

Trends in Water quality Deterioration in the Rift Valley: The case of Lake Nakuru, Kenya

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Abstract

Lake Nakuru is a shallow hyper-eutrophic, alkaline and saline endorheic lake located in Rift Valley's eastern arm. Despite its great importance, Lake Nakuru has undergone profound changes due to anthropogenic activities, mostly due to the amplification of industrial and agriculture activities, urban sprawl and rapid population growth in the last few decades. This paper examines the threats facing the lake in terms of water pollution and quality deterioration trends and its impacts on the Lake wetland. The paper looks at the seasonal variations in the physio-chemical parameters of the surface water and to assess levels of Dissolved Oxygen (DO), Alkalinity and Total Dissolved Solids (TDS) and Suspended Sediment (TSS) in the surface water and sediments in the lake. A total of 20 samples were collected in the wet and dry season to measure pH, DO, alkalinity, TDS, TSS of the surface water and the lake water. The data were processed to descriptive statistics using SPSS and Excel in order to measure distribution trends, dispersions, disparities and associations and inferential statistics, specifically a two tailed t-test was used to assess the significant difference in the lake water parameters in the dry and wet season. Sewage and industrial pollution were amongst the top contributors of water pollution. Physio-chemical properties of the surface water varied in the dry and wet season. Measured pH, DO, TDS and TSS values were above the permissible limits for aquatic ecosystems. Total Dissolved Solids (TDS) were found to be higher in the dry season while alkalinity, DO and TSS concentrations were greater in the wet season. From the findings, the highest level of pollution was in the storm drain, Lake Center, mouth of River Nderit and Lamdiac. Seasonal variations showed there was a significant difference ($p < 0.05$) in DO, TSS levels between both the seasons. The study concludes that the main issues threatening Lake Nakuru are the disruptions to its water quality arising from human activities in the catchment area. Strict implementation of policies related to the protection of Lake Nakuru is required. Legal action should therefore be taken in respect of all of those sectors that discharge toxic chemicals into the feeding rivers and the lake. Public awareness of pollution issues and their implications in the lake is necessary. This can be done through environmental education, as it is critical to enhance, spread knowledge and enable communities to protect the integrity and complexity of nature and ensure that the use of valuable resources is fair and environmentally sustainable.

Key words: Water quality, Wetlands, anthropogenic impacts, sustainability

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1. Introduction

The wetlands of Kenya are a vital part of the natural capital of the nation. They are categorized into riverine, marine, estuarine, lacustrine, palustrine and man-made wetlands which cover roughly 14,000 km² of the country's land cover (Macharia *et al.*, 2010). Many of these wetlands are recognized as significant areas of conservation such as National Reserves, National Parks, Important Bird Areas (IBA) and World Heritage Sites. Wetlands support animals and plants integrating the characteristics of terrestrial and aquatic environments especially water, vegetation, soil and nutrients (Ngodhe *et al.*, 2016). They are highly valued and prioritized by the United Nations (UN) under the Sustainable Development Goals (SDGs). Wetlands are of value to the world's population as over a billion people around the world make their living directly from them (International Water Management Institute [IWMI], 2014). They consist of abundant biodiversity including natural environments for a range of plants and animals, some of which are of high significance comprising endangered, migratory and endemic species like the waterfowl. They deliver several benefits such as water purification and storage, nutrient cycling, storm protection and soil erosion control, flood mitigation, storm and shoreline protection (United Nations Environment Programme [UNEP], 2004).

The Ramsar Convention is one of the first International Multilateral Environmental Agreements (MEA) based on sustainable use and conservation of natural resources. Kenya became a member of the Convention on 5th October 1990. Currently the country has six Ramsar sites which are Lake Nakuru (1990), Lake Naivasha (1995), Lake Bogoria (2001), Lake Baringo (2002), Lake Elementaita (2005), and Tana River Delta (2012) (Government of Kenya [GoK], 2015). The Kenya Wildlife Service (KWS) is appointed as the country's focal national institution and their mandate is to protect the wetlands and to oversee the successful implementation of the Ramsar Convention's objectives. This is done through the implementation of several policies and frameworks.

Lakes are found on terrestrial landscapes and appear like 'blue diamond mosaics' from space (UNEP, 2006). The lakes are part of the larger wetlands. Despite the numerous benefits they provide, wetlands continue to face severe threats particularly due to increased population. This situation is exacerbated as mostly all the townships, establishments, industries, urban centers and institutions within the lakes' catchment areas have poor waste treatment facilities leading to discharge of partly treated or untreated wastes in the water (Oketch, 2006). According to the Ramsar (2015) report, the greatest challenges in implementing wetland conservation in Kenya are: increased agriculture, urbanization, deforestation, pollution, invasive species, eutrophication, overgrazing and overexploitation of resources.

The focus of this paper is based on study on Lake Nakuru which is a closed basin lake in the eastern arm of Rift Valley (Figure 1). This site is also unique as it has been several times described as the lake with a million flamingos as well as the world's greatest ornithological spectacle (Raini, 2009). Regardless of being such an important site, Lake Nakuru continues to face several challenges. Population around its catchment area has rapidly increased, leading to urbanization, industrialization, deforestation, waste production and water pollution. All these factors have led to a decreasing trend in the quality of the water.

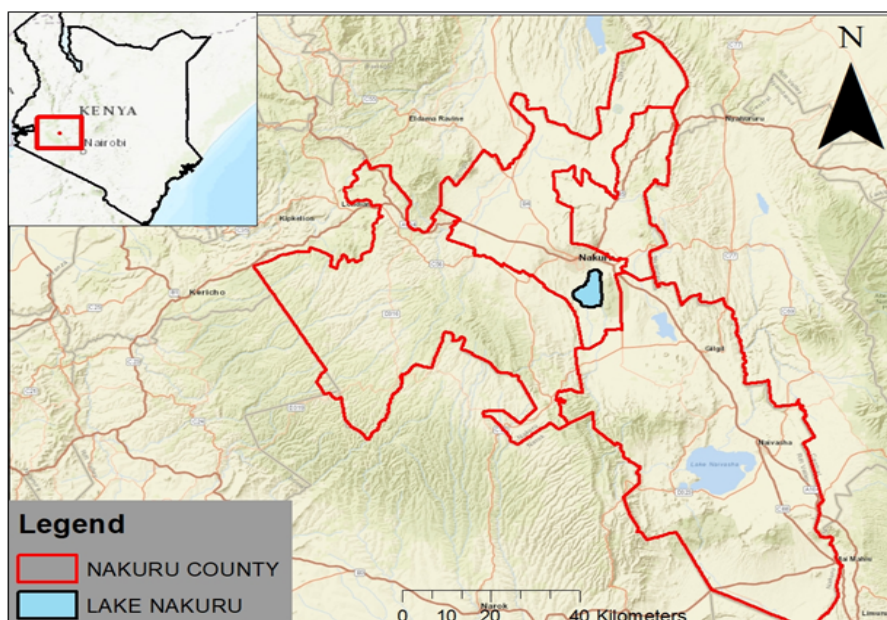


Figure 1: Location of Lake Nakuru in Kenya

Source: Researcher (2023)

A study by Jackson and Kulecho (2008) on the review of environmental impacts of land use changes in Nakuru estimated approximately 178 small-to-medium scale industries that have been known to dump a range of products such as batteries, detergents, paints, and plastics among others. The water level of Lake Nakuru fell dramatically due to an unprecedented drought in 2009 which led to a major evapo-concentration, with a rise in total salinity from around 20‰ to 63‰. Parameters such as Carbon, Sodium, Calcium, Potassium and Arsenic also rapidly increased with dropping water levels (Jirsa *et. al.*, 2012).

2. Study Methodology

This study involved both qualitative and quantitative methods. Quantitative techniques were based upon amount

or quantity measurements. They were applicable to events which describes phenomena in the form of numerical data and can be analyzed mathematically in particular using statistics. The study employed *in-situ* measurements, laboratory experiments and observation methods. *In-situ* measurements and laboratory experiments were used to obtain physical and chemical parameters of the surface water and silt load of the lake. This study was carried out during the wet and dry seasons to collect surface water samples from selected sites before 10 am as there is no mixing of waters within the lake. All the sampling sites were purposively selected based on the presence of any form of emissions, contamination and pollution, inflows, accessibility and drainage patterns. Based on these, ten sampling points were selected (at least 300 meters away from each other) which included the old main gate (lake center), Baharini springs, Nyati camp, Hippo spring, mouth of River Nderit, Nderit point, T junction, Block 7, mouth of Lamdiac River and the storm drain as indicated in Figure 2. Four sediment samples were collected at different points (Hippo Spring, Baharini Spring, Nderit and storm drain) TDS and TSS analysis. A handheld Global Positioning System (GPS) was used to determine the elevation and geographic coordinates of each sample as shown in Table 1.

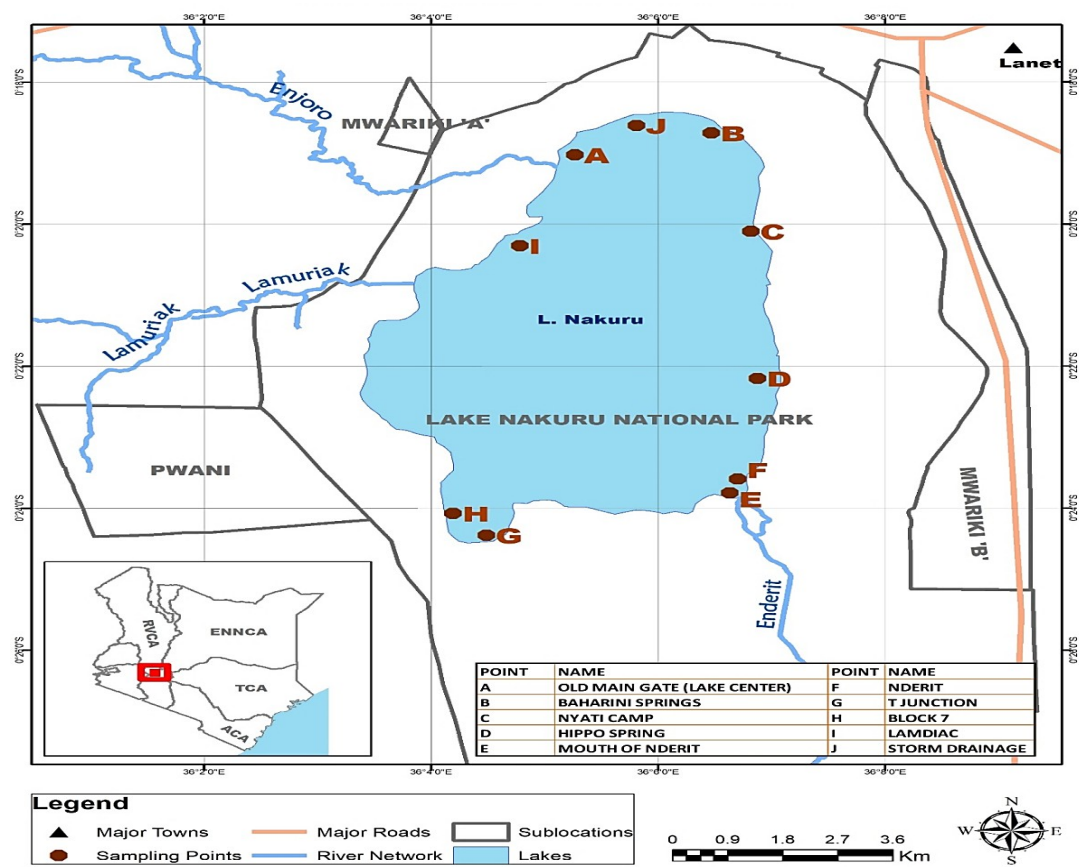


Figure 2: Lake Nakuru Sampling Points

Source: Researcher (2023)

Table 1: Coordinates for water and sediment samples at Lake Nakuru

Point	Site	GPS Coordinates
A	Old Main Gate (Lake Center)	37M 0175521 UTM 9965038
B	Baharini Springs	37M 0178059 UTM 9965831
C	Nyati Camp	37M 0178770 UTM 9962910
D	Hippo Spring	37M 0179343 UTM 9959102
E	Mouth Of Nderit	37M 0178545 UTM 9955417
F	Nderit	37M 0178547 UTM 9955546
G	T Junction	37M 0174331 UTM 9954329
H	Block 7	37M 0173518 UTM 9955446
I	Lamdiac	37M 0174145 UTM 9962892
J	Storm Drain	37M 0176607 UTM 9966052

Source: Researcher (2023)

In-situ measurements were taken at each point for temperature, pH, DO and depth of water. Three measurements were taken at each point and the average was taken as the final value. For laboratory analysis, one liter plastic bottles were used to collect samples. In order to ensure that they were representative of the conditions of the lake water, the sampling bottles were rinsed twice with the water prior to collection. At each point, water filled, capped securely and labelled. The sediment samples were collected using a stainless steel scoop and transferred into zip locker bags. The collected samples were placed in a cooler box, protected from direct sunlight before being transported to the laboratory for analysis.

2.1 Laboratory analysis

For the in-situ measurements of the depth, pH, DO and temperature, a one meter wooden ruler, a WTW Multi 350i pH meter, a H19146 DO meter and a mercuric thermometer were used respectively. The current study employed the American Public Health Association (APHA), (2005) analytical methods for laboratory analysis for the physiochemical parameters summarized in Table 2. APHA (2005) is an enhanced version of the methods used previously and is simple, inexpensive, and quick and assures the immediate preservation of irreversible reactions.

Table 2: Analytical methods used for laboratory analysis

Parameter	Instrument	Method
TSS	Vacuum pump, filter disks, funnel	APHA Standard Method 2450D Colorimetric method
TDS	Filtration unit, balance, oven	APHA Standard Method 2540C
Alkalinity	Titration vessel, magnetic stirrer, volume flask, pipette, burette	APHA Standard Method 2320B Titration method
Heavy Metals in Water	Atomic absorption spectrophotometer	AA5 Direct Air-Acetylene method
Heavy Metals in Sediment	Atomic absorption spectrophotometer	APHA Standard Method Direct flame atomic method
Nitrates	Reduction column, spectrophotometer	APHA Standard Method 4500-NO ₃ -E Cadmium reduction method
Phosphates	Autoclave hotplate, spectrophotometer	APHA Standard Method 4500-PE Absorbic acid method
Ammonia	Spectrophotometer	APHA Standard Method 4500-NH ₃ -D Phenate method

Source: APHA (2005)

2.2 Method used to analyze the results

This section involved the analysis of the results obtained from the laboratory and subsequently interpretation of the results to reveal the water quality status and the trends in the degradation due to identified water pollutants in the basin.

Advanced analysis was carried out by using inferential statistics to test the null hypothesis. A two tailed t-test was used to test the hypothesis. This test is used to compare if the mean difference in two groups is really significant. Important assumptions made when performing a two tailed t-test include those concerning measurement scale, normal distribution of data, random sampling, sample size adequacy and standard deviation variance equality. Selection of this test was supported by Kothari (2004) who noted that the two tailed t-test was the most appropriate statistical tool for evaluating the significance in difference in means between two groups. It was computed using the formula below.

$$t = \frac{X_1 - X_2 - \Delta}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

Where: X_1 and X_2 = Means of the two samples, Δ = Hypothesized difference, S_1 and S_2 = Standard deviations of the two samples and n_1 and n_2 = Sample sizes

3. Results and Discussions

3.1 Threats Facing Lake Nakuru

The results shown in table 3 indicates the respondent's responses when asked to rank the threats facing Lake Nakuru in order of the highest threats. A total of ten threats were identified out of which seven were common across the respondents and ranked as significant. These were industrial, agricultural and sewage pollution, soil erosion and sedimentation, climate change, deforestation and flooding (Table 3).

Table 3: Community and institutional identified threats ranked

Threats	KWS Staff	Households
Industrial pollution	4	2
Agricultural pollution	6	3
Sewage pollution	1	1
Soil erosion and sedimentation	3	5
Over abstraction of water from feeding river		8
Climate change	5	7
Deforestation	2	6
Drying rivers		9
Flooding of lake	7	4
Invasive species	8	

Source: Researcher (2023)

Sewage pollution was observed to be the greatest threat to the lake by both the household (60.7%) as well as the KWS respondents (70%) (Figure 3). Both groups of respondents found industrial pollution, sedimentation and deforestation to be a major threat too. Tourism and overgrazing were not identified as a threat by both the respondents. KWS officials did not recognize over abstraction of water from rivers as a threat whereas the households did not think occurrence of invasive species was a threat to the lake.

Threats encircling many wetlands emerge from rapid population growth leading to pollution, illegal hunting and

deterioration of the ecosystem. The ecosystem rich areas correlate with the growing world population where there is a stronger need for agriculture and settlement which has resulted in land use changes around protected areas like Lake Nakuru that has caused changes in ecological functions and decrease in biodiversity. In their study, Okello and Kiringe (2004) identified ecosystems and management threats in Kenya, and their proliferation around protected areas. The major threats identified during the study were pollution, human encroachment and land use changes, loss of wildlife, tourism and human-wildlife conflicts. The threats are quite similar compared to the current study, but they are more concentrated and accentuated on water pollution.

A similar study conducted in the Ramsar site, Lake Nakuru by Shah (2016), revealed similar results (Table 4). A total of fourteen threats were identified. There were eight common threats between the KWS and the household respondents. These were climate change, invasive species, water pollution, community being hostile, poaching, illegal harvesting of wood, over-abstraction of water and deforestation. Deforestation was observed to be the main threat to the lake by both the household respondents and the KWS officers. Both groups of respondents found water pollution to be a major threat also. According to KWS fire was not a threat. Bush meat, trophy, poisoning, population growth and development projects were not considered as threats to the lake by the community respondents.

Table 4: Community and institutional identified threats ranked

Threats	KWS Staff	Households
Climate change	1	7
Invasive species	4	6
Water pollution	5	3
Development Projects	6	
Community being hostile	7	4
Poaching	8	8
Illegal harvesting of wood	9	1
Bush meat	10	
Trophy hunting	11	
Poisoning	12	
Over-abstraction of water	13	9
Fire		5
Population growth	3	
Deforestation	1	1

Source: Shah (2016)

In comparison with the current study, the ranking of the highest threats changed. Water pollution in specific; sewage, industrial and agricultural were identified amongst the highest threats in the present study whereas Shah (2016) identified climate change and illegal harvesting of wood as the top threat. Deforestation was the top threat identified by both respondents by Shah (2016), however in the present study, the households did not rank it amongst the top five threats. Climate change still remains at the same level (not in the top five threats) as indicated in tables 3 and 4. This may be due to the fact that the households are still not able to understand the issue and the consequences while threats such as flooding of the lake, soil erosion and sedimentation were not identified in the previous studies.

3.2 Factors Contributing to Water Quality Deterioration

The study found that due to these threats, water quality was deteriorating. Respondents were asked to give reasons why the water quality was deteriorating. The reasons varied from solid waste, agricultural waste, industrial waste, sewage, soil erosion and sedimentation and storm water runoff. The majority of the respondents (73%) stated that sewage was the main cause of deterioration followed by industrial waste (22.4%) and solid waste (14.3%) as shown in Figure 5.

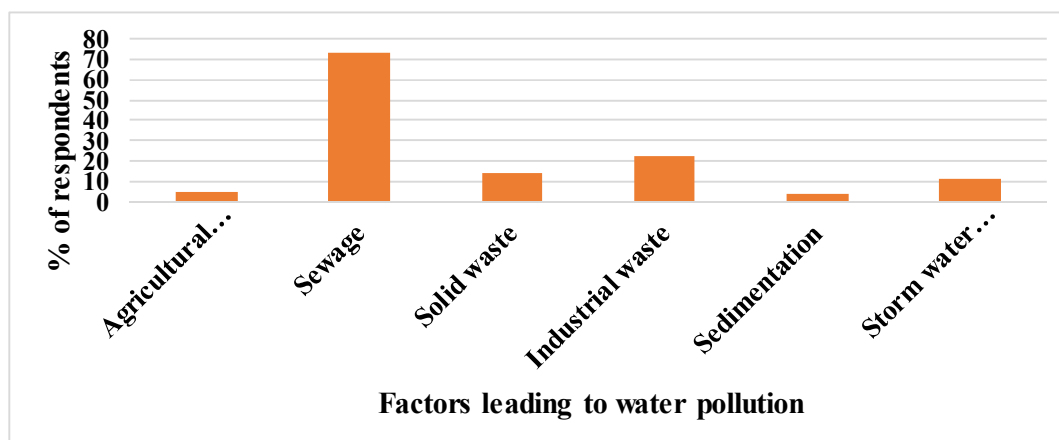


Figure 3: Factors contributing to water quality deterioration

Source: Researcher (2023)

In many developing countries, increase in population requires a serious long term solution in the planning and development of sewage facilities, specifically in urban lake drainage basins such as Lake Nakuru. Just 27% of the population of Nakuru is linked to the sewerage network of the area, emphasizing the need for a safer way of disposing of the high quantities of sewage produced every day. Nakuru's danger to water contamination is significant, as sewage is often deposited into storm drains and waterways, or sunk in small-income areas.

An investigation involving Nakuru sewage treatment plant by Ngari, *et. al.*, (2011) revealed that the final drainage filter line effluents did not comply with the criteria and standards set for the lake discharge. Effluents were polluted chemically and biologically, with high levels of pathogenic microorganisms that present a major threat to the wetland. The mean Ammonia, Nitrogen and Phosphorus concentrations in the final effluent were also much higher than the environmental emission limits. Studies have reported that wildlife susceptibility to human pathogens has led to higher occurrences of wildlife infectious diseases. About two rhinos and more than 500 buffaloes perished in June 2015 after an anthrax epidemic, all of which was linked with water pollution (Gachohi *et. al.*, 2019).

According to a report by WHO (2014), almost 90% of wastewater from factories in developing countries is released directly into streams, lakes and oceans without any treatment, a factor that contributes significantly to the deterioration of water quality. Industries are amongst the highest sources of pollution worldwide, producing toxins which are incredibly harmful to the environment. Estimated 300 million tons of synthetic chemicals used in industries make their way gradually into surface waters. Nakuru town has roughly 70 industries such as food and milk processing, textiles, chemical processing, pyrethrum, battery, bleaching, tannery and paint manufacturing. Many of these factories are in Njoro such as Njoro canning factory, where untreated or partially treated waste water is discharged into River Njoro that eventually enters LNNP. A study by Muwanga and Barifaijo (2006) revealed that industrial effluents was the major pollutant in Uganda's Lake Victoria Basin.

The rise of the population and the rapid growth in solid waste generation have emerged as one of the most pressing problems; especially in third world countries (Ferronato and Torretta, 2019). The issues can be even more prominent in medium sized towns like Nakuru. Over 250 tons of solid waste is generated daily in Nakuru County, of which at least 540 kg is collected at the LNNP daily (Mwanzia *et. al.*, 2013; Cherono *et. al.*, 2019). During heavy rains and storm, the situation is exacerbated and the solid waste eventually finds its way into the lake. The type of waste ranges from plastic, rubber, glass, wood, leather and tins. The findings show a repugnant condition of some areas around the lake, as most of the garbage is spread within and around the lake with little or no proper disposal strategy. Other contributors to the lake's solid waste comprise of tourists activities and lodges within the park. In 2015, a total of 20 tons of solid waste was collected around the lake.

Storm water runoff is a top contributor to pollution in Lake Nakuru. Along with solid waste, storm water carries tons of sediments, nutrients such as Phosphates and Nitrates, pathogens, heavy metals, radioactive waste, domestic effluents and fecal waste. Effluents flowing from the storm water into the lake usually have a low pH around 5-7, making it unfit for the lake and the wildlife. Storm water pollution can lead to deposition of excessive sediment, eutrophication, and toxicity from heavy metals, depleted DO and increased water temperatures. A study by Raini (2005), on the long term trends in water quality and quantity in Lake Nakuru

determined that the storm water channel and the sewage channel entering the lake had the highest concentrations of toxic metals such as Titanium, Nickel, Lead, Chromium, Cadmium, Silver, Mercury as well as maximum amount of pesticide concentrations compared to other parts of the lake. The situation after 15 years still remains the same; storm water runoff and sewage are recognized as major pollutants in Lake Nakuru.

Data on the physical changes of Lake Nakuru such as color, odor, and algal blooms, changes in water quantity and clarity and death of species was obtained by the households as well as through physical observations by the researcher. A total of 33 (16.8%) household respondents observed changes in water color of Lake Nakuru (Figure 5). The researcher observed mostly a brownish unpleasant color at the sampling sites (Figure 4). Dissolved and suspended particles in water usually have an influence in its color. Increased soil erosion and runoff yields a number of shades like red, brown or even grey. However, the most common cause of water color is the presence of various minerals. Red, brown colors are usually as a result of high concentration of Iron, Manganese as well as organic matter. Intensely colored water, apart from being aesthetically undesirable, restricts the penetration of light which reduces the supply of DO and the production of planktons that support the subsistence of fish and other species in aquatic environments.



Figure 4: Observations on water color at sampling sites

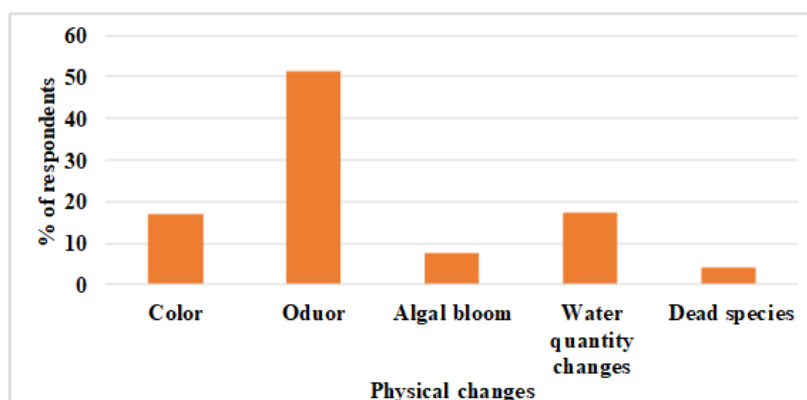


Figure 5: Physical observations at Lake Nakuru

Source: Researcher (2023)

A total of 101 (51.5%) household respondents recorded a different smell at Lake Nakuru (Figure 7). Oduor contamination is an environmental change factor which has an impact on the well-being of the ecosystem and its surroundings. Wastewater treatment plants, sewage treatment plants, municipal waste landfills, composting, propagation of domestic manure may generate pungent smells (Sakawi *et. al.*, 2013). The researcher also smelled

a sewage like and musky smell at some of the sampling points. This could be potentially attributed to the Njoro sewage treatment plant, the old town sewerage as well as toxic waste draining into the lake from the storm drain. Oduor might not cause direct harm to local residents, but intense odour are hazardous and can contribute to health problems like diarrhea, insomnia, nasal inflammation and asthma.

Only a few (15) household respondents indicated that they had previously observed algal blooms in Lake Nakuru (Figure 6). The researcher however did not come across any algal blooms during field work. 34 (17.3%) household respondents recorded changes in water quantity of Lake Nakuru. It has become quite high that a large portion of LNNP is submerged, with in fact a section of the KWS building at the entrance to the park. After 2011, all the lakes in the Rift Valley of Kenya have experienced major rises in water levels, and the volume keeps rising to levels never seen in the past 50 years. The meteorological department stated that the monthly rainfall patterns are pretty normal within the Rift Valley and its catchment areas, while the Ministry of Land, Water and Natural Resources has attributed the rising levels to increased lake siltation due to deterioration of the catchment areas. Empirically, the rise in levels of water could also be purely a result of geographical volcanic activity and tectonic movements that creates convective and tensional pressure and possibly seepage of water. Although the real cause of Lake Nakuru's high water levels may be elusive, the effects on the environment are evident.

A total of eight household respondents had observed dead species in and around the Lake (Figure 6). The researcher had observed dead fish species around the shores of Lake Nakuru in particular the Hippo point and Baharini springs. The surface water quality that the researcher observed was foamy at various sampling points around the shore (Figure 7). Foam may accumulate when plants decompose in the water and most often develop in waters that are heavy in organic content. However, they may also accumulate as a result of human activities such as waste from textile industries, fertilizers and pesticides (Schilling and Zessner, 2011).





Figure 7: Status and Seasonal Variations of Water Quality in Lake Nakuru

Source: Researcher (2023)

The researcher also observed a large number of solid waste deposited around the feeding rivers and the lake (Figure 8). In recent years' solid waste and the quality of water have become serious environmental issues, particularly in developing countries. Solid waste is often carried through storm water runoff in urban areas. They are sometimes illegally dumped in urban as well as rural areas directly into a water body or wetland. Majority of the waste present in Lake Nakuru is from the feeding rivers and tourist activities in the park.

3.2.1 pH

Study findings of the pH from this study are in line with the previous studies. The mean pH was 9.90 with a minimum of 7.60 at the storm drain (J) to a maximum of 10.50 at Nyati camp (C) in the wet season. With similar results in the dry season, the lowest pH value recorded was 7.90 at the storm drain (J) and the highest was 10.20 at Block 7 (H) with an average of 9.70 (Table 5). The pH values for majority of the samples were not within the EPA limit for aquatic systems which range from 5 to 9.

As the pH levels disperse from their operating range, wildlife ecosystems can be disrupted and hatching and survival rates reduced. The more the value is outside the optimized range of pH., the relatively high the fatality rate. PH values of approximately 9-10.5 provide the perfect conditions for growth of *Spirulina platensis* and *Arthospira fusiformis*, types of cyanobacteria consumed by the flamingos. Extreme changes in the pH values along with other factors have previously led to massive flamingo deaths (Kotut *et. al.*, 2010). PH values were the lowest in the storm drain. This could have been possibly as a result of discharge of chemicals used from the nearby areas such as from detergents, fertilizers, chemicals used in printing, solutions used in metal plating, acidic chemicals from textile industries as well as sewerage.

The extreme pH of Lake Nakuru give this lake a fundamental difference of exhibiting a severe chemical and physical environment that appears to interact in defining the existence and structure of organisms' autotrophic assemblages in this aquatic system. The mean pH calculated in Lake Nakuru at eight sites by Raini (2009) was 10.2 ± 0.7 . In comparison with this study (9.9) similar mean pH values were also observed in Lonar alkaline lake in India (10) and other East African Alkaline, saline lakes like Elementeita (9.4), Big Momela (10.4), Manyara (10.3) and Reshitani (9.2).

3.2.2 Dissolved Oxygen (DO)

The study found the mean DO levels at the sampling sites were 10.58 mg/L and 8.72 mg/L during the wet and dry seasons respectively. The highest levels of DO recorded were at the storm drain with values 13.20 mg/L in the wet season and 10.80 mg/L in the dry season. The lowest value recorded in the wet season was 8.00 mg/L at the Hippo Spring (D) and in the dry season; 6.20 mg/L at the Baharini Springs (B) (Table 6). The DO values for

most of the samples were within the EPA limit for aquatic systems which range from 9 to 12. The lake had a high DO concentration in the wet season than that of the dry season by around 1.9 mg/L. Oxygen levels are higher in cold water compared to warm water, hence the result of variations in DO concentrations in both seasons. The lower DO values obtained during the wet season at sampling sites D and G may be due to the increase of phytoplankton and the decomposition of organic materials.

Table 6: Dissolved Oxygen levels of Lake Nakuru in wet and dry season

Sampling Site	DO (Mg/L)	
	Wet Season	Dry Season
A	11.00	10.70
B	10.00	6.20
C	10.20	8.60
D	8.00	7.70
E	12.30	9.80
F	12.10	8.80
G	8.20	6.70
H	10.50	8.70
I	10.30	9.20
J	13.20	10.80
Mean	10.58	8.72
EPA limit	9-12	

Source: Researcher (2023)

Dissolved oxygen in surface water is often used by all aquatic species, so this factor is widely used to estimate the quality of lakes (Diaz and Breitburg, 2009). For ideal wellbeing of aquatic species, a concentration of 5 mg/L of DO is recommended. However, fish species such as the *Sarotherodon alcalicus grahami* in Lake Nakuru, are known to tolerate DO levels as low as 3 mg/L. Though the productivity of *Arthrospira fusiformis* which is a key diet for the Lesser Flamingos significantly decreases at DO levels below 2 mg/L. In August 2004, a massive fish kill emerged in Lake Nakuru due to drastic oxygen depletion.

The Oxygen concentration of water declines when organic materials and nutrients from industrial effluents, sewage discharges, and surface water runoff from land increase. This could be possibly be the reason of Oxygen depletion at the storm drain. A study conducted by Lugomela *et. al.*, (2006) in Lake Momela and Lake Natron found similar mean DO concentrations (9.3 mg/L and 7.8 mg/L respectively) in these alkaline lakes. He ascribed the levels of DO may be affected by the photosynthetic activity, depth, wind action and organic matter decomposition.

3.2.3 Alkalinity

Alkalinity is not really a chemical within water, but instead an attribute that relies on the existence of several other chemicals in water, such as hydroxides, carbonates and bicarbonates. The alkalinity characteristic is its capacity to neutralize acid. In water, therefore, it is essential in that it allows buffering to resist variations in pH. From the results analyzed (Figure 8), the maximum alkalinity detected in the wet season was 4000 mg/L at the lake center (A) and Nderit (F) and minimum was 3650 mg/L at the T junction (G) and Block 7 (H). During the dry season however, the highest alkalinity was 4800 mg/L at the Lamdiac shore (J) and the lowest was 2600 mg/L at the Baharini springs (B).

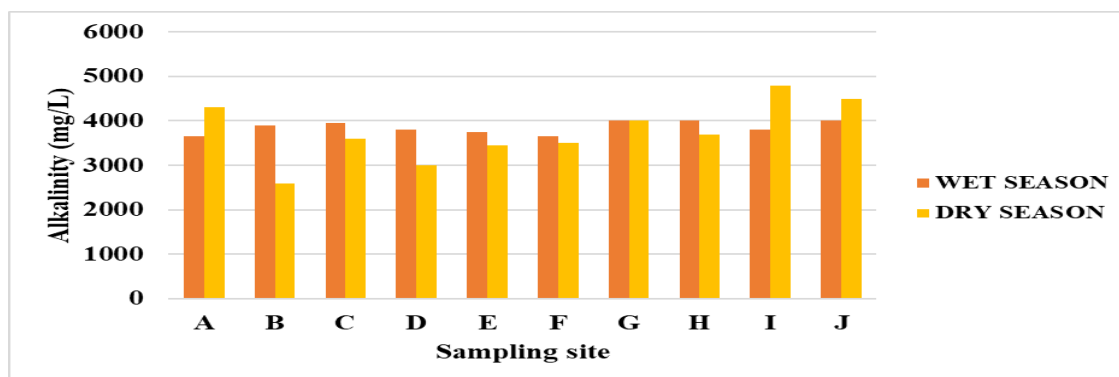


Figure 8: Alkalinity levels of Lake Nakuru in wet and dry season

Source: Researcher (2023)

The mean total alkalinity was slightly lower (3745 mg/L) in the dry season compared to the wet season (3850 mg/L) in the present investigation. The low alkalinity at some sampling sites can be explained by dilutions with fresh water. Above average alkalinity were observed at the storm drain (J) for both the seasons. This could possibly be because of domestic, industrial and agricultural effluents. Many factors could be responsible for the disparity in alkalinity at the different sampling sites in both seasons, such as the variation of geology and soils along the feeding rivers, the flow of the water, weathering and agricultural activities around the lake. This could also explain the highest alkalinity level from both the seasons recorded at the Lamdiac shore (J).

The dilute inflows into East African basins obtain much of its alkalinity via the accelerated hydrolysis of readily weathered rock and lava covering most of the landscape. Acidic water can't fully promote growth of zooplankton, phytoplankton and diterous bacteria, all of which are essential for maintaining a fish-growing in alkaline environments (Kiprutto *et. al.*, 2012). In the case of Lake Nakuru, alkalinity is essential for the growth of the blue-green algae; a key diet for the Lesser Flamingos.

3.2.4 TDS and TSS

TDS is the term that describes inorganic salts and small quantities of organic matter in water solution. They typically constitute of anions of Sodium, Potassium, Calcium, Carbonates, Magnesium, Hydrogen Carbonate, Nitrate, Chloride and Sulfate (Hecky and Kilham, 1973). The measured TDS values ranged from 672 mg/L to 4020 mg/L with an average of 3046 mg/L in the wet season and 578 mg/L to 5055 mg/L with an average of 3700 mg/L in the dry season (Figure 9). Apart from the storm drain, all the other sites had very high levels of TDS which were above the EPA recommended limit (1000 mg/L).

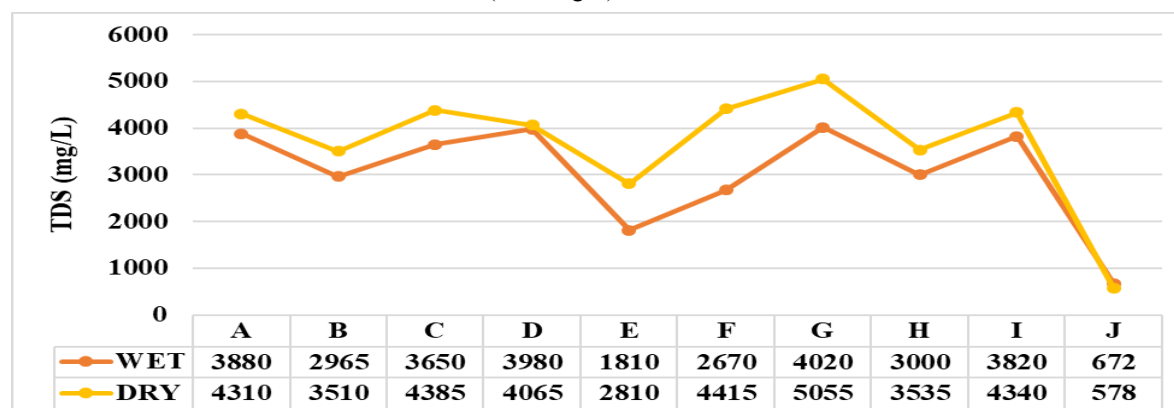


Figure 9: TDS concentrations of Lake Nakuru in wet and dry season

Source: Researcher (2023)

The values of TDS concentrations indicate high levels of pollution in Lake Nakuru which are all probably related

to pollution through the discharge into the feeding rivers from industrial effluents (textiles, food, paint, oil and battery), municipal wastewater, agricultural runoffs and sewage wastewater. The high TDS can also be attributed to depositional site erosion. Increased TDS amounts can reduce the overall clarity, limit photosynthesis, react with toxic substances and heavy metals, and increase the water temperature. Average TDS concentrations were higher in the dry season than the wet season by approximately 650 mg/L. This might have been due to greater temperatures observed during the hot period that stimulated mechanisms of dissolution, ion exchange, evaporation, and weathering. Similar results for seasonal variations were found in Lake Manito and Lake Muskiki in Canada whereby the TDS levels were much higher in the dry season compared to the rainy season.

TSS are both inorganic and organic solids that have been suspended in liquid. These comprise sediment, plankton and toxic pollutants which do not pass through filters (Brosett, 1979). The TSS levels recorded at Lake Nakuru in the wet season ranged from 60 mg/L to 174 mg/L and 42 mg/L to 124 mg/L in the dry season (Figure 10). Out of the ten sampling sites, nine of them had a TSS value higher than the EPA recommended limit (50 mg/L).

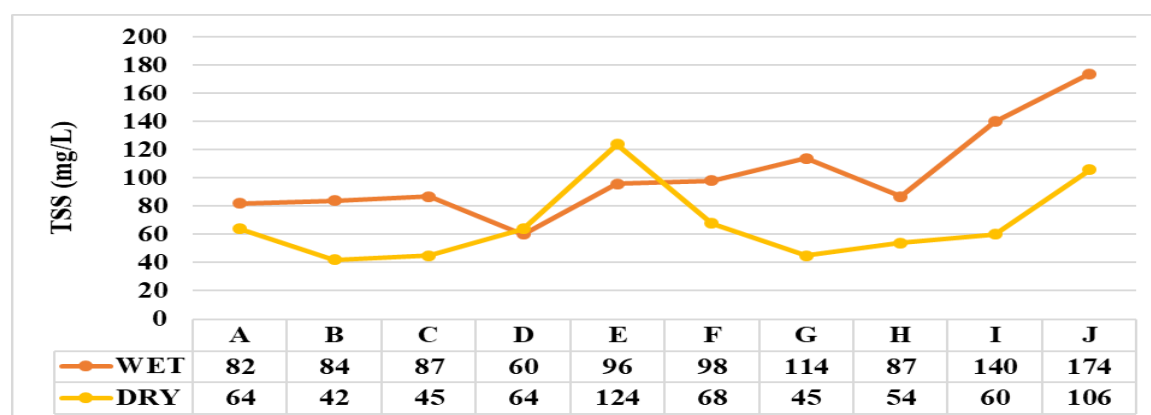


Figure 10: TSS levels of Lake Nakuru in wet and dry season

Source: Researcher (2023)

The highest TSS levels were present at the mouth of Nderit and the storm drain. This could potentially be as a result of urban runoff, soil erosion, effluent wastewater and sewer systems, decomposing plants and animals, nutrient transport, agricultural practices and construction sites. The measured mean value for the TSS amount was high during the wet season by 35 mg/L. This is most usually related to the massive erosion and storm water loads of particulate matter. As TSS levels rise, water body's starts to lose their ability to sustain diversity of aquatic life. Suspended solids radiate heat from sunlight that increases water temperature and consequently reduces the DO levels. The study area results are consistent with (Ashraf *et. al.*, 2010) who found the level of TSS in Varsity Lake in Malaysia to be higher than that of the allowable limit as a result of increased anthropogenic activities.

4. Conclusion

Lakes are perhaps the most spectacular and quaint elements of our global ecosystem, have an abundance of resource assets and are essential elements of the water cycle. They support human livelihoods, provide habitats for plant and animal species, promote economic activities and provide significant aesthetic and religious values. Whilst lakes provide vital goods and services, they sometimes are overlooked or even neglected. Over the decades, several forms of environmental stresses have become apparent. Water pollution in the form of non-point and point sources has rigorously deteriorated the salty lake causing an imbalance of the natural state of the water. Anthropogenic activities including industrial wastes, agrochemicals, soil erosion from overgrazed lands, degraded catchments and infrastructural developments such as road networks and unmanaged storm water from urban centers have highly affected the water quality, quantity and biodiversity of Lake Nakuru. Pollution control at Lake Nakuru is essential in order to achieve SWRM as well as to sustain the ecology of the lake. This requires assurance that practices along the feeding rivers and the lake are environmentally sustainable and can still

maintain the communities' source of revenue.

The physio-chemical properties of the surface water varied in both seasons. Average temperature, TDS and Nutrient values were greater in the dry season and alkalinity DO and TSS values were greater in the wet season. Average surface water temperatures increased by 3°C in the dry season. DO concentrations were greater during the wet season by 3 mg/L. Mean TDS levels were higher in the dry season by approximately 650 mg/L. The mean TSS levels were higher by 35 mg/L in the wet season. The nutrients; Nitrates, Phosphates and Ammonia were all greater in the dry season. There was a significant difference ($p < 0.05$) in the means of DO, Phosphate, Ammonia and TSS concentrations between both the seasons.

5. Recommendations

In informal settlements, there are no adequate waste disposal amenities that lead in the direct disposal of unsegregated solid waste into the feeding rivers. There is need for the County Government of Nakuru town to develop and implement an effective solid waste management plan and to upgrade the sewage systems of informal settlements. For areas with insufficient sanitation and sewerage networks, well-built pit latrines should be provided away from the banks of the rivers. This will effectively solve the problem of uncontrolled pollution of raw sewage into the waterways and thus deteriorate the water quality.

In order to regulate pollution, NEMA can strengthen law enforcement. Legal actions such as prohibition order, compound violations, and strict fines are essential to limit or eradicate the excessive emission of pollutants into the water bodies, thus minimizing their impact. Constant monitoring of the water quality should be carried out within LNNP by KWS and NAWASSCO. Regular and random impact evaluations are needed to check the water discharged from sewage treatment plants are of required standards. Deliberate pollutant monitoring should be conducted at sources of the rivers, the springs, in lake water and sediments. Water quality monitor should be built at each chemical discharge wastewater outlet to confirm that no unauthorized pollutants are released into the river during the day or at night. This should also be enforced in all the lodges inside the park.

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