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Mary MAKOKHA

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Reaserch Article

Groundwater Quality Analyses along Kenyan Coastal Region, Case Study of Kilifi-KENYA

Mary Makokha

Geography Department, Kenyatta University, P.O Box 43844, 00100 GPO, Nairobi KENYA

Corresponding author: Makokha Mary
E-mail:Makokha.mary@ku.ac.ke

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Abstract

The Kenyan coast is a semi-arid region frequently faced with severe water scarcity especially during prolonged drought and a rapid population growth. Groundwater provides 50% of the water demand and most sources are poorly drilled, over-abstracted and abandoned. The aquifers occur in sedimentary formations of fluvial and lacustrine origin. There is a need to have a groundwater monitoring system in place; therefore this study analyses selected physico- chemical and microbial parameters using both laboratory and field methods. Arc-GIS 9.3, SURFER were used to generate thematic maps for some tested parameters. Results indicate pH values within acceptable range of 6.5 – 8.5, though shallow wells in Malindi were acidic, this atrributed to the heavy industries prevalent in the area. Electric conductivity (EC) was above the set standard of 1500µS/m indicating high dissolved ions present especially in Magarini where salt mining is done. Total dissolved solids (TDS) of up to 500mg/L suitable for drinking water was only found during the wet season. Turbidity of less than 5 NTU was established in most areas. Chlorides and salinity levels exceeded 250mg/L pointing to the saltwater intrusion problem that is a challenge along Kenyan coastal aquifers Boreholes and shallow wells had a total hardness ranging from 50mg/L -150mg/L indicating the water was ranging from being slightly hard to hard water. Escheriria coli was present in almost all the boreholes and shallow wells indicating the need to treat water before use. Water Quality index (WQI) calculation indicate that groundwater is unsuitable for human consumption in dry season.

Keywords: Groundwater, boreholes, water quality, shallow wells

Introduction

Access to safe and sufficient water and sanitation is a basic human need and is essential to human wellbeing (UN, 2006, Barut, 2015; Kisaka, 2018) but presently, close to a billion people mostly living in the developing world do not have access to safe and adequate water (UNICEF/WHO, 2012). One of the United Nations Millennium Development Goals (MDG) specifically addresses the problem of lack of access to safe drinking water. Worldwide, water borne diseases are a major cause of morbidity and mortality in humans (WHO, 1996; Gazioğlu et al., 2010; Esetlili et al., 2018). While water borne pathogens infect around 250 million people per year, resulting in 10–20 million deaths (Anon, 1996), many of these infections occur in developing nations that have sanitation problems (Nsubuga et al., 2004; Khorrami et al., 2018). Approximately 6000 children, most of them in developing countries, die every day of diseases related to inadequate sanitation and a lack of access to safe drinking water (Louise, 2005). The majority of the population in developing countries are not adequately supplied with potable water and are thus compelled to use groundwater from sources like shallow wells and boreholes that are unsafe for domestic and drinking purposes due to high possibilities of contamination (WHO 2006, 2011). Kenya's Vision 2030 has attempted to address this lack of equity in the supply of potable water by advocating for the conservation of water sources, rainwater harvesting and enhancing the utilization of groundwater (GoK, 2008). Groundwater provides the only realistic water supply option for meeting dispersed rural demand, as alternative water resources can be unreliable and expensive to develop (Foster et al., 2000; McDonald et al., 2005; Ülker et al., 2018).

Although groundwater has historically been thought to be free of microbial contamination, recent studies have indicated that groundwater can be contaminated and this could easily result in water borne diseases if consumed without prior treatment (Momba & Mnqumevu, 2000; Momba et al., 2006). An investigation was conducted in the Kilifi which lies within the Kenyan coastal region to determine the safety of groundwater sources and to examine the factors influencing groundwater quality. The county falls within the semi-arid region which frequently faces severe water scarcity especially during periods of prolonged drought. Kilifi County receives water supply mainly from Kilifi-Mariakani Water and Sewerage Company (KIMAWASCO), mandated by the Coast Water Service Board and it provides water to 40% of the growing population. Like most of the aquifers found in the coastal areas, the deep aquifers in Kilifi County have been encroached with salty water from the ocean which has greatly interfered with the quality of water. This has seen many boreholes that have been drilled in the area abandoned over time. The groundwater in the county occurs in confined and unconfined aquifers in sedimentary formations of fluvial and lacustrine origin. Scarcity and unpredictability of rainfall in Kilifi County is a major impediment to development. Some parts of Kilifi County such as Ganze and Bamba on the western part experience 5-6 months of continuous dry weather. Groundwater provides nearly 50% of the water in Kilifi County and it is mainly used for domestic and agricultural water supply. Due to the rapid population growth groundwater sources are poorly drilled, there is an overexploitation and salt water intrusion problem.

There is a need to have a groundwater quality monitoring system in place and therefore this research examines the groundwater quality and to determines its suitability for domestic purposes. Groundwater samples from 9 Boreholes and 10 Shallow wells were sampled and analysed for selected physic- chemical and microbial parameters. Standard methods were used for the analysis of groundwater samples in the laboratory. Results were compared to guideline values of the NEMA, USEPA and WHO to establish its suitability for domestic use. The Water quality Index (WQI) was calculated to determine the portability of the groundwater in Kilifi. Arc-GIS 9.3, SURFER were used to generate a thematic map for some of the tested parameters.

Location of the Study Area.

Kilifi Town is located in the coastal area of Kenya and it covers an area of 4779.2 square km. Its geographic coordinates are 3° 38' 00S to 3° 40' 00S latitudes and 39° 45' 00E to 39° 51' 00E longitudes. It is located at an elevation of 150 metres above the sea level. The District consists of seven divisions: Bahari, Kikambala, Chonyi, Kaloleni, Bamba, Ganze and Vitengeni. Figure 1 illustrates the map of the study area. The district has a strong industrial sector with the Mabati Rolling Mill, the Athi River cement Factory, Cashew Nut Milling Industry and Salt Processing Factory that contribute to the region's economy both in employment provision and income generation.

Climatic Conditions

Rainfall is bimodal; short rains occurring in October to December while long rains in March to June. Rainfall intensity varies from 400mm in the hinterland to 1300mm in the high potential areas in the coastal plains. Most of the divisions are located in the hinterland and experience less rainfall hence Kilifi County falls under the coastal dry areas. It has high temperature ranging from 21°C to 35°C.

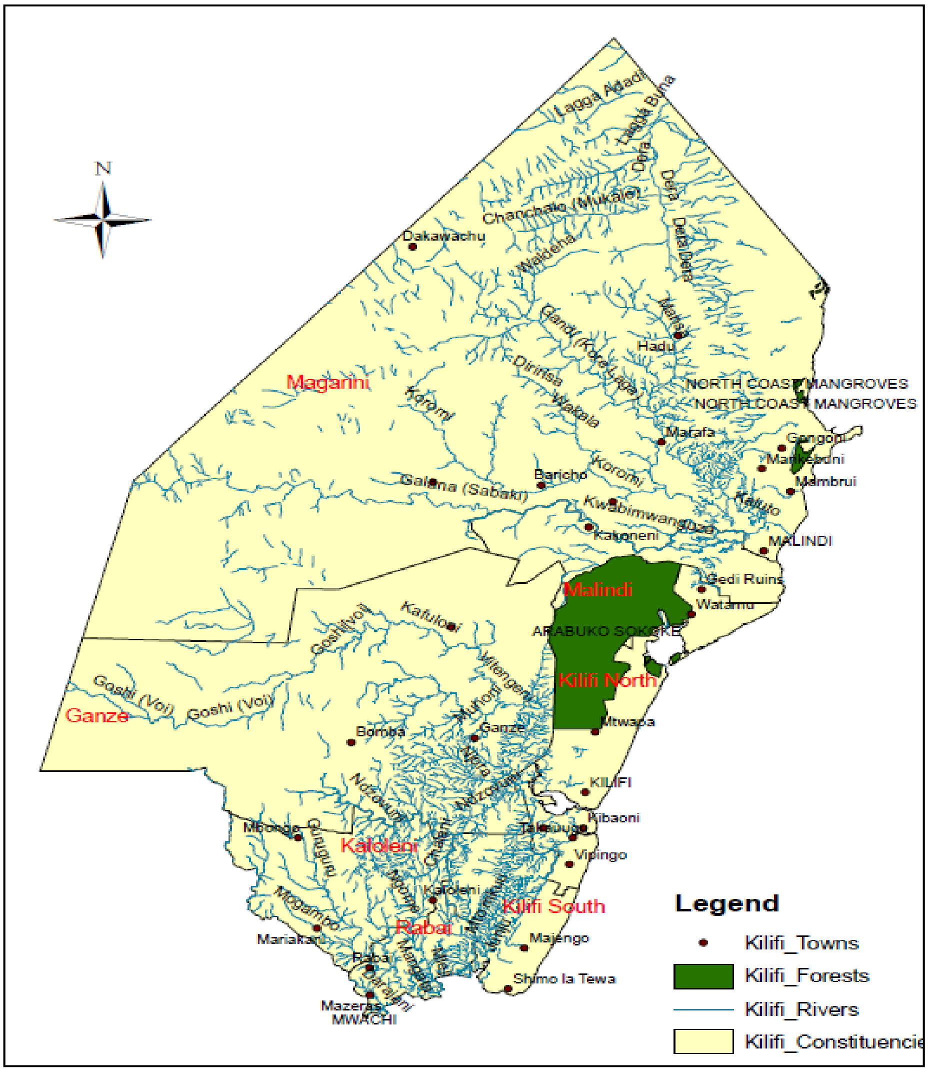

Figure 1. Map of Kilifi Area

Drainage Patterns and Sources of Water in Kilifi.

The drainage pattern in Kilifi County is formed by seasonal rivers and streams such as Goshi, Mzovuni, Wimbi and Mtamkuu. The Sabaki River the only perennial river, originating in the central highlands. Other sources of water in the region consists of hand dug water pans, dams, traditional river wells, boreholes and piped water from Baricho water works.

Geology and Soils

The rocks of the district are mainly of sedimentary origin except in the western side of the district where the basement complex is mainly metamorphic gneisis and schists. The sedimentary system consists of the Duruma sandstone series –grits sandstone and shale; which is further classifeid into: Lower Duruma Series (carbonaceous materials and Taru grits) and Middle Duruma series (Maji ya Chumvi beds and Mariakani sandstone – have the highest shale content). Mariakani sandstone consists of Silty shales and fine grained sandstones. Tertiary sediments consist of the Magarini sands which has a thickness of about 130m. Quatenary sediment series made of coral reefs, coral limestone, lagoon deposits of calcareous sands and quartz sands. The soils are mainly the coastal plain corals, sand, clay, loam, and alluvial deposits. The mangrove forests are poorly drained, very deep excessively saline and vary from loam to clay often with sulfuric material

Hydrogeologic conditions

Research done by Onyancha et, al., (2010) gives a summary of the hydro-geologic conditions across Kilifi. A summary of the results from the borehole drill logs is as seen in Table 1

Table 1. Kilifi hydrogeologic conditions

Borehole(s) Location	**Aquifer(s)**	**Total aquifer Thickness (m)**	**Water Quality and aquifer condition**
Vipingo in Chonyi	Coral, sandstone coral sands, gravelly sands	16	Good quality, saline with deepening or overpumping, caving formations
Roka and Tezo	Sand, sandy clay, coral sands	38	Saline and bitter water, salinity increases with depth, well equipped with hand pump, caving problems
Kilifi plantations	Blue clay, sand coral	24	Good quality, caving problems
Bamba	Sandstone/red shale/grey gravel or sand	15	Saline/bitter water whose yield decreases with time
Kituu	Sandstone (maji ya Chumvi		Water with iron taste, non saline, hydrogen sulphide on pumping
Vitengeni	Sands/sandstone	40	Good quality water when sealed at shallow levels
Jaribuni	Soft sandstones	8	Saline, water loss during drilling, very permeable layer
Kaloleni market	Soft sandstones	31	Good but becomes saline with time
Mazeras in kaloleni	Coral sands	16	Better water when pumped slowly, caving formations

Materials and Methods

On-site Experiments

The methodology involved both laboratory and in situ field methods based on the APHA standards, (2005). In situ tests involved measuring; temperature, pH, and Electrical Conductivity (EC) using a universal portable meter. These parameters are important in analyzing the salinity in water. The temperature of each sample was determined with the aid of the portable Eijkeljamp 18.85.01 Multi Parameter Analyzer. The Bulb end of the thermometer was carefully placed into the beaker of water and the temperature was determined after 2 minutes of waiting for the thermometer reading to stabilize. The pH was measured with the portable PHS - 25 pH meters. The pH electrode of the pH meter was first calibrated against a pH buffer 7 and 9 at a temperature of 25oC to adjust to the response of the glass electrode. The electrode was then immersed in the sample and stirred gently and stopped, allowing for 1-2 minutes for a stable reading to be obtained and recorded. Electrical Conductivity was determined with the aid of a portable conductivity meter. The conductivity cell was rinsed with at least three portions of 0.01M KCl solution.

Laboratory Test

The laboratory methods involved the determination of the turbidity using the Nephelometric Method. It was measured in situ using the AL 250T -IR Turbidimeter. The 25ml of sample was gently agitated and Waited for air bubbles to disappear and then poured sample into cell. The turbidity was directly read from instrument display. To determine the amount of chlorides, 50ml of sample was taken and diluted to 100 ml, One milliliter (1ml) of K2CrO4 indicator solution was added and titrated with standard AgNO3 titrant to a pinkish yellow end point indicating the chlorides presence. Samples were directly titrated in the pH range of 7 to 10. Samples that were not in this range were adjusted with H2SO4 or NaOH. Reagent blank value was established by titrating 50ml of distilled water with 1ml of K2CrO4 dropped in it, against standard AgNO3. To determine the total hardness, 50 ml of sample was pipetted into a conical flask and 1ml of a buffer solution added to it to produce a pH of 10. One gram (1g) of Erio-chrome Black T indicator was also added to it. It was then mixed constantly and titrated with a standard 0.01M EDTA until the last trace of purple disappeared and the colour turned bright blue. Total hardness was then calculated using the Equation 1:

$$\text{Total Hardness} = \frac{ETDA(ml) * B * 1000}{sample(ml)} \qquad \text{(Eg. 1)}$$

Where B = mg of $CaCO_3$ equivalent to 1ml of EDTA titrant.

EDTA solution was also used in the determination of calcium hardness. The sample solution was raised to a pH of 13 and magnesium precipitated as the very insoluble hydroxide which did not react with EDTA and calcium alone was then titrated using calcium indicator. Since the total hardness titration gives the sum of both Ca and Mg in the sample and titration at pH 13 gives Calcium only. Magnesium was obtained by the difference.

To determine total dissolved solids, the sample was stirred with a magnetic stirrer and a measured volume transferred into a 100 ml graduated cylinder by means of a funnel onto a glass fibre filter with applied vacuum. The sample was filtered through the glass fibre filter under vacuum pressure for about three minutes to ensure that water was removed as much as possible. The sample was washed with de-ionized water and suction continued for at least three minutes. The total filtrate (with washings) was transferred to a weighed evaporating dish and evaporated to dryness in a drying oven at 180 ± 2°C for at least 1 hour and cooled in a desiccator to balance temperature, it was weighed afterwards. The cycle of drying and weighing was repeated until a constant weight was obtained.

The Total Dissolved Solids (TDS) was then calculated using Equation 2 below:

$$TDS(mg/L) = \frac{(A - B) * 1000}{sampleVolume(ml)} \qquad \text{(Eg. 2)}$$

where: A = weight of dried residue + dish (mg) , B = weight of dish (mg)

The groundwater abstraction points location was done using hand held GPS that recorded the geographical coordinates of the sampled boreholes and wells. Secondary data about the geology and some groundwater quality data of the area was obtained from Water Resources Management Association (WRMA) and Coastal Water Board branch; Kilifi Mariakani Water and Sewerage Company (KIMAWASCO)

Microbial Analyses

In the laboratory, the samples were removed from ice chest in which they were stored in the field during collection and allowed to cool at room temperature. Before the analyses, the incubation chamber for the analyses was thoroughly cleaned and disinfected with ethanol to avoid contamination of the field. 98% alcohol was used to sterilize the porous plate of the membrane filtration unit and the membrane filter forceps. The membrane filtration unit was set up with the grid side up and a sterile meshed funnel placed over the receptacle and locked in place. After this the membrane filter was transferred onto the porous plate of the membrane filtration unit. Volumes of groundwater samples analysed were, 100ml as the standard method reporting for results of microbial analysis is the number of colony forming units per 100ml volume analysed (Anon, 2000). The groundwater samples were analysed for faecal coliform. The sample was filtered through the membrane filter under partial pressure created by a syringe fitted to the filtration unit. The filtrate was be discarded and the funnel unlocked and removed. The forceps was used to transfer the membrane filter onto a labelled Petri dish containing the appropriate growth medium (M. F.C agar for Faecal coliform).

Faecal coliform counts were determined using the membrane filtration method with m-FC agar plates at 37°C for 24 hours (Grabow, et al., 1991). After incubation, typical colonies were identified and counted. The colony was counted three times with the aid of a colony counter and the mean recorded. Faecal coliform was detected as blue colonies on the M-FC agar. The total numbers of colonies appearing would be counted for each plate.

Results

pH values in Kilifi County

pH set by USEPA (2012) and NEMA (2006) is 6.5 - 8.5. Groundwater sample with low pH is attributed to discharge of acidic water into these sources by agricultural and domestic activities. All points were within the set limit as seen in Figure 2, except for some boreholes in Malindi which were acidic and this could be attributed to the heavy industries that are prevalent in the region.

There was very little seasonality variation in the pH in the wet and dry seasons for both the swallow wells and the boreholes as seen in Figure 3. The values were within the acceptable range of 6.5-8.5, and this could be due the minimal rainfall that is received in the region because of the arid conditions. Though there was some notable difference in the shallow wells in Kibarani where the increased human activities made the ground water conditions tend towards acidic conditions during the rainy season and in Mtwapa and Chasimba the conditions tended towards alkaline conditions. This could be attributed to the surface run off from the agricultural farms present in the area. Similar trends have been reported in previous studies by (Kanaan & Sebu, 2009) .The high pH in some of the wells can be attributed to the influence of fertilizers like ammonium Sulphates and super phosphate in agriculture and to some extent the sulphur and amino acid compounds from human and animal excreta (Navoraj & Krishnammal, 2012).

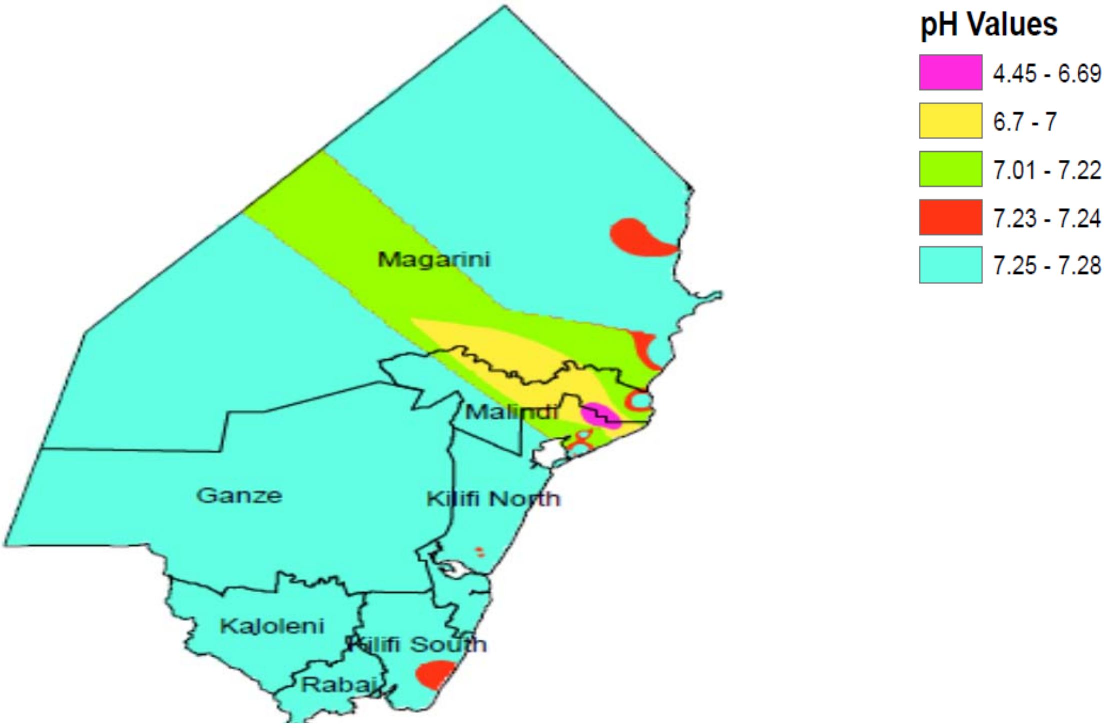

Figure 2. The Geospatial distribution of pH in Kilifi County

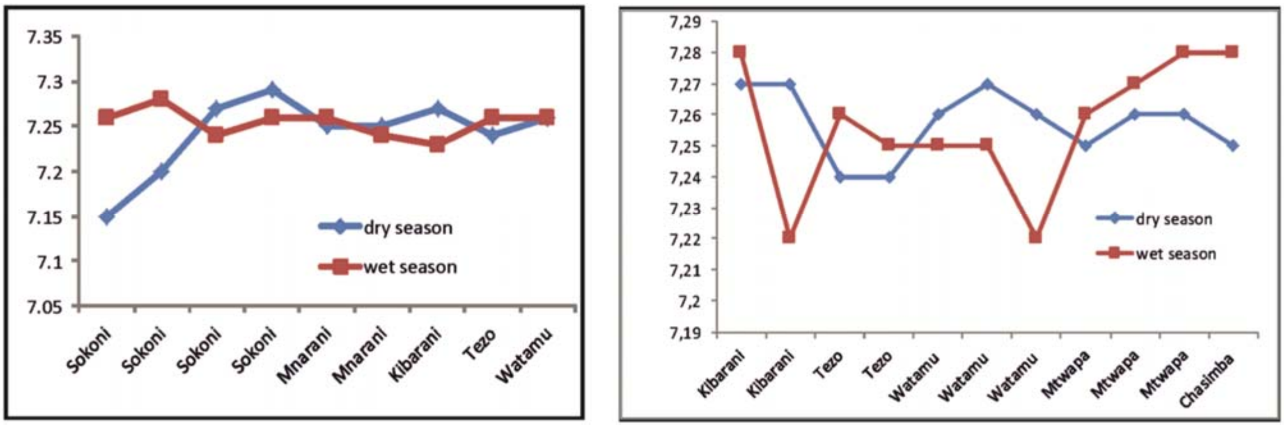

Figure 3. Seasonal variation in pH in boreholes and shallow wells (Boreholes and Shallow wells)

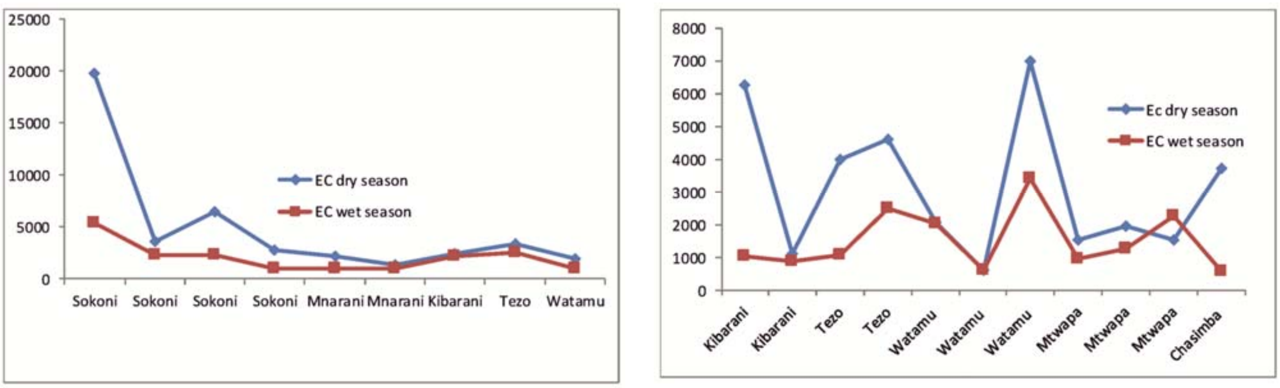

Figure 4. Seasonal variation in EC values in Boreholes and shallow wells

Electrical Conductivity values obtained throughout the study area were very high in both dry and wet season. This indicated the high concentration of ions in the water especially during the dry season and this could have been caused by the high evaporation rates caused by high heat intensity. Only 5 samples out of the 20 study sites were within the acceptable standards as set by WHO, (2004). The geospatial distribution (Figure 5) of the EC in the study area indicated high salt concentrations in Magarini and this could be attributed to the salt mining that heavily takes place in this area. This is similar to past research that indicates that the local environment of the groundwater points can be affected by the geology, soil and land use activities (Ocheri & Ahola, 2007)

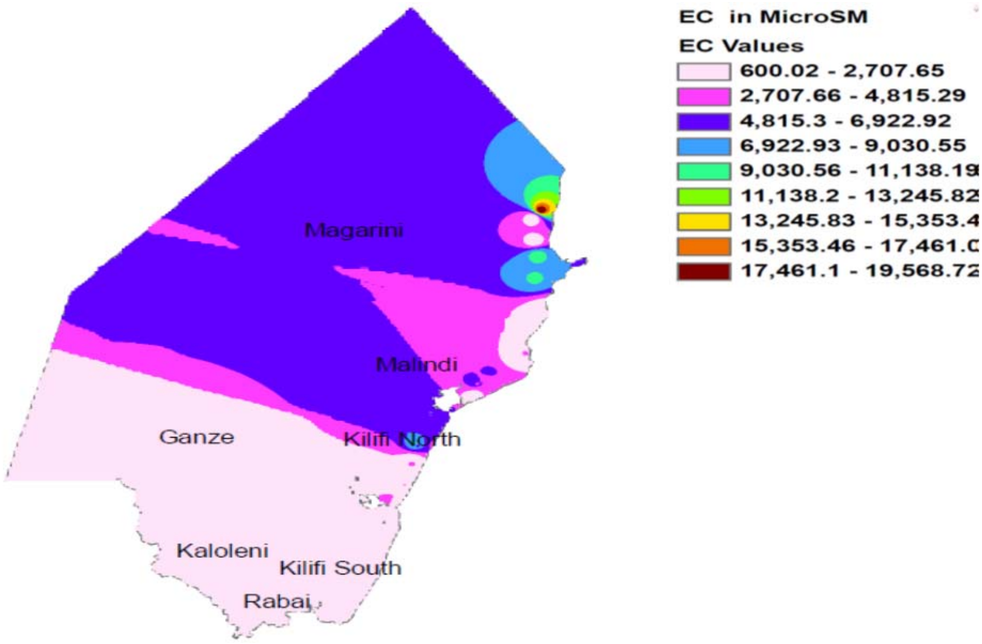

Figure 5. Geospatial distribution of electrical conductivity in Kilifi

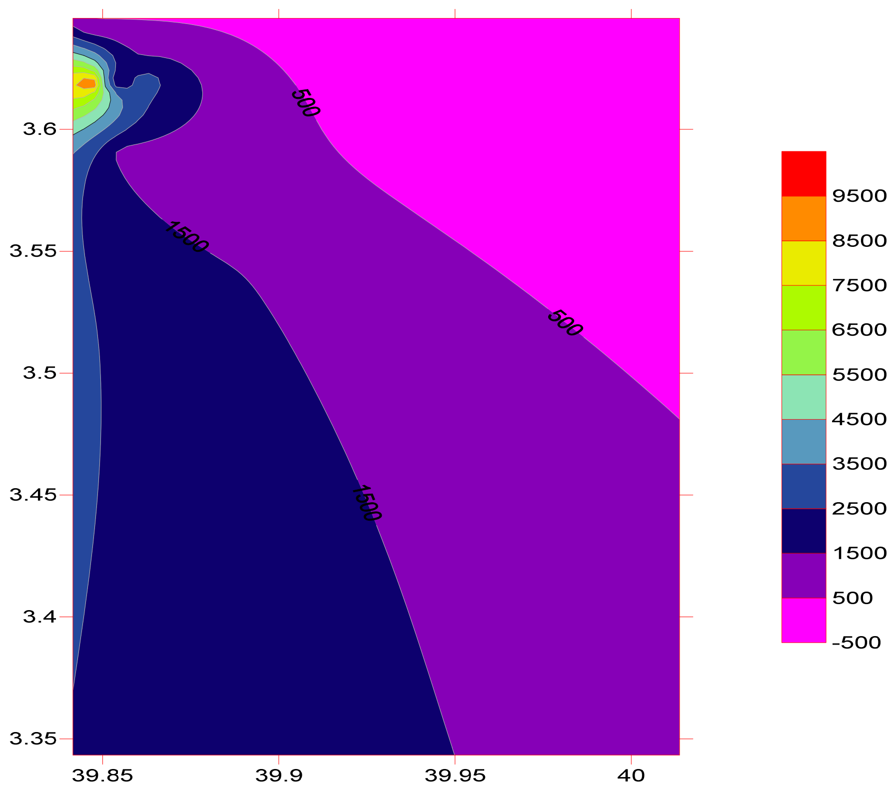

Figure 6. TDS concentration in the Kilifi

Total Dissolved Solids (TDS) during Wet and Dry season

TDS represents the sum of concentrations of all dissolved constituents in water. TDS content is usually the main factor, which limits or determines the use of groundwater for any purpose (WHO, 2011). A total dissolved solid (TDS) is an indicator of polluted water and determines the water's palatability and acceptability. Total Dissolved Salts (TDS) comprise mainly of inorganic salts and some small amounts of organic matter that are soluble in water. According to WHO, (2004); TDS of 500 mg/L is desirable for drinking, 500-1000 mg/L is permissible for drinking, up to 3000 mg/L is useful for irrigation and > 3000 mg/ is unfit for drinking and irrigation. Results from the study area indicate that boreholes and shallow wells with acceptable standards fit for drinking were only found during the wet season (Figure 6) but most showed higher values exceeding 1000mg/l that is permissible for drinking water . This implies that some areas could be suitable for irrigation, but in some areas were completely unfit for both irrigation and drinking.

Comparing the wet and dry season (Figure 7) in both the boreholes and shallow wells, there were high concentrations in the dry season and this could be attributed to that fact that the area is arid and receives less amounts of rainfall increasing the evaporation rates and therefore contributing to the high TDS values.

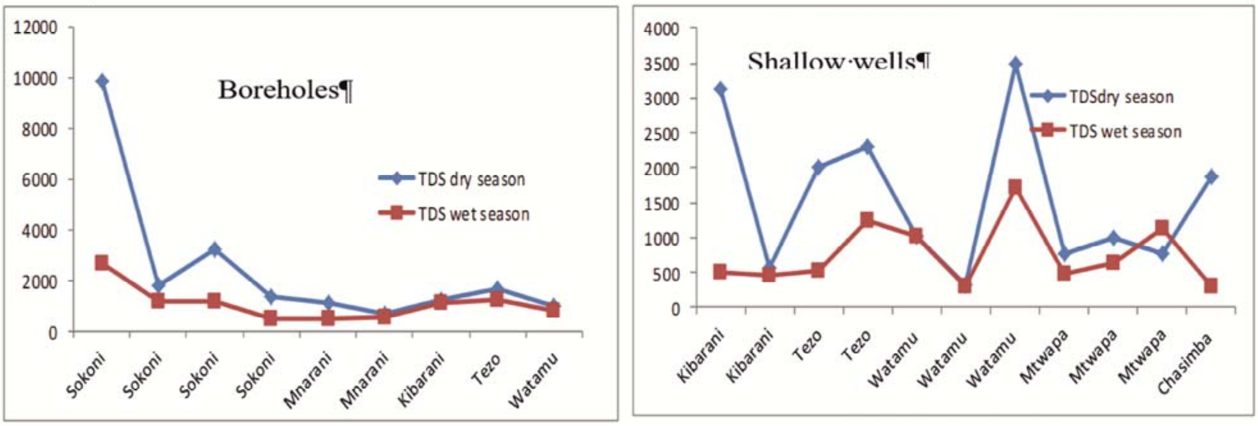

Figure 7. Seasonal variation in TDS in both boreholes and shallow wells

EC and TDS comparison in Kilifi County

The electrical conductivity of the water sample is completely proportional to the TDS value and thus increases with increase in EC and this was also observed at the study site as seen in Figure 8.

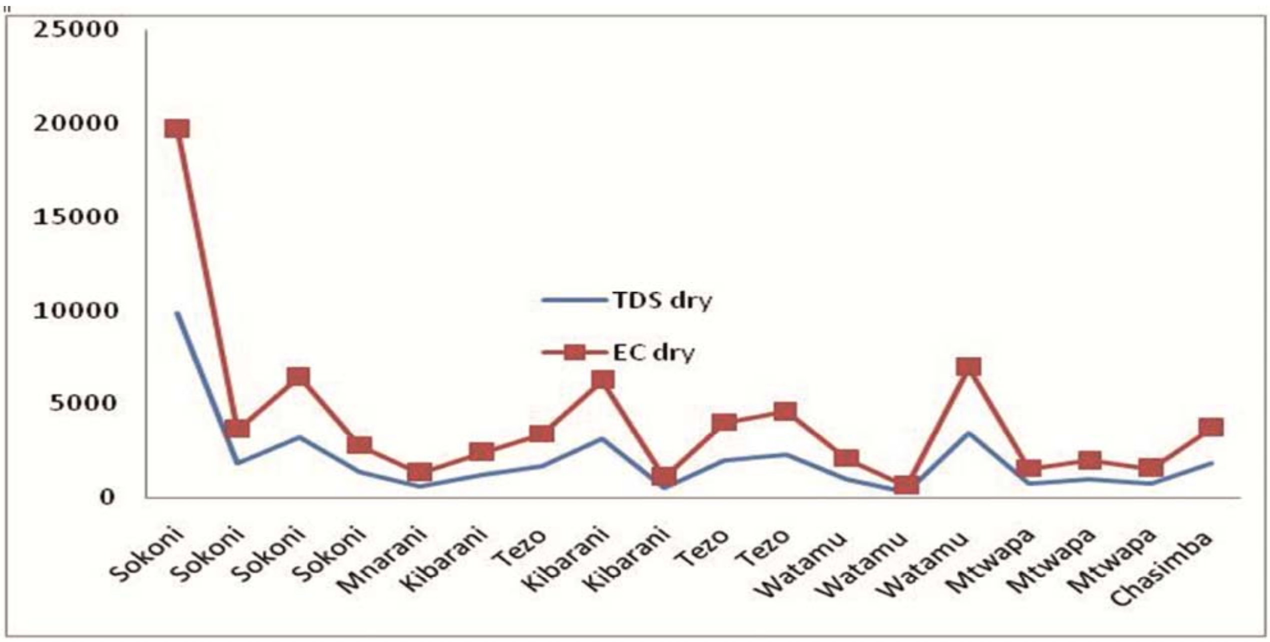

Figure 8. Comparison of the EC and TDS in Kilifi

Turbidity

Turbidity is caused by the presence of suspended clay, silt, organic matter, inorganic matter, plankton, and other microscopic organisms (DWAF, 1996). The measurement of turbidity gives only an indication of the extent of pollution (Momba et al., 2006). The recommended turbidity value by WHO,(2004) is 5 NTU. Most boreholes and shallow wells had a turbidity of less than 5 NTU, except in Kibarani where the wells had higher turbidity values both in the dry and wet season (Figure 9). This could be attributed to soil erosion and the geological sandy formations that allows easy surface run off percolation, and the increase in the influx of surface runoff into the water as irrigation was a common practice in this study area (MPCA, 2008). Turbidity in water causes problems with water purification processes such as flocculation and filtration which normally increases the cost of water treatment. High turbidity values may also increase the possibility of microbiological contamination (Momba et al., 2006).

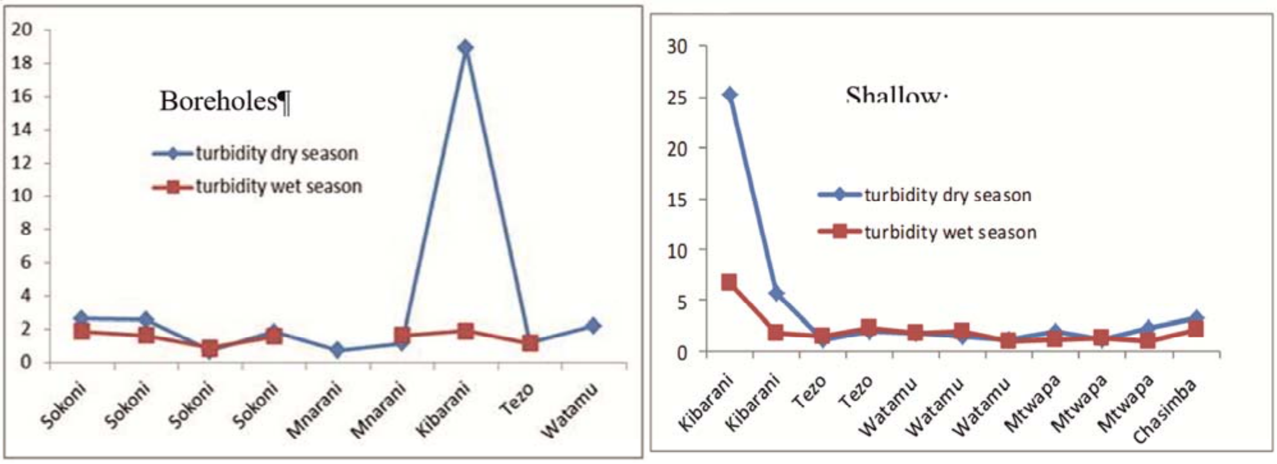

Figure 9. Turbidity in both boreholes and shallow wells in Kilifi

Chlorides

Chloride sources mainly comprise of leaching of chloride-containing minerals and rocks with which the water comes in contact, inland salinity and the discharge of agricultural, industrial and domestic waste waters (Sayed & Bosle, 2011). WHO (2009) recommends a level is 250mg/l for chlorides; most boreholes and wells were way beyond the recommended level especially during the dry season (Figure 10). The boreholes and shallow wells that were closer to the sea revealed high levels of chloride as compared to those in the hinterland, except for two boreholes in Sokoni which had high chlorides. This could be attributed to the geologic formation of the rocks that resulted into the higher chloride concentration as the sources of chlorine in natural water could be drainage waste and dissolving rocks. The high value in shallow wells could be due to leachates from the surface runoff. Betram & Balance, (1996) study indicate that an increase in the mean value of chloride content of water may indicate possible pollution from human sewage, animal manure or industrial wastes.

Salinity corresponds directly to chlorides as an increase in salinity causes a corresponding increase in salinity. Most the boreholes and wells close to the sea exhibited high levels of salinity as compared to those in the hinterland as seen on the contour map Figure 11.

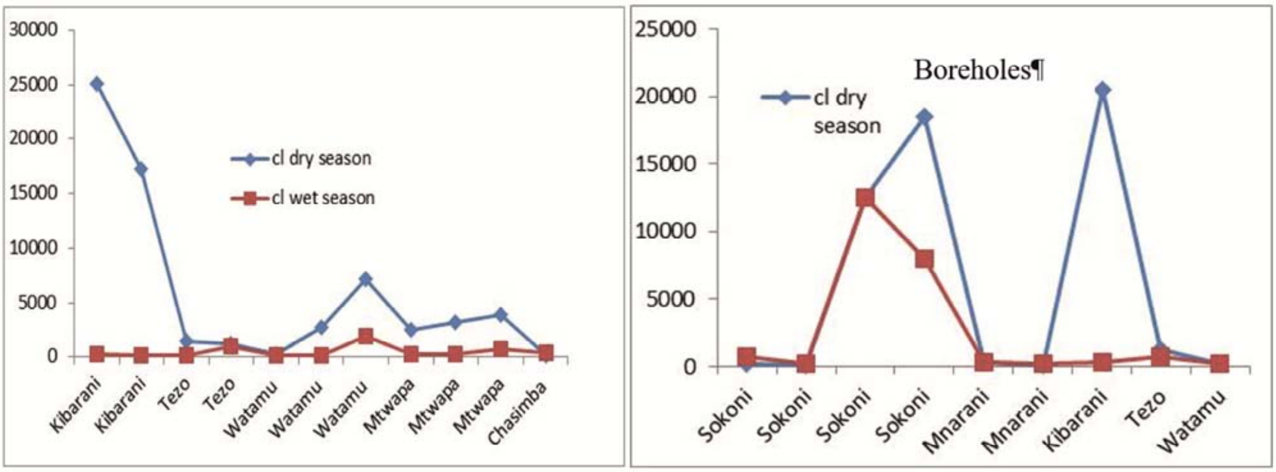

Figure 10. Chloride levels in the shallow wells and boreholes in Kilifi

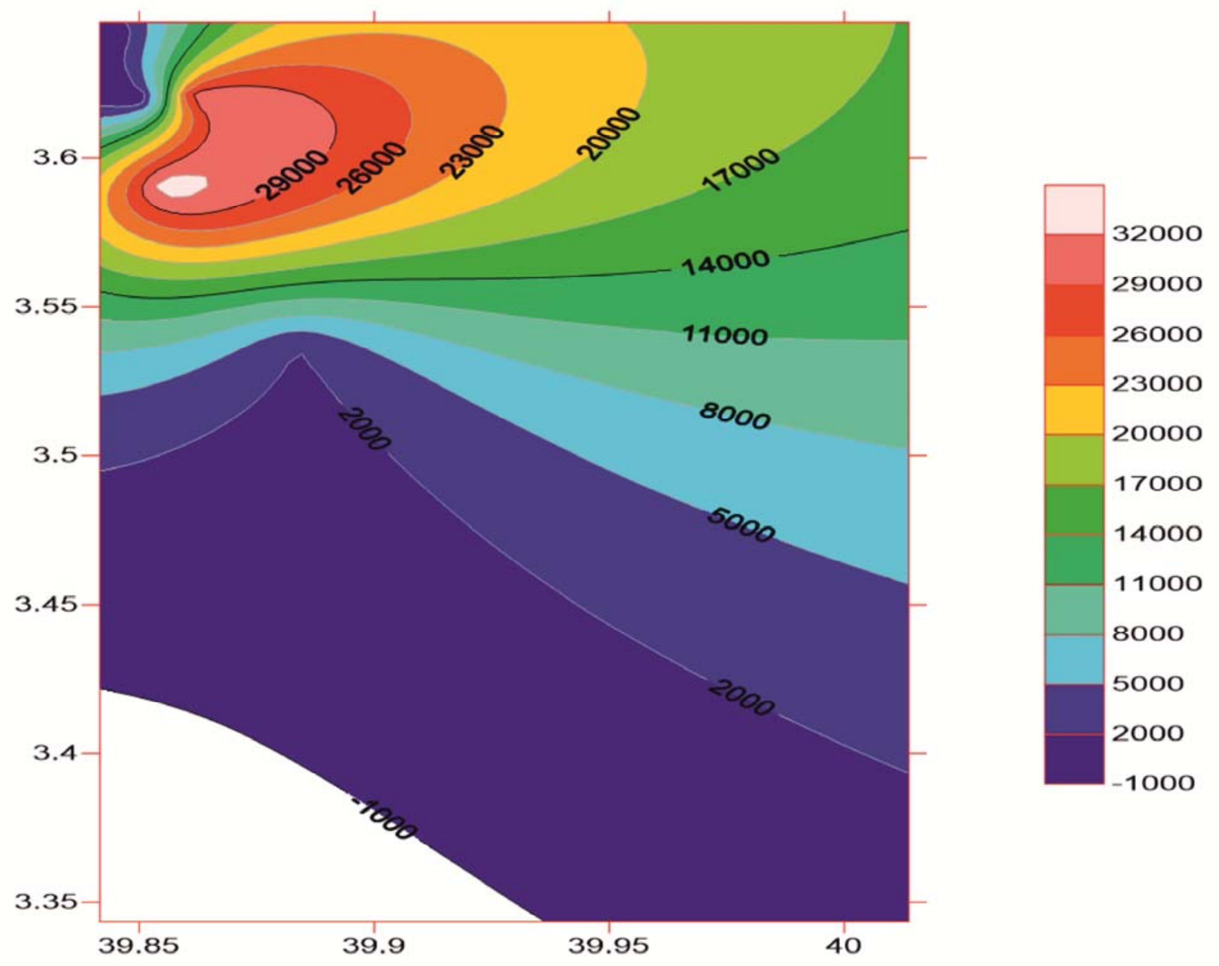

Figure 11. Salinity concentration in Kilifi

Hardness

Water hardness is the traditional measure of the capacity of water to react with soap, hard water requiring considerably more soap to produce lather. The guideline value set for hardness by WHO (2006) is 500 mg/L. In groundwater, hardness is mainly due to carbonates, bicarbonates, sulphates and chlorides of Calcium and Magnesium. The principal natural sources of hardness in groundwater are sedimentary rocks and seepage and runoff from soils. In general, hard waters originate in areas with thick topsoil and limestone formations. Water hardness can be classified as Soft, 0 to 50 mg/L; Moderately Soft, 50 to 100mg/L; Slightly Hard, 100 to 150mg/L; and Moderately Hard, 150 to 200 mg/L, Hard, 200 to 300mg/L and Very Hard above 300mg/L. Results (Figure12) obtained indicate the water ranging from being slightly hard to hard water, though some shallow wells in Tezo exhibited high values greater than 300mg/L indicating the presence of very hard water. This could be attributed to the heavy agricultural activities that are carried out in the region. Similar results have been obtained by Olonga, (2015)

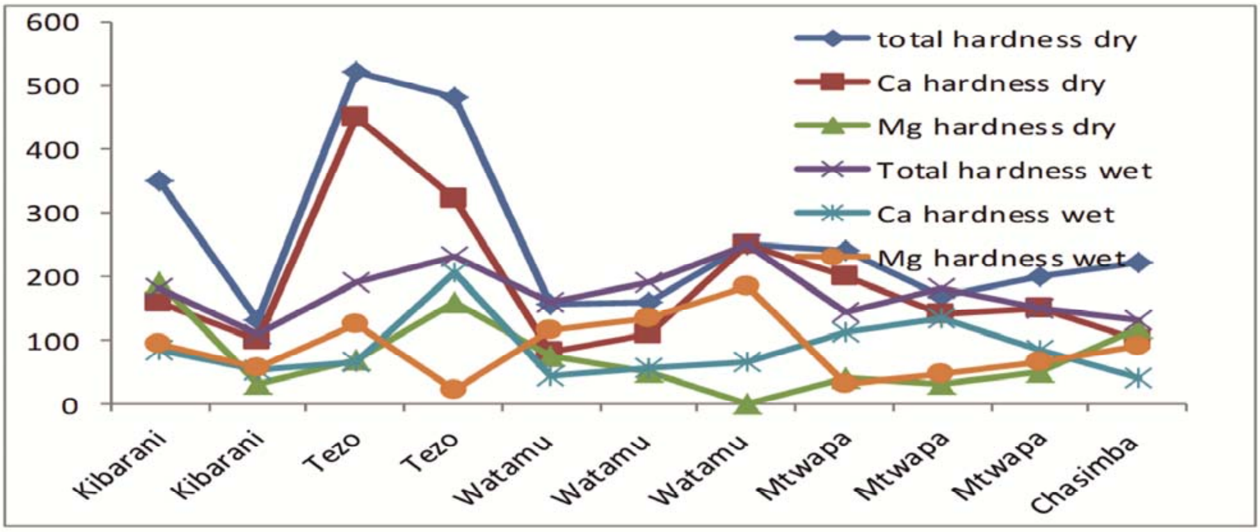

Figure 12. Total Hardness, Calcium and Magnesium hardness in boreholes and shallow wells in Kilifi

Microbiological characteristics (E.coli)

Faecal coliforms (FC) of which E.coli is one of them, is the most commonly used bacterial indicator of faecal pollution (Chukwunenyoke & Igboekwe, 2012). E.coli is commonly found in water that is contaminated with faecal wastes of human and animal origin. The WHO (2004), NEMA (2006) and USEPA (2012) requires that no faecal coliform should be detected in 100 ml of any drinking water supplies Table 2 gives the guidelines and set limits that are permissible in drinking water by WHO, (2004).

Results from the study for the E.coli tests were as seen in Figure 10. The results indicate that most of the water in the boreholes and shallow wells were contaminated and risky for human consumption as most of the areas recorded E.coli count of more than 100cfu/100ml; indicating the presence of pollutants. Inadequate and unhygienic handling of solid-wastes in the coastal area could have generated high concentration of microbial organisms agreeing with results of Laluraj et al., (2005).

Table 2: WHO permissible limits for *E. coli*

Faecal Coliform level(CFU/100 ml sample)	Risk	Recommended Action
0-10	Reasonable Quality	Water may be consumed as it is
10-100	Polluted	Treat if possible, but may be consumed as it is
100-1000	Dangerous	Must be treated
> 1000	Very Dangerous	Rejected or must be treated thoroughly

Water quality index (WQI)

Water quality index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameters communicating the information on overall quality of water on human and thus providing an important tool for management purposes (Bordalo et al., 2001).

The procedure that was used involves;In the first step, each of the parameters is assigned a weight (wi) cording to its relative importance in the overall quality of water for drinking purposes. In this study based on research by Bordalo et al., (2001) the maximum weight of 5 was assigned to chlorides, salinity and Total Dissolved Solids (TDS); a weight of 4 assigned to parameters pH, Turbidity and Electric Conductivity (EC) and a weight of 2 assigned to Total and Calcium hardness depending on their importance in the overall quality of water for drinking purposes.

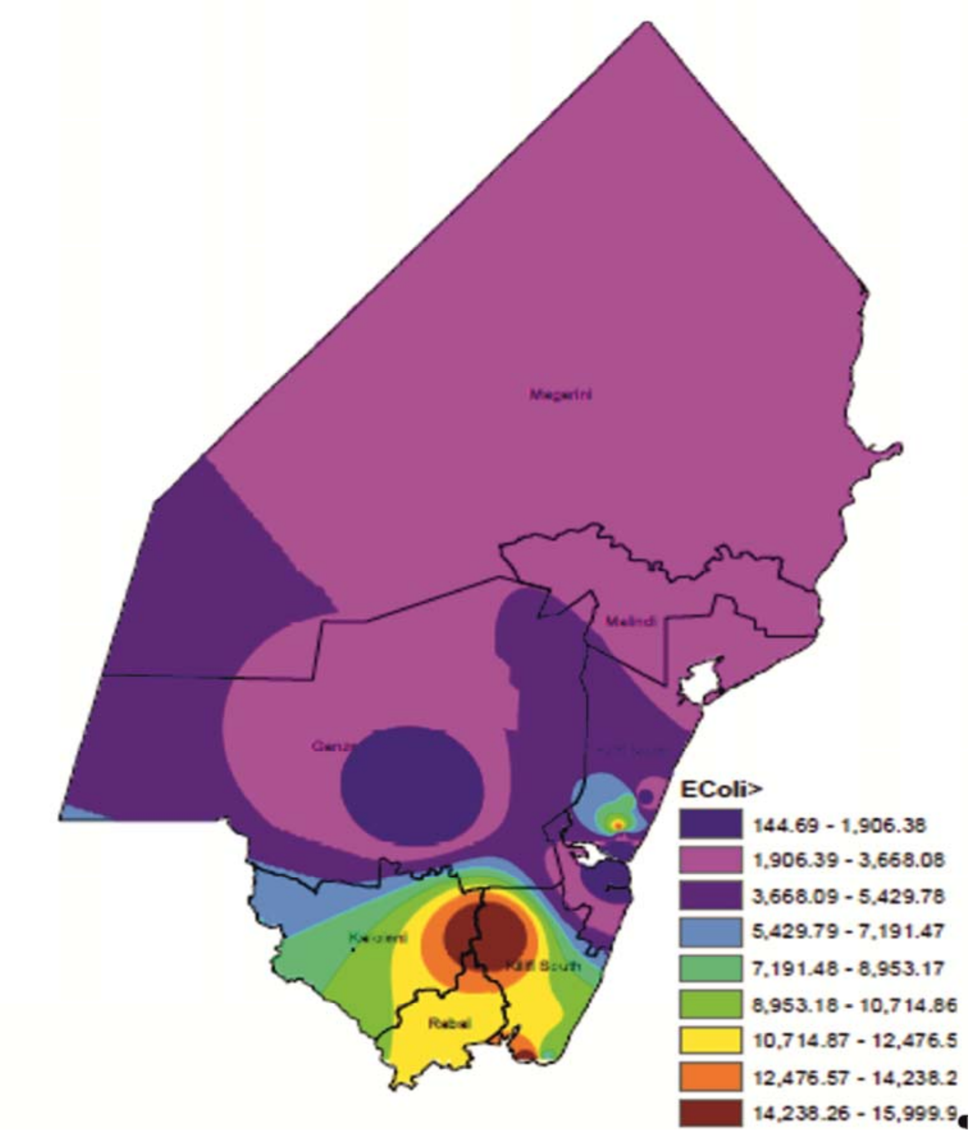

Figure 13. Geospatial distribution of the *E. coli* in Kilifi

In the second step, the relative weight (Wi) was computed using a weighted arithmetic index method given in Equation 3 in the following steps;

$$W_i = \frac{w_i}{\sum n w_i} \quad \text{(Eq. 3)}$$

i =1, Where, Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

In the third step, a quality rating scale (qi) for each parameter was assigned by dividing its concentration in each groundwater sample by its respective standard according to the guidelines by WHO and the result multiplied by 100 in Equation 4, (Gebrehiwot et al., 2011)

$$q_i = 100 \times \frac{V_i}{S_i} \quad \text{(Eq. 4)}$$

Where, qi is the quality rating, Vi is the concentration of each parameter in each water sample, and Si is the WHO drinking water standard for each parameter. Except for pH, Equation 4 shows the relationship between the water quality rating (qi) for the ith parameter, averages of the observed data (Vi) and water quality standards (Si).

For pH, the quality rating qpH can be calculated from Equation 5

$$qpH = 100 * \left[\left(VpH \approx \frac{7.0}{8.5 - 7.0} \right) \right] \quad \text{(Eq. 5)}$$

Where VpH is the observed value of pH and the symbol '≈' is essentially the algebraic difference between VpH and 7.0. For computing the WQI, the SI was first determined for each parameter (Equation 6), which was then used to determine the WQI as indicated by the following Equation 7,(Reza and Singh, 2010):

$$SI = W_i \times q_i \quad \text{(Eq.6)}$$

$$WQI = \sum SIi_i \quad \text{(Eq. 7)}$$

Where, SIi is the sub index of ith parameter; qi is the rating based on concentration of ith parameter and n is the number of parameters

Computed WQI values were classified into five categories based on classification by Chatterji & Raziuddin,(2002) (Table 3).

The results from the WQI (Table 4) calculation indicate that most of the boreholes and shallow wells in the dry season are unsuitable for drinking as their values exceeded 100 based on the classification of Table 3 as indicated by (Chatterji &Raziuddin, 2002). This was true as it was observed from the field that most of the boreholes were abandoned or used for irrigation especially those close to the ocean because of the high salinity.

During the wet season (Table 4) most of the wells seem to be diluted by the rainfall given the geological formation of the coastal region is mostly sandy and it allows easy percolation of the rain water. With application of proper water treatment methods, the shallow wells and the boreholes could be used for domestic purposes as most of the values were within the range of 50 -100.

Table 3: Water Quality Index (WQI) and status of water quality (Chatterji &Raziuddin, 2002)

Water Quality Index (WQI)	Water quality status
0 - 25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76 - 100	Very poor water quality
>100	Unsuitable for drinking

Table 4: Water quality index (WQI) values for the boreholes and shallow wells in Kilifi

BOREHOLES	**WQI=$\sum(q_i w_i)$ *DRY SEASON***	**WQI=$\sum(q_i w_i)$ WET SEASON**
Sokoni	1596.80	437.76
Sokoni	296.43	189.41
Sokoni	549.98	207.66
Sokoni	250.11	94.31
Mnarani	183.77	86.66
Mnarani	109.02	181.14
Kibarani	231.35	206.27
SHALLOW WELLS		
Kibarani	550.33	86.46
Kibarani	121.38	74.83
Tezo	327.99	89.53
Tezo	376.11	206.64
Watamu	169.15	166.46
Watamu	57.68	53.07
Watamu	577.43	282.39
Mtwapa	130.72	81.38
Mtwapa	167.46	105.54
Mtwapa	134.68	186.25
Chasimba	304.90	51.52

Conclusions

The boreholes and shallow wells within the study region had electric conductivity (EC) way above the set standard of 1500µS/m indicating the presence of high dissolved ions in the groundwater especially in Magarini where salt mining is carried out high wells. The EC values were also found to be directly proportional to the TDS value which is also true from previous related studies. The chlorides and salinity is most prevalent problem in almost all the boreholes and shallow wells in the study area as it exceeded the WHO recommended value of 250mg/L indicating the saltwater intrusion problem that poses a challenge to most coastal aquifers. The microbiological analysis also indicate that the E.coli was present in all the boreholes and shallow wells, implying that they were all contaminated and therefore need to treated before use. pH values in both the dry and wet season were within the acceptable range of 6.5 – 8.5, though the shallow wells in Malindi were acidic and this was attributed to the heavy industries that are prevalent in the region.. Most boreholes and shallow wells had a turbidity of less than 5 NTU which is the set standard value except in Kibarani where the value went up to 18 NTU. This could be attributed to the irrigation activities prevalent in the area and the sandy geological that allows easy percolation.. The boreholes and shallow wells had a total hardness ranging from 50mg/L -150mg/L indicating the water was ranges from being slightly hard to hard water though in the Tezo region where agricultural activities were dominating, the water was very hard with values greater than 300mg/L. The results from the Water Quality Index (WQI) calculation indicate that most of the boreholes and shallow wells in the dry season are unsuitable for drinking and human use.

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