FACTORS AFFECTING QUALITY OF WATER IN MOMBASA COUNTY

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ABSTRACT

The aim of our project was to understand the factors that contribute to the quality of water in Mombasa County and if they are fit for human consumption. We also set out to investigate the state of our water bodies in terms of quality as our study sites play a key role in human consumption in Mombasa County.

We first collected water samples from four different water sources, River Kombeni, River Sabaki, Likoni Ferry Channel, and the Indian Ocean. We tested for various parameters such as pH, turbidity, calcium hardness, total hardness, conductivity, and presence of microorganisms. These tests were carried out at the Coast Water Works Development Agency Laboratory of Mombasa and Pwani University Biosciences Laboratory. We compared the results of the chemical analysis with the standards of water quality given by the Coast Water Works Development Agency, which ensures that the water distributed in the County is suitable for human consumption.

We discovered that River Kombeni had almost all parameters in accordance with the water quality standard except for turbidity where it recorded highest turbidity and a large amount of microorganisms. We also discovered River Sabaki had highest calcium hardness and had the most diverse microbial colonies. On the other hand, the Indian Ocean water sample had the highest total hardness, conductivity, alkalinity and largest amount of microorganisms present. The Likoni Ferry Channel water was consistent with the Indian Ocean water in total hardness but differed in calcium hardness. Likoni Ferry Channel also had the highest pH and highest chloride content. We concluded that all the water sources we studied were not fit for human consumption.

Human activities such as agriculture, sewage dumping, industrial processes and transport, results in eutrophication, reduced alkalinity and increased amount of chlorides, thereby affecting the quality of water. There is need to mitigate this, and this can be done through wastewater treatment, green agriculture and wetlands, denitrification and water conservation. The main factors affecting water quality include agriculture, sewage dumping, industrial waste, and greenhouse gas emissions.

RESEARCH QUESTIONS

1. What is the water quality of the local water bodies linked to Mombasa County?
2. What factors affect the quality of water in Mombasa County?
3. To what extent have human activities affected water quality and what are the effects?

HYPOTHESIS

1. The general water quality in water bodies around Mombasa County is poor and unfit for human consumption.
2. Water quality in Mombasa County is mainly affected by human factors.
3. Human activities such as dumping of sewage, industrial and agricultural processes affect the quality of water considerably.

INTRODUCTION

Water is essential for all forms of life, and the ocean and rivers are two of the most important sources of water on Earth. However, the quality of water in these bodies can vary greatly, many of which contain harmful bacteria resulting in the spread of many water-borne diseases like typhoid fever and cholera through the use and consumption of contaminated water. Water is contaminated by disease-spreading microbes and pathogens that are a result of human activity. Water is contaminated through the release of waste and chemicals from fertilisers and pesticides from farms, sewage from households, and greenhouse gases from industries.

It is important to understand the factors that contribute to this variability in order to protect and preserve these vital resources.

Community Relevance and Importance

We are seeing a surplus of adverse effects in our local rivers and the Indian Ocean due to the large-scale global commercialization of Mombasa Island. As the largest port in East Africa, it becomes an international trading hub that greatly aids the Kenyan economy. Increased port activities and amphibious transport services such as the Mombasa ferries also bring along added pollutants such as dissolved metals including lead, copper, and zinc.

One of the major causes of concern is sewage pollution in the Coastal waters of Mombasa.

Sewage pollution has been identified as one of the most serious of all land-based threats to the marine environment and as an area where the least progress has been achieved (UNEP, 2006). Between 80-90% of sewage is discharged in the coastal zones of many developing countries untreated (UNEP, 2006). With the current population level, man has the potential to pollute every single waterway, ocean, and drinking water supply with raw sewage if no urgent measures are put in place (Okuku et. al., 2011). Kenya's rivers and main tributaries such as River Sabaki, Galana, and Athi are also suffering from alarming levels of pollution. A technical report from the Kenya Marine and Fisheries Research Institute (KMFRI, 2015) reports that the Athi-Galana-Sabaki River eutrophication is partially attributed to sewage input. Water samples analysed for microbial content revealed the presence of *E. coli* indicating that sewage is a factor in the pollution of the River Galana water. (KMFRI, 2015). As a result, the local communities have suffered serious health effects, possibly attributable to consumption of water from the river experiencing Eutrophication. These effects include cases of diarrhoea, vomiting, malaria, and stomach ailments (KMFRI, 2015). Another focal point of this study is the extent of ocean acidification in Mombasa's seawater. Ocean acidification refers to the decrease in pH levels in the ocean as a result of the absorption of carbon dioxide (CO_2) from the atmosphere. Ocean acidification has a range of negative effects on marine life. For example, it can make it harder for marine organisms such as coral, molluscs, and plankton to build and maintain their shells and skeletons, which can lead to declines in population. The increasing carbon emissions due to growing industries and port activities provide a justification to investigate coastal seawater quality.

RESEARCH METHODS

1. Study Sites

The following sites were used to collect water samples for the purpose of analysis:

a. Kombeni River
b. Sabaki River
c. Indian Ocean
d. Likoni Ferry Channel

1.1 River Kombeni

Kombeni River is located in the coastal region of Kenya, specifically in Kilifi County. The river originates from the hills near Kaloleni town and flows eastward towards the Indian Ocean. The river flows through the nearby villages of Jomvu and Mitsolokani as shown in Figure 1 and Figure 2. It is a seasonal river, therefore has an intermittent stream. Though, during the rainy season, it experiences high flows that could lead to flooding in the surrounding areas. It can be described as a tropical dry savanna climate. The river is an important source of water as it provides water for activities such as irrigation, domestic use, and livestock watering for the local communities living along its course.

However, pollution from human activities such as agricultural activities, domestic waste, industrial effluents, and climate change has led to the degradation of the river's water quality. This is posing a threat to human health, aquatic life, and surroundings. One of the main factors of industrial effluent pollution in the river is the dumpsite located near the river.

Moreover, this is an unreliable source of water for localities as it is a very prone area to accidents. The Kombeni bridge had been a victim of heavy rains and flooding so many times, breaking links to nearby areas. Flooding around the river has also affected lifestyle, negatively, as the increase in rainfall has led to numerous deaths in nearby areas.

Figure 1: Satellite image of Kombeni River study site

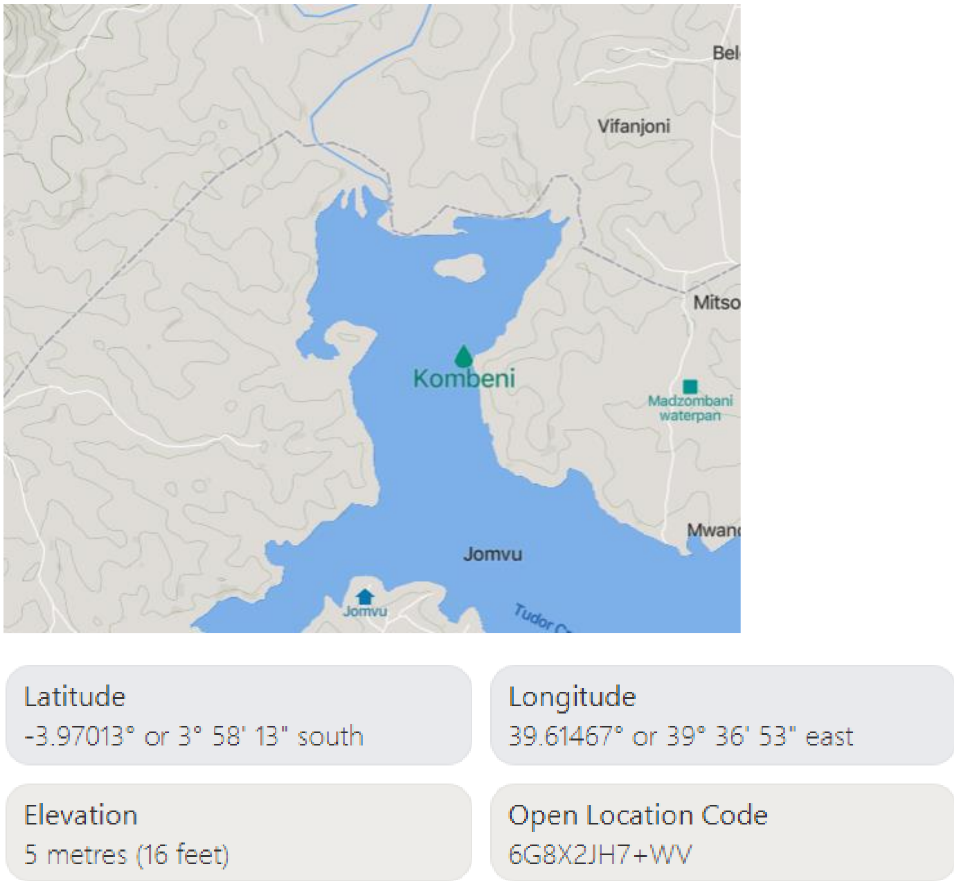


Figure 2: Map and coordinates of Kombeni River study site

1.2 River Sabaki

River Sabaki is located in Kenya and is a major tributary of the Tana River, the longest river in Kenya. It originates from the slopes of Mount Kenya and flows through the coastal plain before emptying into the ocean. The river also serves as a boundary between the counties of Kilifi and Kwale as can be seen in Figure 3 and Figure 4.

The climate of the Sabaki Tributary is categorised as tropical savannah, with a rainy season that typically runs from April to June, and a dry season from October to December. The area receives an average annual rainfall of around 600-800mm. The temperature ranges from 20-35°C. The land cover of the Sabaki Tributary region is primarily savannah grassland and forests, with some areas of cropland and human settlements. The area is also an important habitat for aquatic life.

River Sabaki is an important resource for the local population, and as such, there are a variety of activities that take place along its banks and in its basin. Agriculture is a significant activity in the area, with crops such as sugarcane, rice, and fruits being grown in the fertile land near the river. The river is also used for irrigation, which helps to support the agricultural activity in the area.

Fishing is another important activity along River Sabaki. The river is home to a variety of fish species, including tilapia, catfish, and barbel, and local fishermen rely on the river as a source of livelihood. The river also provides a habitat for many species of water birds and is a popular spot for birdwatching. Tourism is also an important industry in the Sabaki River basin. Visitors can take boat rides on the river, go fishing, or enjoy the natural beauty of the area by taking a hike or bike ride along the river's banks. There are also several lodges, campsites, and resorts along the river that provide accommodation and other facilities for tourists.

Figure 3: Satellite image of Sabaki River study site

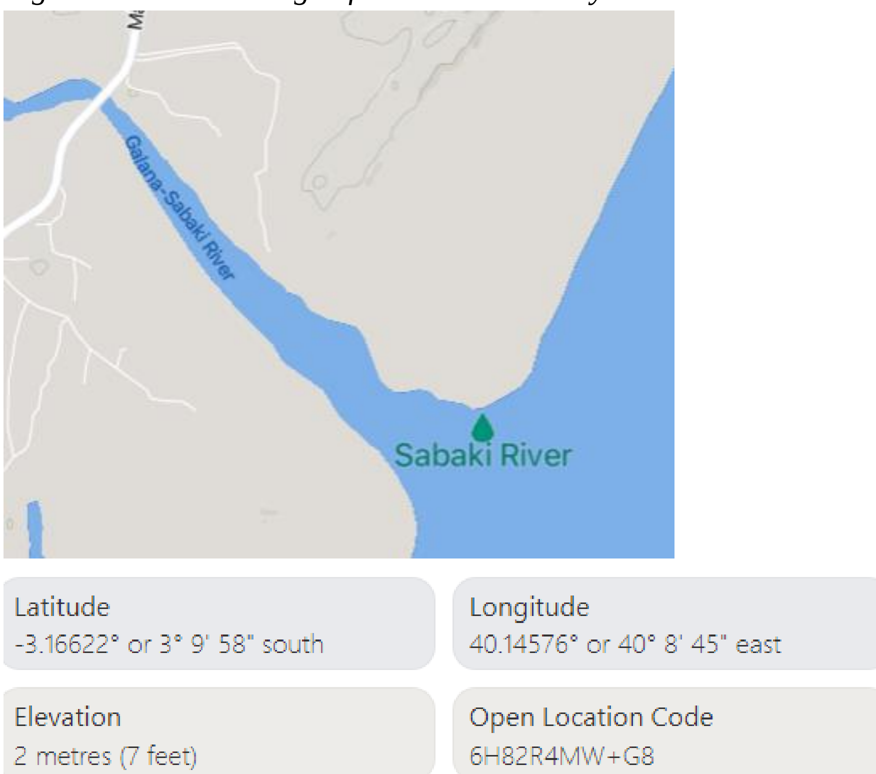


Figure 4: Map and coordinates of Sabaki River study site

1.3 Indian Ocean, Mombasa Coastal area

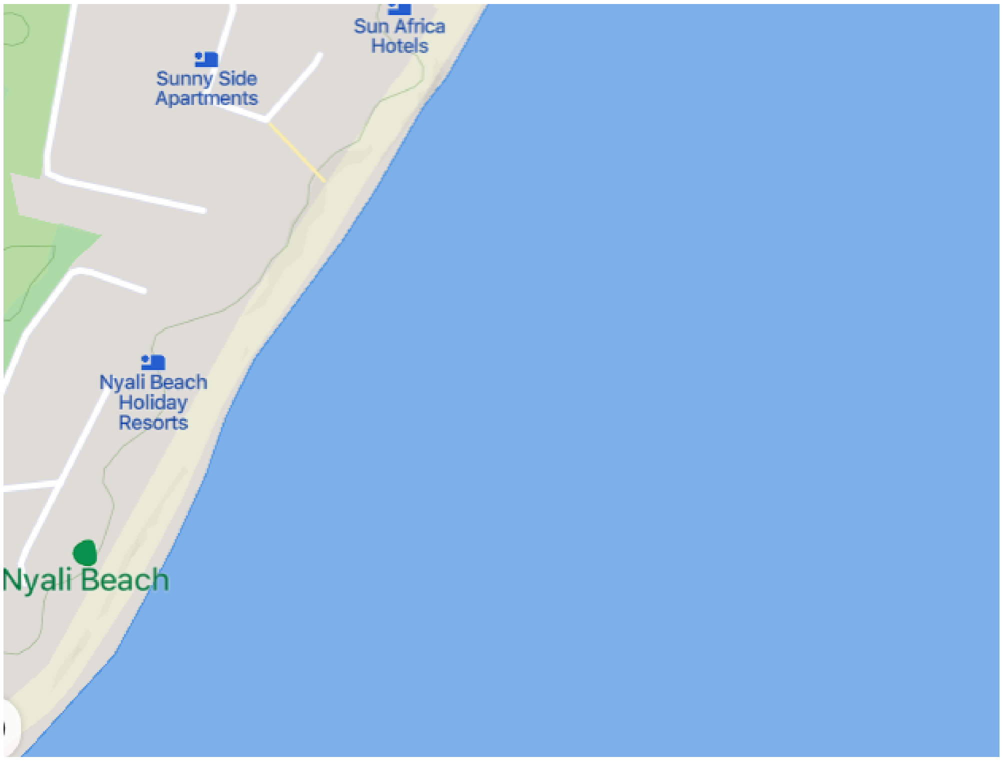
The coastal waters of Mombasa are part of the Western Indian Ocean and are characterised by warm temperatures, clear blue waters, and a rich diversity of marine life. A satellite image and the map of the area are shown in Figure 5 and Figure 6

The Mombasa coastal waters are home to a variety of marine habitats including coral reefs, seagrass beds, mangrove forests, and sandy beaches.

In addition to their ecological significance, the Mombasa coastal waters also provide important economic and social benefits to the local communities. They support a thriving fishing industry, provide opportunities for tourism and recreation, and serve as important transportation routes for trade.

However, the Mombasa coastal waters are facing several environmental challenges such as overfishing, pollution from human activities, habitat destruction, and climate change. These challenges threaten the health and sustainability of the coastal ecosystem and the livelihoods of the people who depend on it. Efforts are being made to address these challenges through conservation and sustainable management practices.

Figure 5: Satellite image of Mombasa Coast study site



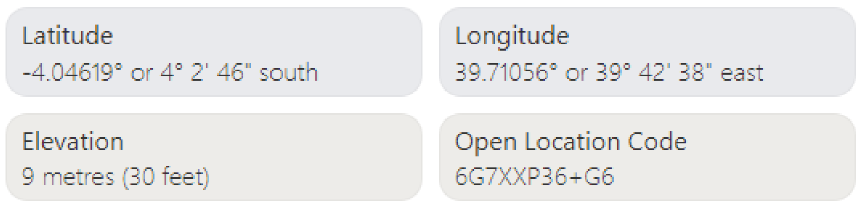


Figure 6: Map and coordinates of Mombasa Coast study site

1.4 Likoni Ferry Channel

The Mombasa Likoni Ferry water channel connects the southern mainland of Mombasa with Likoni, a suburb located on the southern side of Mombasa Island. The channel is part of the Indian Ocean and is influenced by tidal fluctuations, with high and low tides occurring twice a day. This is shown in Figure 7 and Figure 8.

The water in the Mombasa Likoni Ferry Channel is typically characterised by warm temperatures, clear to slightly turbid waters, and a low to moderate salinity level. The channel is also subject to a range of human-induced impacts, including pollution from runoff, waste disposal, and oil spills from passing ships.

Despite efforts to improve water quality and reduce pollution, the Mombasa Likoni Ferry Channel continues to face environmental challenges that can impact the health and safety of passengers and marine life. The ferry channel is an important transportation link for residents and visitors to Mombasa, and efforts to mitigate environmental impacts through improved waste management and pollution control measures are ongoing.

Figure 7: Satellite image of Likoni study site

Figure 8: Map of Likoni Ferry Channel study site

2. Data collection methods

We collected water samples from the above locations and visited the Coast Water Works Development Agency Laboratory in Mombasa (Figure 9a) to test the water samples for pH, conductivity, turbidity, alkalinity, chloride, total hardness and calcium hardness in accordance with the GLOBE Water Quality Protocol Bundle which focuses on the Hydrosphere (Figure 9b). Microbiological analyses were conducted at the Pwani University Biosciences Laboratory. A water sample from Mzima Springs was also collected as a control, as this is a source of potable water, considered uncontaminated and safe to drink.

Figure 9a: Coast Water Works Development Agency Laboratory

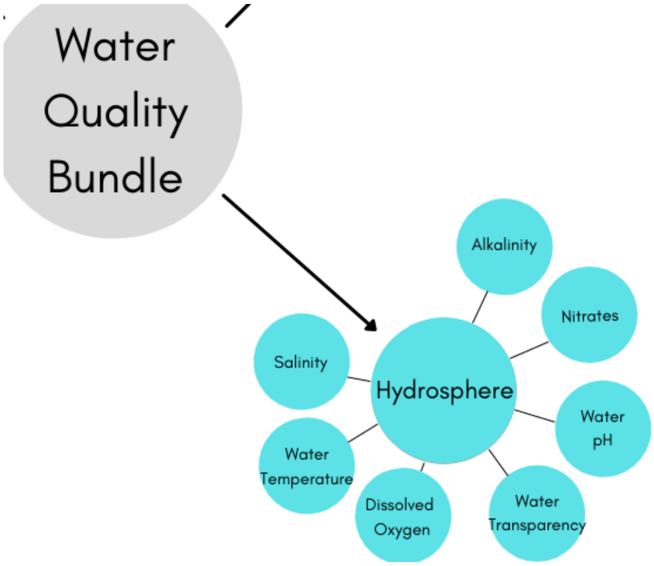


Figure 9b: GLOBE Water quality bundle

2.1 Chemical Tests

2.1.1 pH measurement

- The Palintest Photometer was used to measure the pH of water samples
- First a 'blank' (water sample with no tablet added) is inserted into the photometer.
- Once blanking is complete, the water sample is extracted from the photometer.
- A phenol red tablet is added to the water sample and is crushed and mixed.
- A sample is then inserted into the photometer and a pH reading is displayed as shown in Figure 10.

Figure 10: Measurement of pH

2.1.2 Conductivity

- The Wagtech Con 700 is used to measure the conductivity levels of our water samples
- Machine probe is cleaned using distilled water and inserted into the water sample
- A reading is displayed indicating conductivity levels, as seen in Figure 11

Figure 11: inserted probes and corresponding conductivity readings

2.1.3 Turbidity

- Turbidity was measured using a turbidity metre and was measured in nephelometric turbidity units (NTU).
- The sample was shaken and placed in a tube.
- The tube was inserted into the metre and aligned with the marker.
- A reading is displayed indicating conductivity levels, as seen in Figure 12.

Figure 12: Turbidity reading

2.1.4 Alkalinity

We performed a titration to test the alkalinity of each sample (Figure 13).
Procedure:

- Wash the burette with distilled water.
- Add 50 cm^3 of the sample into a beaker.
- Add 3 drops of methyl orange indicator to each sample.
- Add magnetic stir bars into each of the samples.
- Add sulfuric acid into the burette, to the 0 mark.
- Place each sample onto the magnetic stirrer.
- Perform the titration.
- Observe the colour change

The colour changed from yellow to pink.
This indicated the end point of the titration

Figure 13: Titration test for Alkalinity

2.1.5 Chloride

We performed a titration to test the chlorides in each sample.

Procedure:

- Wash the burette with distilled water.
- Add 50 cm^3 of the sample into a beaker
- Dilute the water samples from the different sources, by adding 1 cm^3 of the sample into a measuring cylinder and then adding distilled water to the 50 cm^3 mark. This is because these samples have a high conductivity that is above 1500 micrometres.
- Add 4 drops of potassium chromate indicator to each sample.
- Add magnetic stir bars into each of the samples.
- Add silver nitrate into the burette, to the 0 mark.
- Place each sample onto the magnetic stirrer.
- Perform the titration.
- Observe the colour change (Figure 14).

The colour changed from yellow to brick red. This indicated the end point of the titration

Figure 14: End point of chloride test titration

2.1.6 Total hardness

We performed a titration to test the total hardness in each sample.

Procedure:

- Wash the burette with distilled water.
- Add 50 cm^3 of the sample into a beaker.

- Dilute the samples from river Kombeni and the ocean by adding $1cm^3$ of the sample into a measuring cylinder and then adding distilled water to the 50 cm^3 mark. This is because these samples have a high conductivity that is above 1500 micrometres.
- Add 1.5 cm of ammonia (buffer solution) to each sample.
- Add eriochrome black t indicator to each sample.
- Add magnetic stir bars into each of the samples.
- Add EDTA (reagent) into the burette, to the 0 mark.
- Place the sample onto the magnetic stirrer.
- Perform the titration.
- Observe the colour change (Figure 15).

The colour changed from purple to blue. This indicated the end point of the titration

Figure 15: End point of titration test for total hardness

2.1.7 Calcium hardness

We performed a titration to test the calcium hardness in each sample.

Procedure:

- Wash the burette with distilled water.
- Add 50 cm^3 of the sample into a beaker.
- Dilute the water samples by adding 1 cm^3 of the sample into a measuring cylinder and then adding distilled water to the 50 cm^3 mark. This is because these samples have a high conductivity that is above 1500 μm.
- Add 1.5 cm^3 of sodium hydroxide (buffer solution) to each sample.
- Add a pinch of murexide indicator to each sample.
- Add magnetic stir bars into each of the samples.
- Add EDTA (reagent) into the burette, to the 0 mark.
- Place the sample onto the magnetic stirrer.

- Perform the titration.
- Observe the colour change (Figure 16).

The colour changed from pale pink to purple. This indicated the end point of the titration

Figure 16: End point of titration test for calcium hardness

2.2 Bacteriological Tests

2.2.1 Sample preparation

1. The samples were prepared by making serial dilutions of 10^{-3} and 10^{-5}
2. About 5.6g of nutrient agar was measured and dissolved in 200mls of distilled water. The mixture was then autoclaved and later left to cool.
3. After cooling it was dispensed into the petri plates and allowed to solidify (Figure 17).

Figure 17: Samples prepared into the petri plates

2.2.2 Sample Inoculation

1. About 100µl of the original sample, 10^{-3} and 10^{-5} was inoculated on the dispensed media and spread all over the plate using a wire loop

2. The plates were sealed and incubated at 37°C for 24 hours then later retrieved for observation. (Figure 18)

Figure 18: Petri plates being incubated

3. Data analysis

We used Microsoft Excel to present our results in form of graphs and analyse our data. We also captured images of the results of the microbial analyses.

Our research questions were:

1. What are the current conditions in terms of water quality of the local water bodies linked to Mombasa?

We were able to answer this question by comparing the data we obtained with the standards of water quality of Coast Water Works Development Agency which tested and produced water suitable for human consumption. This allowed us to compare our data from the results of the study sites with the range of good quality water in order to conclude the quality of our water.

2. What factors affect the quality of water?

We analysed the results to find the causes of the variations in the data. We were therefore able to identify which parameters appeared to be beyond the acceptable standards, in order to identify the main factors that affect the quality of water.

3. To what extent has human activities affected river water quality and what are the effects?

From our results, we were able to identify which factors are caused by human activities in order to see which human activities affect water quality and to what extent.

RESULTS

1. Chemical analysis

1.1 Conductivity

The Likoni Ferry channel water sample had the highest conductivity, followed by the Indian Ocean sample and Sabaki River, while the sample from River Kombeni had the lowest conductivity (Figure 19).

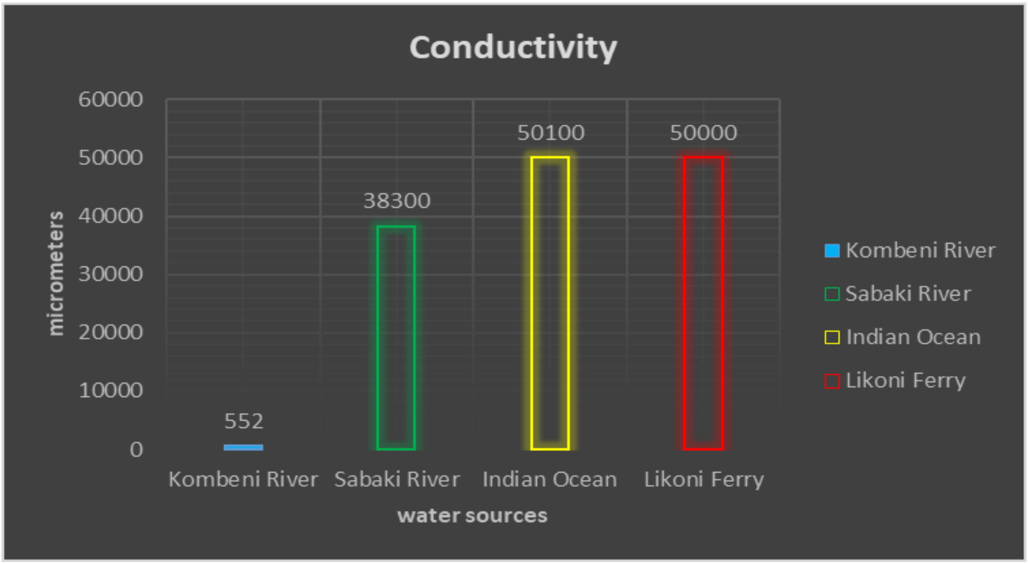


Figure 19: Comparison of conductivity of water samples

1.2 pH measurements

The water sample from the Likoni Ferry channel had the highest pH, of 8.4, compared to the rest of the samples, which had a pH of 7.4 (Figure 20).

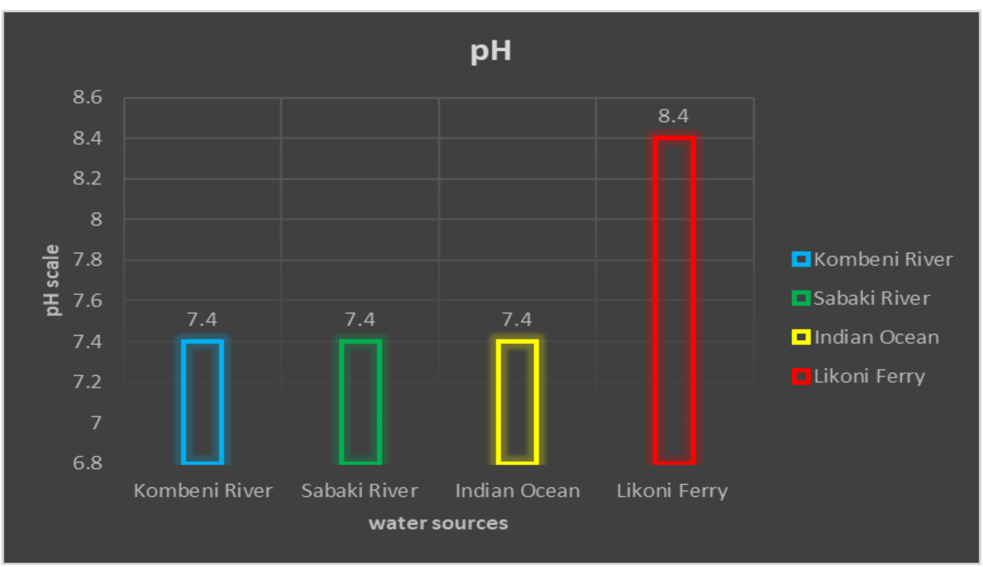


Figure 20: pH of water samples

1.3 Turbidity

The water sample from River Kombeni had the highest turbidity (55 NTU), compared to the rest of the samples, which had a turbidity ranging 2.3 and 21.7 (Figure 21)

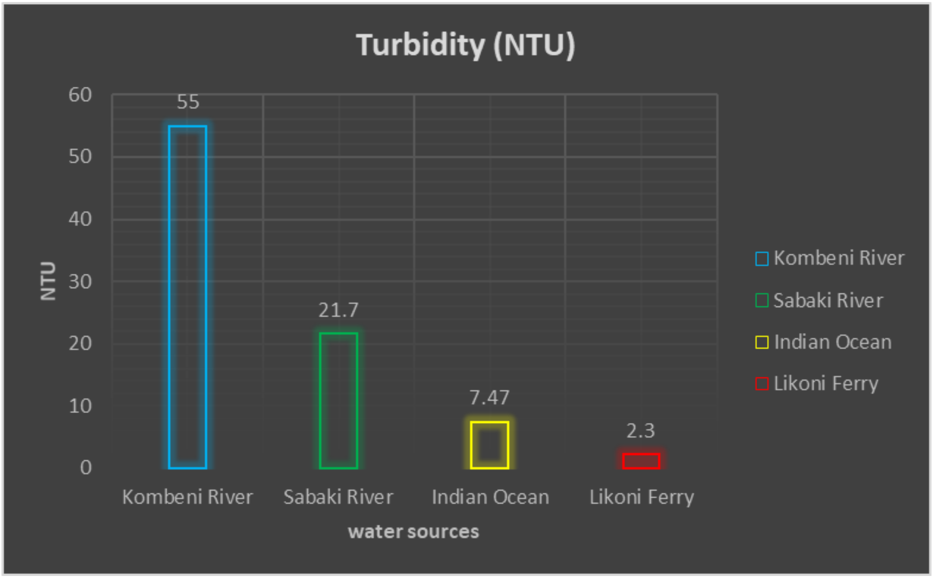


Figure 21: Turbidity of water samples

1.4 Alkalinity

The water sample from the Indian Ocean had the highest alkalinity (192 mg/l), followed by Likoni Ferry channel (124 mg/l), River Sabaki (122 mg/l) and River Kombeni (114 mg/l) as seen in Figure 22 below.

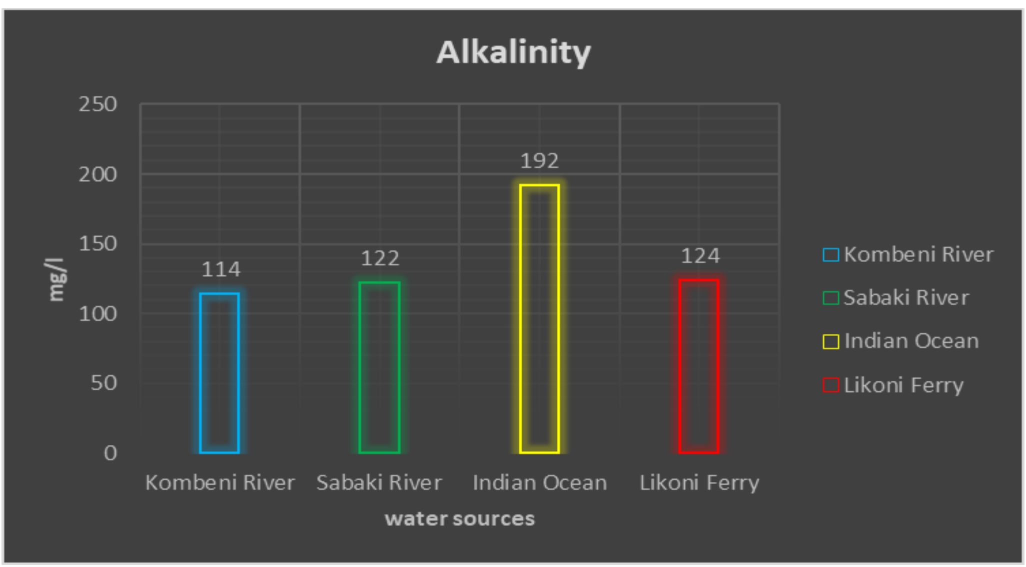


Figure 22: Alkalinity of water samples

1.5 Mineral content

Water from the Likoni Ferry channel had the highest amount of chlorides, followed by Indian Ocean water (Figure 23), whereas River Kombeni had the least amount of minerals compared to other water samples.

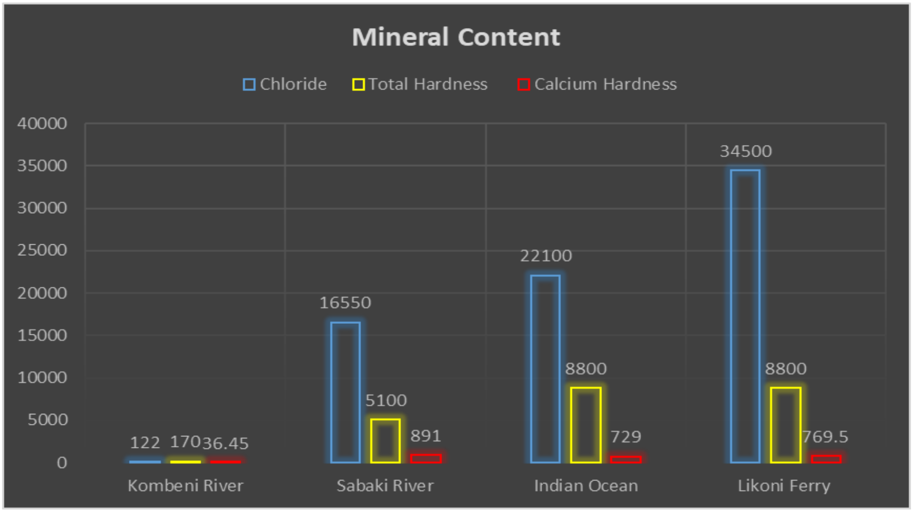


Figure 23: Mineral content of water samples

The results of the chemical analyses conducted on the different water samples are summarised in Table 1 below.

Table 1: Summary of results of the chemical analysis from the different water samples

	CHEMICAL ANALYSIS						
WATER SOURCES	pH	Turbidity (NTU)	Conductivity (µm)	Alkalinity (mg/l)	Chloride (mg/l)	Total Hardness (mg/l)	Calcium Hardness (mg/l)
Recommended Value	6.5 - 8.5	Max 5	Max 1500	Max 300	Max 250	Max 300	Max 150
River Kombeni	7.4	55	552	114	122	170	36.45
River Sabaki	7.4	21.7	38300	122	16550	5100	891
Indian Ocean	7.4	7.47	50100	192	22100	8800	729
Likoni Ferry Channel	8.4	2.30	50000	124	34500	8800	769.5

2 Microbiological analysis

2.1 Indian ocean

The Indian Ocean water sample had cream colonies that appeared to have a uniform structure and smooth edges being the majority (Figure 24).

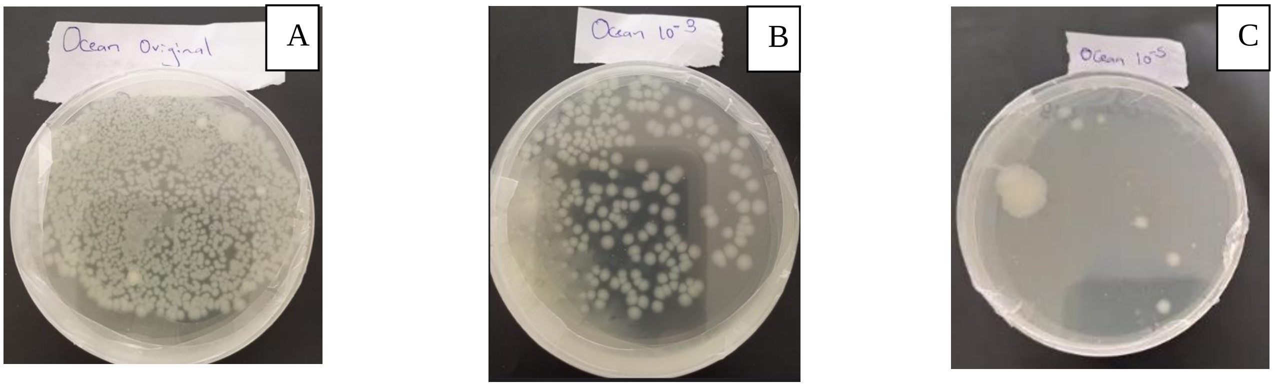


Figure 24: Microbial growth from Indian Ocean water sample. A: undiluted sample, B: 10^{-3} dilution, C: 10^{-5} dilution

2.2 River Sabaki

The water from River Sabaki appeared to have the most diverse colonies from smooth, irregular, serrated, and filamentous shaped colonies (Figures 25).

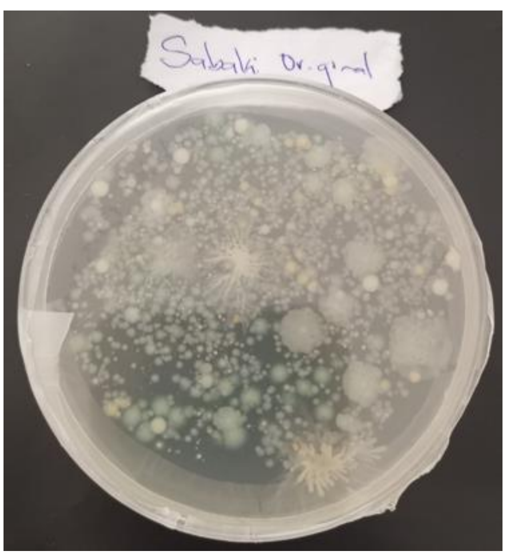
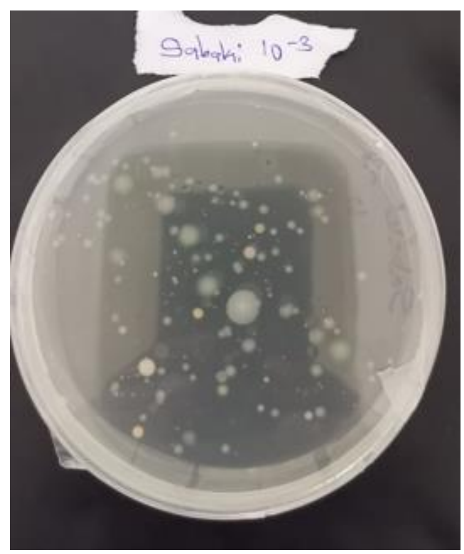


Figure 25: River Sabaki undiluted sample



River Sabaki sample at 10^{-3} dilution

2.3 River Kombeni

River Kombeni water sample seemed to have a high number of morphologically diverse microbial colonies (Figure 26).

Figure 26: River Kombeni undiluted sample

2.4 Likoni Ferry Channel

Water samples from the Likoni Ferry channel showed presence of pigmented colonies (Figure 27).

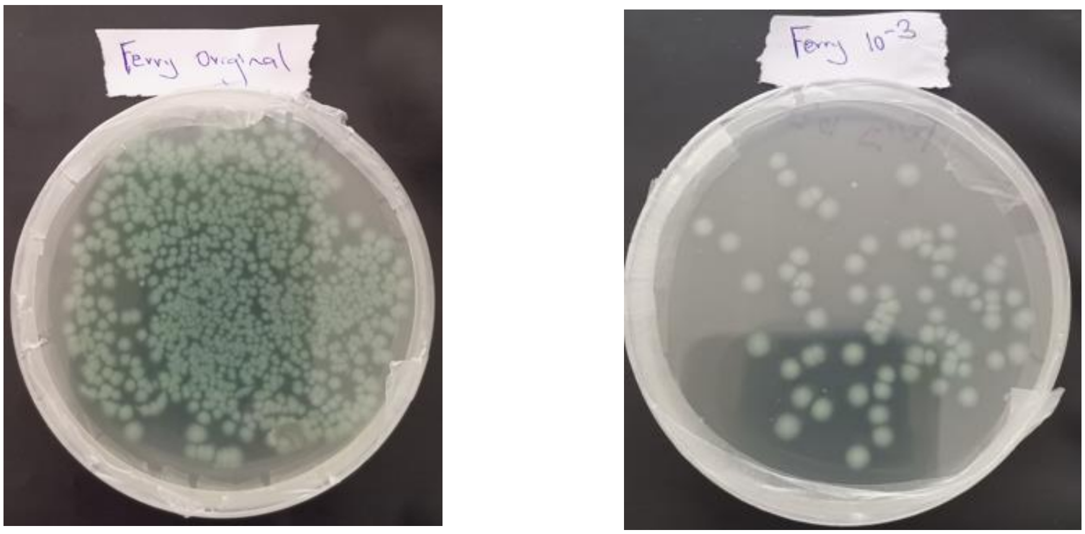
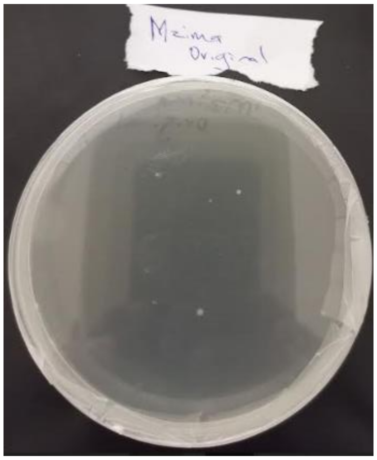


Figure 27: Likoni Ferry channel undiluted sample and sample at 10^{-3} dilution

2.5 Mzima Springs

It had the least number of colonies and was the least contaminated of all the water samples analysed (Figure 29). This was included in the analyses as a control, as it is considered to be an uncontaminated source of water, that is fit for human consumption.



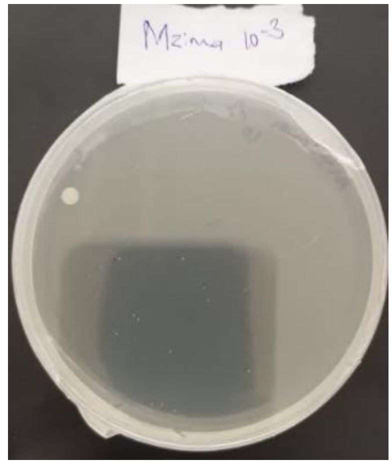


Figure 29: Mzima springs original sample *Mzima springs water sample at 10^{-3} dilution*

DISCUSSION

pH

pH is a measure of the acidity or basicity of a solution. In the context of water quality, pH is an important parameter as it affects the solubility and reactivity of chemicals in the water.

The Indian Ocean, River Sabaki, and River Kombeni water samples all had the same pH of 7.4.

Ocean acidification has reduced the pH levels of Coastal waters in Mombasa, this is prevalent from data results portraying a 7.4 pH which is more acidic than healthy ocean pH levels which lie at 8.1. This could be due to human activities, causing increased carbon dioxide (CO_2) emissions. Ferries and ports are sources of carbon dioxide emissions, as they often use diesel engines and other equipment that release carbon dioxide into the air. This carbon dioxide can dissolve in seawater, leading to the formation of carbonic acid and a decrease in pH levels.

The Likoni Ferry Channel water sample had a pH of 8.4, which was higher than the rest of the water samples. Presence of phosphates, limestone, calcium carbonates and borax tend to increase alkalinity of sea water. This could be due to human activities such as agriculture (phosphate based fertilizers), or leaching of carbonates and other chemicals from rocks and soils, which end up in the ocean waters. There is higher human activity along the Likoni Ferry Channel as compared to open ocean waters around Mombasa.

However, all pH levels were still within the range of 6.5 - 8.5

Turbidity

Turbidity is a measure of the cloudiness or haziness of water caused by suspended particles.

The Ocean had the lowest turbidity (7.47 NTU) due to the deep water and slow-moving currents. The Indian Ocean is also a large body of water that is located far away from land and therefore may have lower levels of sediment and other particles compared to rivers that flow through the land.

Meanwhile the Rivers Sabaki and Kombeni had higher turbidity (21.7 and 55.0 NTU respectively) which was due to the shallow waters and fast-moving currents resulting in a lot of sediments being carried by the water. Rivers like River Sabaki and River Kombeni receive a lot of sediment and organic matter from the surrounding land, which contributes to higher turbidity levels in the water.

Deforestation and land use changes in the Sabaki River basin are affecting the river's environment. Deforestation leads to soil erosion, which increases the sedimentation of the river, increasing its turbidity and reducing its water quality and habitat for aquatic life.

The area around River Kombeni uses outdated agriculture methods including monoculture, overgrazing, and over-irrigation. This leads to a higher surface runoff which may contain high levels of pollutants in the area near River Kombeni leading to an increased risk of soil erosion. Therefore the river quality deteriorates affecting the turbidity as shown by the high turbidity level.

The turbidity at the Likoni Ferry Channel (2.3 NTU) was much lower than the turbidity of the Indian Ocean sample. It was also the only sample that had a turbidity reading that met the recommended standard of a maximum of 5. This is most likely because ports and ferry areas are often designed to minimise sediment inputs and maintain deep channels to allow ships to dock. This can reduce the amount of sediment that is stirred up from the seabed and suspended in the water, resulting in lower turbidity levels. Ports and ferry areas also have increased water circulation due to the presence of currents generated by tides and ship traffic. This increased water flow helps disperse any sediment or particles in the water, leading to lower turbidity levels.

Conductivity

Conductivity refers to how well water can carry an electrical current. It's the minerals or dissolved particles that carry an electric charge. Conductivity is a measure of a solution's ability to conduct electrical current.

We can identify that the Indian Ocean (50100 µm) and Likoni Ferry Channel (5000 µm) are the most conductive sources of water compared to the Sabaki (38300 µm) and Kombeni (552 µm) Rivers respectively. This is because the Indian Ocean and Likoni Channel are saltwater bodies, and the high conductivity is mainly due to the high concentration of dissolved salts, such as sodium, chloride, and magnesium. In comparison, the rivers are freshwater sources and have a lower conductivity rating as they do not have as many dissolved salts.

River Sabaki did have a much higher conductivity than River Kombeni. This may be because one of the main environmental challenges of River Sabaki is pollution, which is caused by a variety of sources, including industrial waste, agricultural runoff, and sewage. The discharge of untreated industrial waste and sewage into the river leads to the accumulation of pollutants, such as heavy metals and chemicals, which is harmful to aquatic life and the people who rely on the river for drinking water and other uses. River Sabaki had conductivity levels of 38300 µm a which is very high for river water; this can be attributed to the aforementioned accumulation of heavy metals and chemicals.

River Kombeni is the only water source that has a conductivity rating below the maximum 1500 µm in accordance with the water quality standards.

Alkalinity

Alkalinity is a measure of a solution's ability to neutralise acids. The Indian Ocean has a higher alkalinity (192 mg/l) compared to the rivers. This could be because of the presence of naturally occurring bicarbonate and carbonate ions in the water. The higher the concentration of bicarbonate and carbonate ions in the water, the higher the alkalinity.

River Sabaki has lower alkalinity levels (122 mg/l) and this may be because River Sabaki is a freshwater river that originates from inland sources and so, the overall alkalinity levels are likely to be influenced more by freshwater sources. The geological conditions in River Sabaki are also different from those in the Indian Ocean, which affects the alkalinity levels of the water. For example, the rocks and soils in the Sabaki River basin are less rich in bicarbonate and carbonate ions compared to those in the ocean, resulting in lower alkalinity levels in the water. River Sabaki also had a large number and diverse amount of microorganisms. This reduces the alkalinity as the bacteria releases carbon dioxide increases the acidity of the water

River Kombeni also has low alkalinity levels (114 mg/l) and this is because the river is located inland and is not directly connected to the Indian Ocean. As a result, the river is not influenced by the alkalinity levels of the ocean water. Instead, the alkalinity levels of the river are primarily influenced by the dumping of sewage, mainly faecal matter, which encourages the growth of bacteria. The bacteria use up the oxygen and the release of carbon dioxide increases the acidity of the water which reduces the alkalinity.
The alkalinity levels are also affected by local geology. The rocks and soils in River Kombeni basin may be less rich in bicarbonate and carbonate ions compared to those in the ocean, resulting in lower alkalinity levels in the water.

Likoni Ferry Channel had lower alkalinity levels (124 mg/l) than the Indian Ocean. Its alkalinity levels are closer to River Sabaki. This is because of increased carbon dioxide (CO_2) emissions. The ferry is a major transportation hub, with significant road traffic and commercial shipping activity. There are also several facilities such as refineries, cement factories, and power plants that burn fossil fuels to generate energy. The city relies on electricity generated by power plants, which often burn fossil fuels such as coal, oil, or gas. Emissions from the burning of fossil fuels in transportation, industrial activities, electricity generation and commercial and residential activities all emit significant amounts of carbon dioxide and so contribute to the carbon dioxide emissions. This carbon dioxide dissolves in seawater, leading to the formation of carbonic acid which decreases alkalinity levels.

All water sources have an alkalinity level in accordance with the water quality standards, a level below 300 mg/l.

Chlorides

Chloride is an anion of chlorine that is found in many natural water sources.

Likoni Ferry Channel had the highest amount of chlorides (34500 mg/l). This may be because of shipping activity as the ferry area is a busy shipping hub, with ships regularly transporting goods and people to and from different locations. These ships often use seawater as ballast (stabiliser), which can lead to the discharge of large volumes of seawater that contain high levels of chloride. Another reason for high chloride levels is the large amounts of wastewater discharged into the surrounding ocean, which can contain high levels of chloride from sources such as saltwater toilets or cleaning operations. The high quantities of chlorides may be carried by water, as it runs off paved surfaces as virtually all of the land at a port terminal is paved and therefore impervious to water.

The Indian Ocean has a higher amount of chlorides (22100 mg/l) compared to River Sabaki (16550 mg/l) and River Kombeni (122 mg/l). This is because it is a body of saltwater and therefore has higher levels of chloride due to the natural presence of salt in these bodies of water.

River Sabaki also has a high amount of chlorides (16550 mg/l). This is because the river basin is an important agricultural area, with crops such as maize, beans, and fruits grown along its banks. The use of chloride-based fertilisers and the disposal of animal waste from livestock farming increase the chloride levels in the river.

River Kombeni, although there are a lot of agricultural activities and high surface runoff, has low chloride levels (122 mg/l) and this is due to the distance from the ocean: The Kombeni River is located about 30 kilometres inland from the Indian Ocean, and therefore does not receive much influence from seawater as compared to River Sabaki, which is located about 10 kilometres away from the Indian Ocean. Chlorides are typically present in higher concentrations in water sources that are closer to the ocean.

River Kombeni is the only water source that has chloride levels below the maximum of 250 mg/l in accordance with water quality standards.

Total Hardness

Total hardness is a measure of the concentration of certain minerals, primarily calcium, and magnesium, in water. The Indian Ocean and Likoni Ferry Channel have the same high value of total hardness (8800 mg/l) meaning they both have the same high amounts of calcium and magnesium ions. This may be due to the presence of minerals such as calcium and magnesium in the water. These minerals are naturally occurring and are dissolved in seawater due to the erosion and weathering of rocks and soils on land, as well as volcanic activity on the ocean floor.

River Sabaki also has high total hardness (5100 mg/l) and this may be influenced by human activities, such as agricultural runoff, sewage discharge, and industrial waste. These activities introduce additional minerals and contaminants into the water, which increase the total hardness.The discharge of untreated industrial waste and sewage into the river leads to the accumulation of heavy metals and chemicals. River Sabaki had a total hardness which is very high for river water; this can be attributed to the accumulation of heavy metals and chemicals.

River Kombeni had the lowest levels of total hardness (170 mg/l). This may be because River Kombeni also has an uneducated population surrounding it, hence the number of people using outdated agriculture methods is very high, these include monoculture, overgrazing, and over-irrigation. These outdated methods lead to a bad use of the land. Overgrazing and monoculture make the land bare and barren. This increases surface runoff. The significant amount of rainfall and surface runoff the river receives, dilutes the mineral content of the water and results in lower total hardness levels.

River Kombeni is the only water source that has total hardness levels below the maximum 300 mg/l in accordance with the water quality standards.

Calcium Hardness

Calcium hardness is a measure of the number of calcium ions present in the water, which is a type of total hardness.

River Sabaki had the highest levels of calcium hardness (891 mg/l) or the highest amount of calcium ions. This is because River Sabaki is located closer to the Indian Ocean which means that it is influenced by seawater intrusion. Seawater contains higher concentrations of dissolved minerals, including calcium, increasing the hardness of the water. The Sabaki River also has a larger catchment area and may receive more runoff from agricultural areas, which can also contribute to higher calcium levels in the water due to the use of calcium-based fertilisers.

In contrast, River Kombeni had very low calcium hardness levels (36.45 mg/l). This is because it is located further inland and is not as influenced by seawater intrusion. It also receives less agricultural runoff, resulting in lower calcium levels in the water.

The Indian Ocean has high levels of calcium ions (729 mg/l) due to the minerals being naturally occurring in saltwater bodies. Likoni Ferry Channel has a high level of calcium ions (769.5 mg/l) this is similar to the Indian Ocean sample as the calcium concentration in seawater is relatively constant and does not vary significantly over small distances.

River Kombeni is the only water source that has calcium hardness levels below the maximum of 150 mg/l in accordance with the water quality standards.

Microbiological analyses

Microbiological water analysis tests the water to evaluate the presence of microorganisms that are contaminants. These microbes include bacteria, viruses, and pathogenic protozoa.

The Indian Ocean Sample appeared to have the highest amount of microorganisms which may be caused by large amounts of sewage being dumped into the ocean. The dumping of sewage, mainly faecal matter, encourages the growth of bacteria.

The Indian Ocean sample and Likoni Ferry Channel sample have different types of microorganisms present. This may be because of several factors. Firstly, the Likoni Ferry Channel is used by people to cross the channel between Mombasa Island and the mainland. The presence of people, their activities, and their waste can influence the type and number of microorganisms found in the surrounding environment. Secondly, the water conditions around the ferry may be different from those in the open ocean. For example, there may be more nutrients or pollutants in the water around the ferry due to human activity, which can influence the microorganisms present. Finally, physical structures such as the ferry itself and the infrastructure around it, docks and piers, can create a different environment for microorganisms compared to the open ocean. For example, the surfaces of the ferry and the structures around it may provide a place for microorganisms to attach and grow.

River Sabaki had the greatest diversity of microorganisms. This may be due to human activities happening along the river such as agriculture, mining, and industrial processes that contribute to high levels of nutrients that can promote the growth of microorganisms. Industrial waste may also include a large number of microorganisms that may not otherwise be found in the river. The dumping of sewage also contributed to the growth of the bacteria by providing them with nutrients.

River Kombeni had a large number of microorganisms, this may be because this area is surrounded by impoverished communities which dump large amounts of waste into and around the river due to the inaccessibility of proper waste management. The dumping of sewage encourages the growth of bacteria. Another impact of untreated sewage is that it elevates the concentration of nutrients as well as stimulates the growth of algae which can lead to algal blooms resulting in eutrophication which harms the ecosystem.

Climate change also increases the temperature of the water over time, this affects the growth and survival of microorganisms as warmer temperatures are more favourable to harmful bacteria. This increases the growth of these bacteria which also increases the acidity of the river and decreases the oxygen levels, this means that marine life such as fish dies due to lack of oxygen, and inadequate temperature. Climate change also affects the nutrient cycle of the rivers, leading to higher phosphorus and nitrogen levels which fuels the growth of harmful bacteria and algae leading to depletion of oxygen and large populations of marine life killed.

Mzima Spring samples were tested as a control due to the water being generally considered uncontaminated and safe to drink. The springs had the lowest amount of microorganisms present. This may be because as spring water rises through the rocks, it undergoes a natural filtration process as it has travelled through natural filters like limestone, sandstone, and clay therefore the bacteria and other contaminants have been filtered out of the water by rock, sand, gravel or soil layers.

Evaluation of hypothesis

The following conclusions about our hypothesis were made:
1 - The general water quality in Mombasa county is poor and unfit for human consumption.
Our findings supported this hypothesis as the data we collected indicated that each of the water samples tested are chemically unfit for human consumption due to the following:

- Kombeni River- Water is not chemically suitable for human consumption due to high turbidity and large amount of microorganisms present.
- Sabaki River- Water is not chemically suitable for human consumption due to high mineral content and large amount of microorganisms present.

- Indian Ocean- Water is not chemically suitable for human consumption due to high mineral content and large amount of microorganisms present.
- Likoni Ferry Channel- Water is not chemically suitable for human consumption due to high mineral content and contamination.

2 - Water quality in Mombasa island is mainly affected by human factors.
Our findings show that the main factors affecting water quality include, agriculture, sewage and dumping, industrial waste, deforestation and land use changes and increase in greenhouse gas emissions which contributes to climate change. These are all human factors which support the hypothesis that water quality is affected by human activities.

3 - Human activities such as dumping of sewage, industrial and agricultural processes affect the quality of water considerably.
According to microbiological tests conducted, all study sites contain high levels of bacteria colonies making the water contaminated and unsafe for human consumption. There is also an increase in pH and therefore a decrease in alkalinity which largely affects the quality of water. Such contamination arises due to dumping of sewage, and other industrial waste hence emphasising on the impact of human activities. Agricultural processes such as adding fertilisers and pesticides affected the quality of water by introducing additional minerals and contaminants into the water, which increased the total hardness of the water. Therefore, our results support this hypothesis.

Possible sources of error

Sampling.
A sample of a single point of a water body cannot truly represent the entire water body. This is seen in rivers because the river changes and becomes deeper and slower as it travels from source to mouth. A sample near the source of the freshwater river will most likely have less dissolved salts and minerals as it is very far from the Indian Ocean allowing for less saltwater intrusion compared to a sample near the mouth of the river. There may also be different human activities occurring along the river. For example, if a sample is taken close to the industry there may be industrial waste released into the river that could affect the alkalinity of the water. Turbidity is also affected by whether the sample is collected from a point in the river with shallow waters and fast-moving currents causing high turbidity or deep water and slow-moving currents causing low turbidity. This is also seen in the Indian Ocean, where two samples were collected. One was a water sample in an open area and the other was a sample of the area around the ferry. These two samples had some differing results showing that a single sample of a water source is not a good representation.
Secondly, we collected water samples during Mombasa's hottest season, and so many of the water bodies dried up, this may reduce the accuracy of the impurities that may or may have not been detected by the tests conducted.

SOLUTIONS

What can be done?

There are numerous ways to effectively combat the water pollution affecting the water sources of Mombasa, these include:

- Wastewater treatment
- Green Agriculture and Wetlands
- Denitrification
- Water Conservation

Wastewater Treatment

The most effective way to treat contaminated water is to treat it before it enters the waterway system, and this can be achieved through the use of wastewater treatment plants, this is one of the most common forms of pollution control. These installations have the technology and tools to extract most pollutants through natural, physical, and chemical processes effectively. For example, sewage treatments allow water to travel through multiple sanitization chambers to reduce the level of dangerous chemicals and prevent leakages into water systems. However regular maintenance of the equipment is needed to ensure these wastewater treatment installations function properly and efficiently. This includes applications such as water treatment detectors, which are vital to measure and remove potential pollutants in order to effectively treat water pollution in Mombasa.

Green Agriculture & Wetlands

Agriculture is one of the major economic activities in Mombasa and makes up a large percentage of Kenya's GDP. However, agriculture can be incredibly detrimental to the quality of water. As agriculture is such a large industry, it's one of the primary causes of water pollution. When it rains, runoff transports pesticides and fertilisers. However, agriculture can be environmentally friendly, this is known as "Green Agriculture". Green agriculture involves using pesticides and fertilisers that contain no percentage of hazardous chemicals. It also involves the growing of trees and other foliage as well as the creation of wetlands to form buffer zones, which filter runoff and water pollutants hence reducing water pollution.

Denitrification

This refers to the process of reducing nitrate and nitrite to gaseous forms of nitrogen through the use of microorganisms. When nitrate levels are high in water, the surrounding environment enables the process of eutrophication additionally over fertilisation may occur affecting surface runoff. This enables algae and phytoplankton in the water to grow rapidly, reducing water quality, and contributing to high levels of water pollution. Denitrification directly converts nitrates into nitrogen gas. This ecological process prevents nitrate from leaking into soils and helps reduce the contamination of groundwater.

Water Conservation

Water conservation includes all the policies, strategies, and activities to sustainably manage and avoid the loss of water, these policies can be advocated by the citizens of Mombasa in order to reduce the loss and contamination of fresh water, some examples include rain-water harvesting which can be amplified on a large scale, protecting groundwater resources and lastly practising sustainable methods of utilising groundwater resources. These methods effectively aid in the conservation of water hence reducing water pollution.

CONCLUSION

The aim of our project was to understand the factors that contribute to the quality of water in Mombasa County and if they are fit for human consumption. We also set out to investigate the state of our water bodies in terms of quality as our study sites play a key role in human consumption in Mombasa County.

Our results show that all the water sources that we studied were not fit for human consumption.

We analysed our results and therefore concluded that the main factors affecting water quality include, agriculture, sewage dumping, industrial waste, and increase in greenhouse gas emissions which contributes to climate change. We came to this conclusion as we realised that these factors appeared most often as the cause of the poor water quality of our study sites and had broad impacts. These findings are important as they identify the problems and can be used to find ways to improve the water quality.

The improvements we could make on our research methods are as follows;

- Improve sampling method, collect more samples to be able to assess an entire water body as a whole better
- Investigate water quality using other parameters such as plastic pollution
- Compare factors affecting water quality in other regions in the world and what measures are being taken to address these.

The next step is to implement the solutions we have come up with to try and improve water quality in Mombasa County, and if proved efficient, implement them in the whole of Kenya.

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BADGES

I AM A STEM PROFESSIONAL- Collaboration with the Coast Water Works Development Agency Laboratory allowed us to enhance our research methods. Working alongside skilled professionals in the water quality testing field allowed us to improve our precision of testing and get an in-depth understanding of the procedures and parameters taken into consideration when testing for water quality. Collaboration with Pwani University Biosciences Laboratory aided learning of microbiology analyses and improving experimental skills, data analysis and presentation of results.

I AM A DATA SCIENTIST- We were able to design experiments, generate extensive data and conducted an in-depth analysis of the data in order to draw our conclusions. Limitations on data were also discussed.

I AM A COLLABORATOR- The team members involved in this study collaborated through every step to ensure this project reaches the finish line. Students involved collaborated with respective teachers in terms of research. Data collection was made possible through organising expeditions for sampling. Chemical and microbial analysis of samples collected was made possible through collaboration with technical personnel from Coast Water Works Development Agency Laboratory and Pwani University Biosciences Laboratory respectively. Data analysis and formation of the report was carried out among students, each student played a role in each step of the study, including: sample collection, experimental work, data collection, data analysis and report writing and poster preparation.