition of NaCl to the water samples, the f.p decreased. The f.p of filtered water sample from Kisiani river mouth, exhibited the lowest f.p of 265K, while the rest posted a narrow variation in the ΔT_f . Water samples from Nyamasaria and Kibos posted a similar f.p of 268K (Table13). This was the highest f.p registered. The ΔT_f (K) ranged from -3K to -7K during the wet season. The variation in ΔT_f values was attributed to the different chemical compositions of the samples and the seasons when they were collected.

Table 13: Determination of ΔT_f (K) during the wet season.

Sample site		F0.	F1.	ΔT_{fp} (K)
Distilled H2O		271	268	-3.0
Sondu	1	270	266	-4.0
	2	269.5	265.5	-4.0
Nyamasaria,	1	272	267	-5.0
	2	272	268	-4.0
Kibos	1	272	267	-5.0
	2	272	268	-4.0
Kisiani	1	272	265	-7.0
	2	272	266	-6.0

Key: 1. Unfiltered; 2. Filtered; F₀. Freezing point before addition of NaCl, F₁. Freezing point after addition of NaCl

Table 13 presents the freezing points before and after addition of NaCl to water samples obtained from selected river mouths during the dry season. Filtered water samples from Kisiani river mouth exhibited the lowest freezing point of 263.5K. Unfiltered water samples from Sondu and Nyamasaria river mouth exhibited a similar freezing point of 269.5K (Table13) before addition of NaCl. After the addition of NaCl, the freezing points of all the water samples decreased, with data ranging from -4.5 to -8.0K therefore, there was a slight difference in the ΔT_f of the water samples between the wet and the dry seasons.

Determination of freezing point depression $\Delta T_f(K)$ during the wet season

Table 14 presents descriptive statistics of the freezing point of the samples collected from the five river mouths and the control obtained from inner the part of the lake during both seasons. The overall mean of the ΔT_f during wet season was $4.22 \pm 0.33K$ while that of the dry season was $6.05 \pm 0.43K$.

Table 14: Descriptive Statistics for $\Delta T_f(oc)$ during the wet and the dry seasons.

	N	Range	Min.	Max.	Mean		Std. Dev.
	Stat.	Stat.	Stat.	Stat.	Stat.	Std. Error	Stat.
$\Delta T_{fp}(K)$ (Wet)	9	3.00	3.00	6.00	4.2222	.32394	.97183
$\Delta T_{fp}(K)$ (Dry)	9	3.50	4.50	8.00	6.0556	.42853	1.28560

Determination of freezing point depression $\Delta T_{fp}(K)$ during the dry season

Table 15: Determination of $\Delta T_f(K)$ during the dry season.

Sample site		F0	F1	$\Delta T_f(K)$
Control (H2O)		273	265.5	-4.5
Sondu	1	269.5	265.0	-4.5
	2	268.5	261.5	-7.0
Nyamasaria	1	269.5	263.5	-5.5
	2	266.5	259.0	-7.5
Kibos	1	268	262.0	-6.0
	2	265	260.0	-5.0
Kisiani	1	264	257.5	-6.5
	2	263.5	255.5	-8.0

Key: F₀-Freezing point before addition of NaCl(K); F₁-Freezing point after addition of NaCl(K)

The freezing point depression had a range of -3.5K. The highest depression was -8.0K from Kisiani water (filtered) whereas Sondu water (Unfiltered) sample had the lowest depression of -4.5K. The differences observed were attributed to the different salt concentrations at the different sampling sites (the different river mouths) and the season when the samples were collected.

Data Validation and Real Sample Analysis

Based on the calculated deficit values of relevant thermodynamic parameters for saltwater concentrations, calibrated graphs of the changes of boiling and freezing points and vapor pressure deficit were plotted

versus TDS value of water. Sampling was performed in two events for both wet and dry seasons. In each event, three samples were collected and analyzed for their vapour pressure and f.p and b.p. There was no significant difference from the estimated values; the maximum error barely exceeded 2% for the parameters.

Table 16: Experimental Data for Lake Victoria Water

Parameter	Wet period	Dry period
Total dissolved solids (TDS)	147 g L ⁻¹	294 g L ⁻¹
Salt concentration (C _m)	0.423 mol kg ⁻¹	0.767 mol kg ⁻¹
Van't Hoff's coefficient (i)	1.8	1.8
Ebullioscopic constant (k _b)	0.512 K kgmol ⁻¹	0.512 K kgmol ⁻¹
Cryoscopic constant (k _f)	-1.86 K kgmol ⁻¹	-1.86 K kgmol ⁻¹
Standard vapor pressure (P ₀ H ₂ O)	23.32 mmHg	24.21 mmHg

Table 17: Comparison List of Real Sample Analysis versus the Calculated Values

Key: Cal. – calculated; Obs- observed

Parameter	Wet Period	Error (%)	Dry Period	Error (%)
Calc. Bp (K)	374.00	0.9	378.23	0.9
Obs. Bp (K)	371.00		374.67	
Calc.Fp(K)	262.71	0.3	253.03	0.2
Obs. Fp (K)	261.9		253.6	
Calc. Values				
Bp Elevation	(ΔT_b) +0.390K		+0.707 K	
Fp Depression	(ΔT_f) -1.42 K		-2.57 K	
Vp Deficit (Δp)	2.35mmHg		2.45 mmHg	
Calc. Vp	20.97 mmHg	1.2	19.02 mmHg	1.8
Obs. Vp	21.22 mmHg		19.37 mmHg	

Conclusion

This study confirms salt concentration causes boiling point elevation and vapor pressure deficit of water but depresses the freezing point. The cations, Na⁺, K⁺, Ca²⁺ and Mg²⁺ influence the three factors. In addition, when Na⁺, K⁺ and Ca²⁺ ions are high, a higher concentration of Mg²⁺ positively synergies their effects by increasing boiling point elevation, vapor and freezing point depressions. The concentration of Mg²⁺ and Pb²⁺ ions were much lower than those of Na⁺, K⁺ and Ca²⁺. This is dictated by the geochemistry of the catchment that are drained by the rivers that were sampled. The differences in b.p, vapor pressure and freezing point depressions of the samples can be attributed to the different sizes of the catchments and the rivers themselves since the latter two determine the diversity and the of cations in water.

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Conflict of Interest

The authors wish to declare that there are no competing interests.

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