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Effects of Salt Harvesting on Ground Water Quality in Gongoni Ward, Kilifi County, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Author AG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PGN and BM supervised field work and data analyses and reviewed and edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To determine the effects of salt harvesting on ground water quality in Gongoni ward, Kilifi County.

Study Design: The study design was purposive where sampling points were deliberately chosen.

Place and Duration of Study: The study was carried out in Gongoni ward and its environs in Kilifi County from May 2015 to July 2015.

Methodology: Sixteen sampling points were selected within the study area and sampling was done twice between May and July 2015. The water samples collected were analyzed for sodium (Na^+), Chlorides (Cl^-), Fluorides, (F^-) Calcium (Ca^{2+}), alkalinity, acidity (pH), *E. coli*, Total Dissolved Solids (TDS) and Salinity as NaCl in the Government Chemist laboratories in Mombasa. The collected data was analyzed using SPSS and Microsoft Office Excel.

Results: The ground water sources in Gongoni ward registered high levels of key parameters (TDS, Salinity, Chloride, and Sodium) than the adjacent areas of Mambrui, Ngomeni and selected secondary data from Mombasa County wells where no salt harvesting occurs. Gongoni water sources had a mean TDS of 1969.00mg/L and the adjacent area shad TDS of 1050.00 mg/L. The level of *E. coli* and total coliform were above the Kenyan and WHO permissible limit of 0 MPN/100ml

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for treated water and 10 MPN/100mls for untreated water.
Conclusion: Despite the elevated concentration levels of chemical parameters from Gongoni ward water sources, the differences are not statistically significant when compared to the adjacent areas of Mambrui and Ngomeni.
Recommendations: The water from sources with high levels of TDS and salinity should be pre-treated to make the water more suitable for human use. Those with high coliform and *E. coli* bacteria should be regularly treated using the appropriate disinfection methods. It is recommended that all projects on salt harvesting should be subjected to an Environmental and Social Impact Assessment (ESIA) before implementation as provided by the Kenya Environmental Management and Coordination Act of 1999.

Keywords: Salinity; total dissolved solids; sodium; water quality; gongoni ward.

1. INTRODUCTION

1.1 Background of Study

Coastal salt harvesting has been practiced since salt crystals were first identified in trapped pools of ocean water [1]. Salt extraction from sea water through the solar evaporation method is common in warm climate regions where evaporation rate exceeds precipitation rate annually for projected periods. The process involves capturing sea water in a connected series of shallow ponds where solar radiation evaporates most of the water [2,3,4]. The sea water starts off with a natural salinity of about 3% and ends up at about 25% salinity [5].

The salt extraction process can lead to the pollution of marine and freshwater ecosystems mainly through the discharge into the environment and estuary of mother liquor (UNHCR, 2006, [4] which mainly consists of sodium chloride together with other salts like calcium carbonate, potassium sulphate, potassium chloride, sodium carbonate among others [6] The concentrated salt water increases sea salinity, thus impacting negatively on ground water, marine life such as juvenile fishes, fish eggs and mangrove saplings. Furthermore, the discharge of the mother liquor onto land poses a pollution risk of groundwater supplies. Pollution of groundwater can be through lateral encroachment from the ocean due to excessive water withdrawals; upward movement from deeper saline zones due to upcoming near coastal discharge/pumping wells or lowering of water levels when constructing drainage canals [7]. The study area lies more or less at sea level and the lagoonal depression experiences daily incursions of sea water during high tides [8].

Salt harvesting from brine in Kenya is the oldest source of the common salt (sodium chloride). Salt harvesting activities in Gongoni were started by Mombasa Salt Works Limited, a German company established in 1928 and operating on a 1017 ha piece of land [9]. Five more companies joined the salt harvesting activities and acquired more land in adjacent areas. As salt harvesting activities in the area intensified the negative impacts on the local environment deteriorated. These generated complaints from the local community that the fresh water sources from which they traditionally drew its water were being contaminated by underground salt seepages and other activities emanating from the salt manufacturing companies' actions. The residents of Gongoni presented their environmental-related grievances attributed to the establishment and operation of salt manufacturing in Gongoni, Marereni and Kurawa areas, during an inquiry conducted by the KNCHR in July 2005. The grievances included salinization of freshwater wells and springs, flooding as a result of dyke-building and pollution on both coastal and marine ecosystems and soils [9].

However, salt harvesting activities in Gongoni offer employment to the local communities. This has attracted people from the adjacent areas in search of employment while others come to take advantage of the business opportunities presented by the increased population. Human and animal sources of fecal contamination represent a serious health risk because there is a high likelihood that their waste contains pathogenic E. coli strains [10]. These can access the drinking-water and affect its quality and have an adverse impact on human health [11].

The health of those working at the salt mines and those using the polluted groundwater can also be at risk of suffering from other diseases. A study by S. Murugan et al, [12] showed that working environmental conditions of salt industry exposes the workers to direct contact with inhalable salt dust; salt crystals give direct impact on brine, physical stress, direct bright sunlight and glare due to sunlight reflected by salt crystals and brine surface. This situation can be aggravated by the intermittent supply of piped tap water and over reliance on groundwater in the study area. According to a field survey by Ocholla et al. [4] corrosion of iron sheets within the neighborhood of the study area (Gongoni) was closely linked to acidic rains resulting from the evaporation of highly concentrated brine water from the salt lagoons.

This study was designed to determine the effect of the salt harvesting on the ground water quality in Gongoni ward, Kilifi County. The specific objectives of the study were to determine the chemical and biological contamination levels of ground water sources in Gongoni ward and to determine the relationship between the influence of the proximity of the salt harvesting ponds on the water quality of groundwater sources.

2. METHODOLOGY

2.1 Study Area

The research was carried out in Gongoni ward, Magarini Sub-County of Kilifi County, Kenya (Fig. 1).

Water samples were collected from Gongoni ward and adjacent areas such as Ngomeni 8 km and Mambrui 15 km away from the salt harvesting ponds. This was necessary to provide comparative analysis to check the effect of salt water contamination (Table 1).

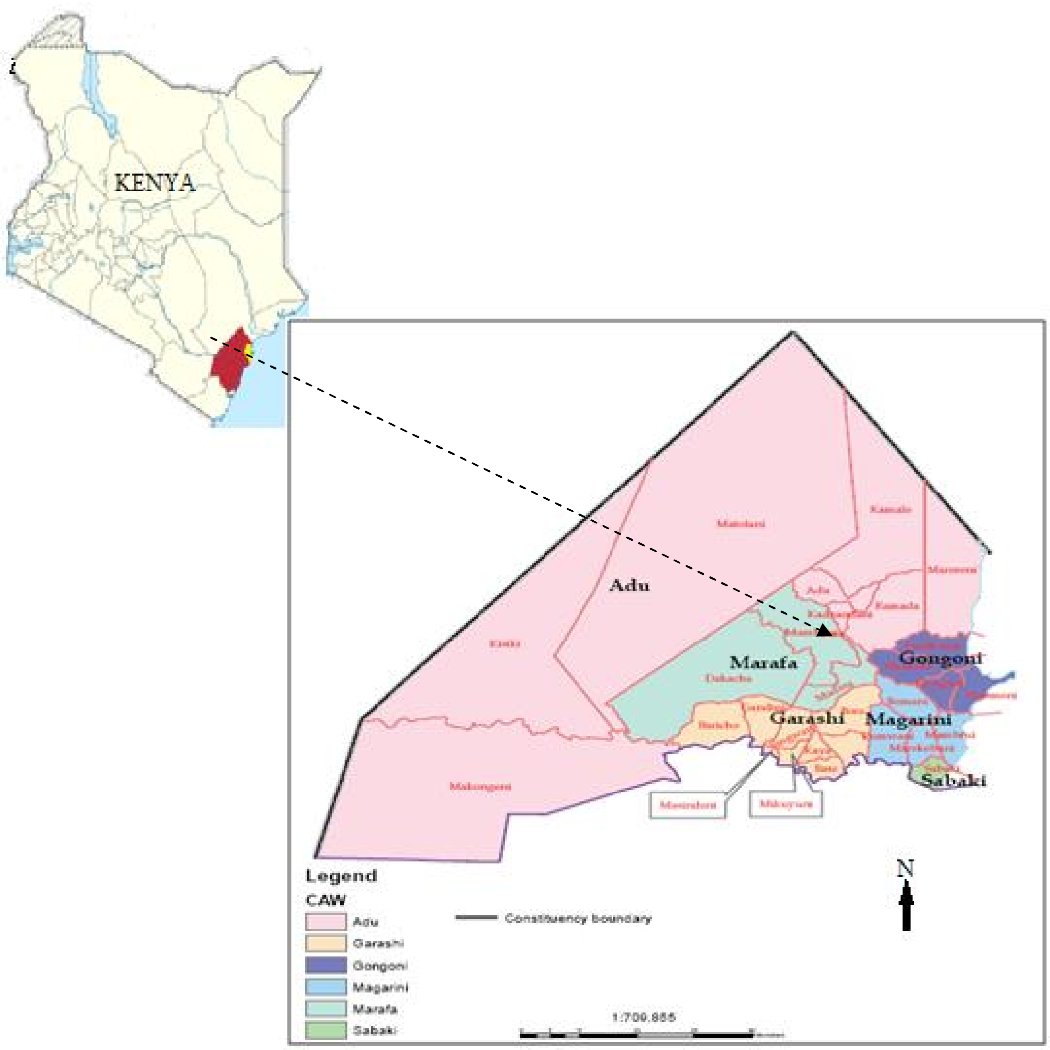

Fig. 1. Map showing location of the study area (Gongoni) in Kilifi County, and in Kenya (inset)

Table 1. Wells sampled in Gongoni and neighboring areas

S/No	Sampled at	Facility	Covered	Est.dist. from salt firm(s) (KM)
1	Ken-Salt-Kadzuhoni	Tank	Yes	<0.5(3°2'5.0''S – 40°8'16.8''E
2	Krystalline salt firm-Madukani	Tap	Yes	<0.5(3°2'8.0''S – 40°8'13.6''E
3	Krysatalline salt firm-Inside	Well	No	<0.5(3°2'5.0''S – 40°8'16.8''E
4	Gongoni- Mapimo village	Well	No	<0.5(3°2'20.2''S –40°8'12.4''E
5	Timboni (A)- Timboni	Well	No	5.0(2°59'56.1''S 40°11'15.1''E
6	Timboni (B)-Timboni	Well	No	5.0(2°59'53.0''S-40°11'35.6''E
7	Ngomeni(A)- Ngomeni	Well	No	8.0(3°3'55.8''S-40°8'56.4''E
8	Ngomeni (B)-Ngomeni	Well	No	8.0 3°3'57.0''S – 40°8'49.8''E
9	Mjanaheri (A)-Gongoni	Well	Yes	3.0 (3°4'18.8''S – 40°8'48.2''E
10	Mjanaheri (B)-Gongoni	Well	Yes	3.0(3°4'33.1''S – 40°8'34.2''E
11	Gongoni (A)-Gongoni	Well	No	1.0(3°2'8.5''S – 40°7'59.4''E
12	Gongoni (B)-Gongoni	Well	No	1.0(3°2'11.0''S – 40°8'.5''E
13	Mambrui-Secondary	Well	Yes	15 (3°7'20.2"S-40°9'33.6''E
14	Mambrui-Dispensary	Well	No	15(3°7'4.1''S - 40°9'25.4''E
15	Gongoni-Fundisha village	Well	No	3.0(2°55'47.0"S-40°5'41.6''E
16	Gongoni-Fundisha village	Well	Yes	3.0(2°59'40.0''S –40°8'30.1''E

2.2 Sampling and Analysis

Two water samples per well were collected between June and July 2015 from 16 wells. Sampling points were located through the assistance of the Public Health Officer in charge of Gongoni ward. 75% of the wells were from Gongoni ward while 25% were from neighboring wards of Ngomeni and Mambrui'. Sampling for chemical analysis was done using clean two and half liter plastic bottles. The collected samples were immediately transported to the Government Chemist laboratories in Mombasa where they were analyzed for sodium (Na^+), Chlorides (Cl^-), Calcium (Ca^{2+}), alkalinity, acidity (pH), Total Dissolved Solids (TDS) and Salinity (as NaCl) using CONTR AA 700 analytik-jena device Flame Atomic Absorption Spectrometer (FAAS). Standard stock solutions for Sodium, Potassium, Calcium and Magnesium were prepared and diluted with distilled water and run in the AAS as control samples. Total carbonate hardness was analyzed using the titrimetric ethylenediaminetetraacetic acid (EDTA) method and end point was achieved when the color changed from purple red to blue.

To check other possible causes of groundwater contamination in Gongoni, microbiological analysis of the groundwater sources was carried out. Total coliform, fecal coliform bacteria and *Escherichia coli*(*E. coli*) were analyzed using Multiple Tube Fermentation Technique (MTFT). Samples for microbiological analysis were collected using 100ml sterile bottles and stored at around 4°C under ice in cooler boxes and were delivered to the laboratory within 24 hours for analysis. MacConkey medium was inoculated with portions of the well water samples and incubated at a temperature of 36°C for 48 hours. The tubes showing gas formation were regarded as presumptive positive for coliform. Confirmatory tests were done using samples collected from the presumptive positive tubes and inoculated into a selected culture broth and incubated for 24 hours. The most probable number (MPN) of bacteria present was then estimated from the number of tubes inoculated and the number of positive tubes obtained in the confirmatory test.

2.3 Data Analysis

Data was analyzed using Statistical Package for the Social Sciences (SPSS) version 16 for windows. Scatter plots were drawn to test for relationship between different parameters and the coefficient of determination, also known as regression were calculated to determine the effect of the independent variable (distance from the salt harvesting ponds have on the dependent variable (Chemical parameters). The means from Gongoni and the neighboring areas were subjected to independent t-test at 95% confidence levels to determine the significance of difference.

3. RESULTS AND DISCUSSION

3.1 Chemical Contamination Levels of Groundwater Sources in Gongoni ward

The study intended to establish whether distance from the salt harvesting ponds affected the chemical composition of the ground water sources. Chemical parameters over and above acceptable standards by WHO/KEBS are deemed to be contamination. The six sources were randomly picked from the two areas of Gongoni (4 sources) and the adjacent areas of Mambrui and Ngomeni (2 sources). However, the general trend of chemical composition in the 16 sampled wells showed sodium chloride as the predominant source of chemical contamination. Magnesium, Calcium and phosphates were present in the water sources. Source 1 is the closest to the salt harvesting ponds while source 6 is the furthest (Table 1). Source 1, which was closest to the salt harvesting ponds and the sea than all the water sources showed abnormally high total dissolved solids (TDS).Percolation emanating from discharged mother liquor from the ponds in to the streams may have contributed to the enhanced salinity of the water sources, similar to findings of another study [4].The sea water intrusion and percolation to this ground water source could be an important factor.

There was a general trend of decreasing concentrations for TDS, Chlorides, Salinity and Sodium from source 1 to source 5 and a slight increase in source 6. Gongoni water sources had a TDS mean of 1969.0mg/L, which was higher than and the control sources (1050.0 mg/L). Water with TDS value above the WHO limits of 1000 mg/l is unfit for human consumption. Source 1 at Kensalt recorded a highest TDS value at of 6500mg/l while source 5 recorded the lowest at 460mg/l. The reason that may have enhanced total dissolved solids in ground water sources closer to the ocean include salt water intrusion which concurs with report by Sefelnasr & Sherif [13]. However, the very high levels could be attributed to pollution from mother liquor from the salt harvesting fields. Salinity as NaCl had a mean of 965.87±328.54 in Gongoni while the control area had mean of 578.50±441.50. Source 1 at Kensalt had concentration of 3600 mg/L, which was the highest while Source 5 at Ngomeni had the lowest value of 69mg/L.

The fluoride and pH levels for the water sources increased with distance from the salt harvesting firms and shows significant statistical difference between the means (p=0.009 for fluorides and p<0.001 for pH) at 95% confidence level (Table 3). Despite the significant differences, both means fall within the recommended standards for WHO (Fluorides 1.5 mg/l and pH 6.2-8.5). The acidity of the water sources is compliant as per the WHO and KEBS standards. The p value for the means of sodium concentration was 0.684 which is above 0.05 and outside the 95% confidence level.

3.2 Influence of Distance from Salt Mines

Total dissolved solids (TDS) reduced gradually with increase in distance from the salt harvesting ponds (Fig. 2). TDS is a measure of the combined content of all inorganic and organic substances contained in the water. The regression shows that only 9.7% of the variance in the concentration of the total dissolved solids (TDS) arises as a result of the distance from the salt mines.

The concentration of sodium chloride ions (salinity) in ground water decreased with increase in distance from the salt harvesting ponds (Fig. 3). The regression shows that only 5.4% of the variance in salinity of the water sources arises as a result of the distance from the salt mines. In contrast, pH showed an increasing trend with the salt mines and the regression with the distance showed as strong relationship, with the distances from the salt mines accounting for over 43% of variance in pH of the water sources (Fig. 4).

Large standard deviations were observed in concentrations of total dissolved solids, sodium, and chloride ions among the water wells in Gongoni ward. This implies that some wells were highly contaminated while others were less contaminated depending on their distance from salt harvesting ponds. Percolations emanating from discharged mother liquor from the ponds in to the streams contribute to the enhanced salinity of the water sources, which agrees with a study by Ocholla et al. [4].

3.3 Microbiological Contamination Levels of Groundwater Sources in Gongoni ward

All the 16 water sources were sampled for microbiological tests. None met the WHO/KEBS portability standards (Table 4). *E. coli* and total coliform counts in all the sampled wells were above the Kenyan and WHO permissible limit of 0 MPN/100ml for treated water and 10 MPN/100mls for untreated water. This observation gives an indication of poor sanitation associated with influx of high population around the salt harvesting firms.The *E. coli* is an indicator for contamination from human and animal waste whose main source would be the pit latrines or/and animal waste from the surrounding areas. The lack of a sewer system to manage the sewage may have exacerbated the situation.

The highest total coliform was 2539 ±347 per 100mls at source 6, Kensalt, while source 1 and 2 had the lowest mean count of 2400±345. In contrast, source 1, had the high *E. Coli* count of 2400, an indication of higher human impact on ground water in this area compared to other sources of microbial contamination.

There was a positive relationship between biological parameters (*E. coli* count) and Phosphates in the sampled wells (Fig. 5). There was a strong correlation between microbial parameters *E. coli* counts and concentration of phosphates in the sampled wells (R^2=98 %), which maybe be an indication of influence on anthropogenic pollution of ground water sources in the areas.

The significant relationships between microbial and phosphate parameters are very interesting and suggest greater regeneration of the limiting phosphorus element by planktonic food webs that supports the bacterial abundance. The presence of microbial contamination was not affected by well cover. These microbial parameters were also influenced by water pH. Bacteria prefer neutral pH, which was mostly found in the study wells.

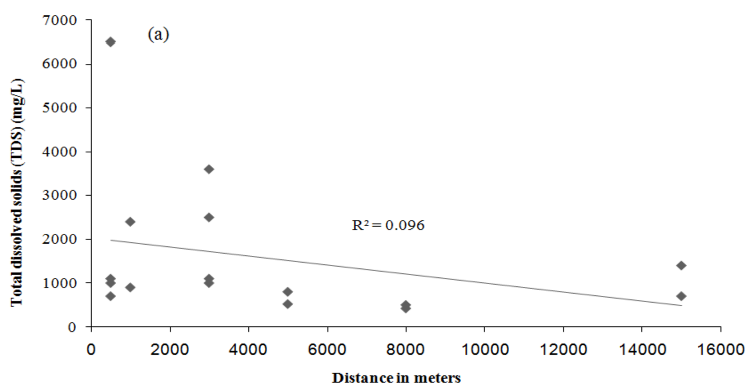

Fig. 2. Regression of total dissolved solids (TDS) with distance from the salt mines

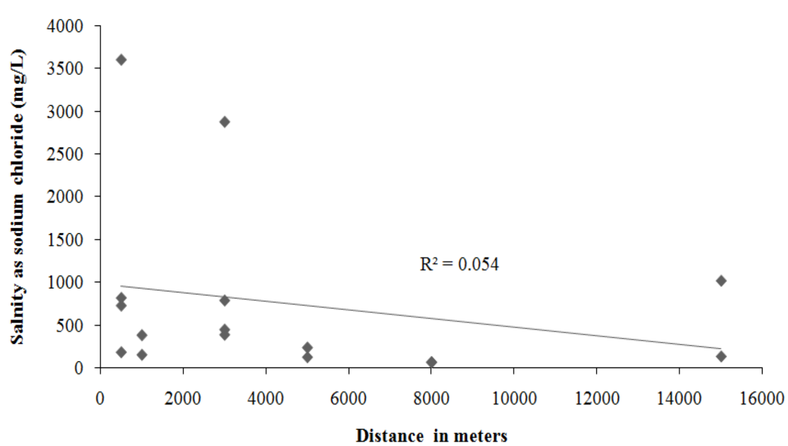

Fig. 3. Regression of Salinity (as Sodium Chloride) with distance from the salt mines

Table 2. Chemical composition of groundwater sources and comparison with KEBS/WHO standards

SNo	Parameter	Source 1Kensalt firm	Source 2Gongoni (A	Source 3Mjanaheri (A)	Source 4Timboni (A)	Source 5Ngomeni (A)	Source 6Mambrui-Dispensary	KEBS/WHO Standard (mg/l)
1	TDS	6500	1650	2367	807	460	1050	1000
2	Salinity as NaCl	3600	271	1238	386	69	579	900
3	pH	7.3	7.6	7.4	7.6	7.6	8.5	6.2—8.5
4	Chloride	2500	67	883	275	45	485	250
5	Sodium	1100	203	255	111	24	96	200

Table 3. Comparison of means for ground water sources at Gongoni and neighboring areas

Parameter (mg/L)	Control Mean±SE	Gongoni Mean±SE	p-value
PhosphatePO_3^{4-}	0.17±0.15	0.31±0.08	0.527
Fluorides	0.07±0.02	0.66±0.07	0.009*
Chloride	485.00±415.00	662.00±250.44	0.808
Sodium	93.50±26.50	283.87±90.98	0.469
Total Dissolved solids Residue dried at180^{o}C	1050.00±350.00	1969.33±527.13	0.546
pH	8.50±0.20	7.54±0.06	<0.001*
Salinity as NaCl	578.50±441.50	965.87±328.54	0.684
Total Alkalinity	185.75±109.25	252.85±38.52	0.560

**parameters show significant difference between the control and Gongoni samples (independent t-test, 95% CL*

Table 4. Effect of distance from salt mining site on microbial parameters

Parameter (MPN/100ml)	1 km		5 km		10 km		15 km		p-value
	≈ value	± error	≈ value	± error	≈ value	± error	≈ value	± error	
E. coli count	2400	438	571	426	538	421	539	473	0.079
Total coliform count	2400	345	2400	327	2497	363	2539	347	0.254

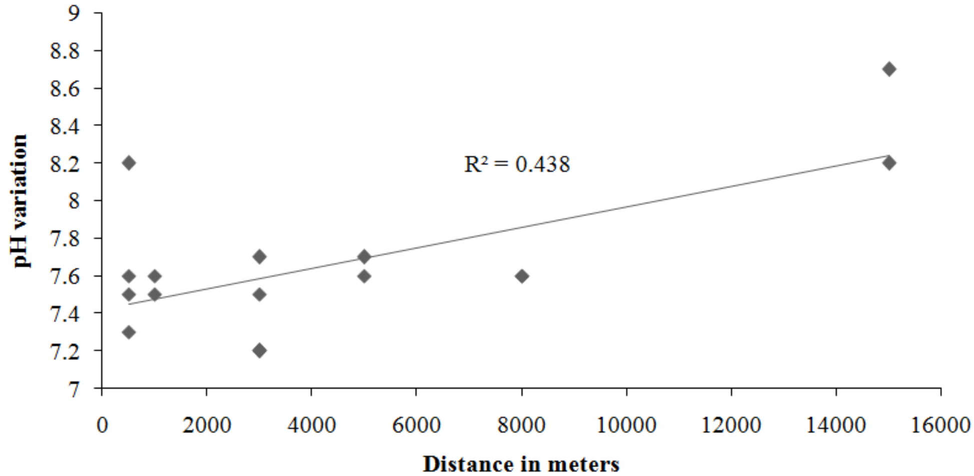

Fig. 4. Regression of PH of water sources with distance

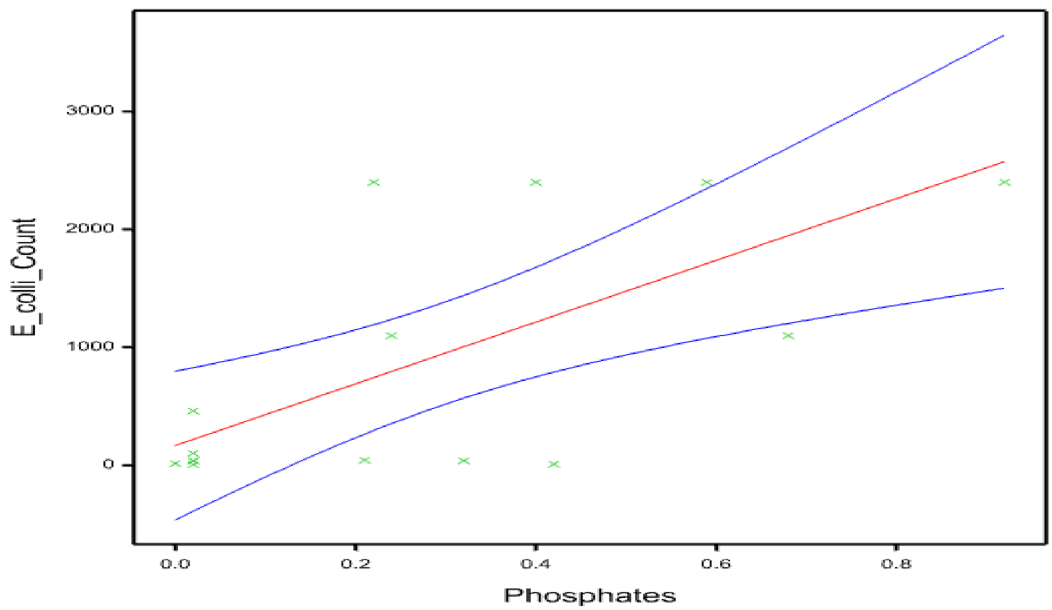

Fig. 5. Correlation of *E.coli* plotted with phosphates
R^2=0.98

4. CONCLUSION AND RECOMMENDATIONS

The study showed that the means of the concentrations of the selected parameters (TDS, Salinity, Chlorides, and Sodium) for ground water sources in Gongoni ward are higher, but not significantly higher, compared to the sources from control areas of Mambrui and Ngomeni. These high salinity and total dissolved solids could be associated with both the salt harvesting activities and salt water intrusion from the ocean.

The TDS and salinity levels in many of the sampled wells were higher than the WHO/KEBS recommended standards for portable and therefore there maybe need to pre-treat the water from these sources to improve its quality for human use. However, fluorides and pH values were within the WHO/KEBS standards.

The ground water sources in Gongoni and the adjacent areas had relatively higher coliform and *E. coli* bacteria counts compared to the WHO/KEBS recommended standards for drinking and it is therefore recommended that the water should be regularly treated using the appropriate disinfection methods before use.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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