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GROUNDWATER RESOURCES AND SEA WATER INTRUSION IN KWALE DISTRICT

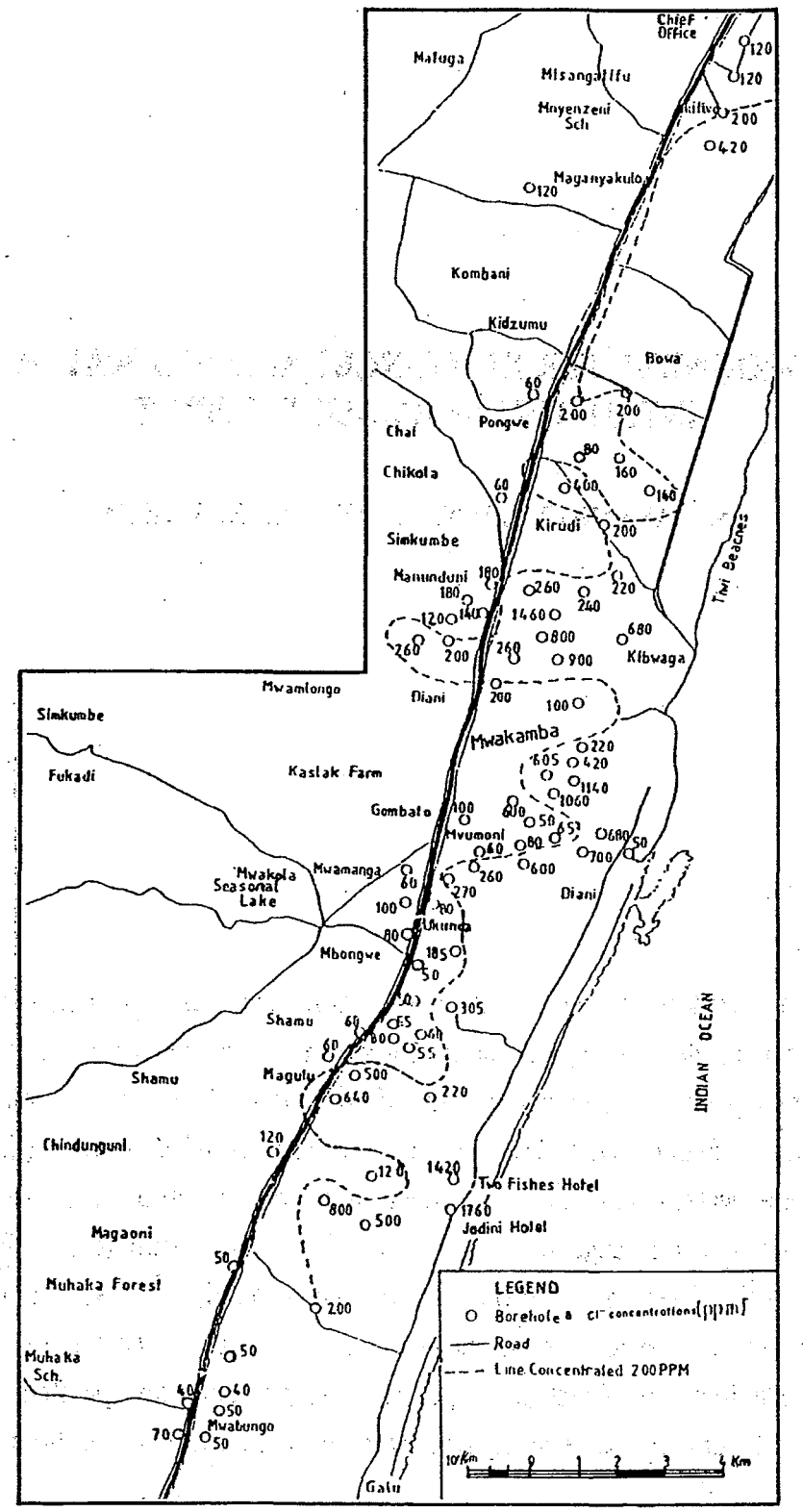
S.O. ANYANGO, M.P. TOLE AND E.K. UCAKUWUN

Introduction

Although Kenya straddles the equator like the Amazon Basin, it has nothing near the equatorial vegetation of the latter region due to altitude and monsoons, resulting in great variations in rainfall patterns. Roughly four-fifths of Kenya is semi-arid or arid. This covers all areas from the shrub of the coastal region to the northern semi-desert region (Camponera, 1979). The open water resources in lakes, rivers and dams constitute 11,230 km^2. In addition, Kenya receives an average annual rainfall of 567 mm converting to 323 billion m^3 of water (GoK, 1989). These limited resources need to be properly harnessed and conserved.

The problems of water resource management emerge at two critical levels. Firstly, the resources are limited and subject to competing demands from human settlement both in urban and rural areas. This is demonstrated by the frequent shortages in the major urban

Figure 5.1 *Concentration of chloride in boreholes in Diani-Tiwi area*



centres and in rural areas where women and children have to walk long distances to fetch water. This calls for appropriate measures for resource allocation. Secondly, resource utilisation and human activities may have adverse impacts on water quality and it is therefore essential that water utilisation and quality be managed.

Kwale District lacks adequate water resources. Several seasonal springs from the Shimba Hills catchment area and a few seasonal rivers in the south coast are some of the sources of water. According to the studies done in the area by the Ministry of Water Development and other studies, the area has potential for groundwater exploitation. But the development of groundwater resources requires carefully controlled pumping, accompanied by proper operation surveillance (Chapman, 1992).

The present trends in groundwater exploitation have not differentiated between renewable and non-renewable resources. The determination of maximum and minimum water levels in order to regulate storage capacity is important (Balek, 1983). A decrease in groundwater levels due to excessive pumping besides causing permanent damage to the stability of the groundwater storage, increases the cost of further pumping, facilitates salt water migration and the pollution of the aquifers with sea water (Balek, 1983).

The present study was carried out to determine the extent of groundwater exploitation and its effect on water quality in Kwale District. The area hosts a chain of tourist hotels and due to frequent water shortages from the main pipeline, most of them have drilled boreholes from which they extract large amounts of water. In addition, the National Water Pipeline and Conservation Corporation(NAWACO) is operating several boreholes and the Kwale Water and Sanitation Project (KWASP) has come up with an extensive network of shallow boreholes to provide water to the rural population. It is quite possible that extraction may by now surpass recharge, hence causing depletion of groundwater and resulting in sea water intrusion.

This study was conducted to determine:

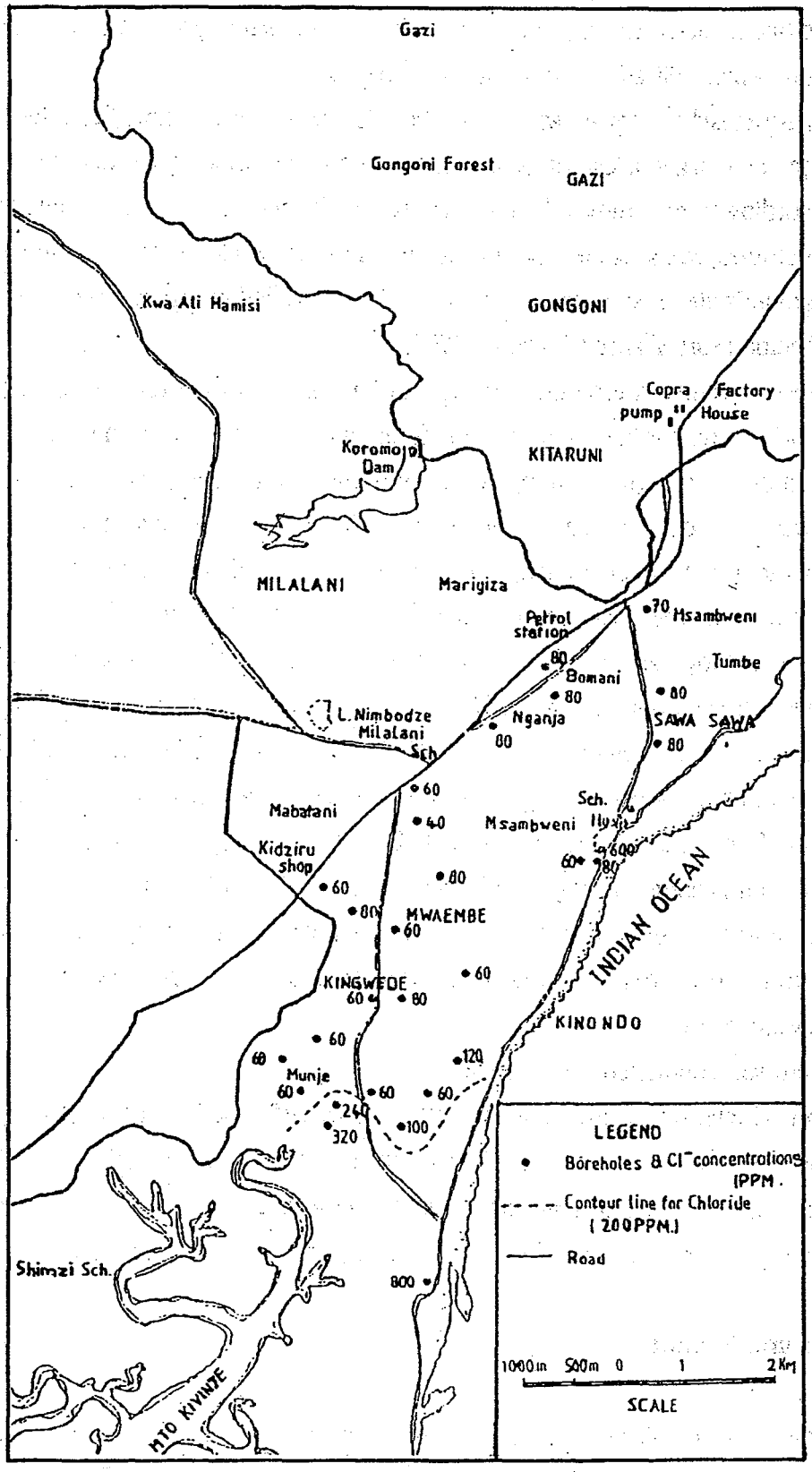
- The groundwater quality from public supply sources threatened by sea water intrusion;
- Whether the tidal changes have an effect on the quality of groundwater;
- The sustainability of water facilities established in the area;
- The hydrogeochemical correlation which may be prevailing in the study area.

Materials and Method

FIELD METHODS

Water samples were collected from 125 points, consisting mainly of boreholes and open dug wells. At each point, samples were collected twice at different times. Each sample was

Figure 5.2 *Concentration of chloride in boreholes in Msambweni area*



analysed in duplicate. The specific conductivity, temperature and pH were determined in the field using automated instruments (probe meters).

Polyethene bottles were used for the collection of samples. They had screw cap stoppers to prevent leakages during transportation. The containers were pre-cleaned with metal-free nitric acid and then rinsed several times with glass distilled water. Samples from boreholes were taken after the water was allowed to flow for 3 to 5 minutes after the pumps were in operation. This was to ensure that a representative sample of the source was taken.

Analysis was carried out the day following sampling to ensure that there was no significant change in the concentration of the parameters to be determined. The samples were then stored in a cold storage at about 4^0C for future reference if need arises. Methods applied in the analysis were basically those used by the Kenya Government Chemist Department (water section). The parameters determined are TDS (Total Dissolved Solids), Potassium, Sodium, Calcium, Total Hardness, Magnesium, Alkalinity, Chloride, Hydrogen Carbonate, Fluorides and Silicon.

Some specific sampling points were selected and water quality monitored by taking water samples and measuring the depth of the open well after every one hour throughout the cycle of the tide (from low to high and to low).

DATA ANALYSIS

The data was treated to correlation analysis procedures to determine relations between parameters.

Hydrological data analysis involved the plotting of the locations of all the boreholes in the study area. Borehole data on aquifer depth and the water rest levels were then used to depict the water flow directions. Hydrogeochemical data analysis involved preparation of a contour on a map to depict the area of sea water intrusion using chloride concentrations.

General classification of the water was done using the classification adopted from Davis and Dewest (1970). Possible increase in sea water intrusion was investigated by checking for significant increase of chloride and sodium concentrations by comparing the initial data (from KWASP) and the data obtained in the study. Graphs of water rest levels against time and height of tides in the ocean were produced to depict the influence of tidal changes on the selected wells near the ocean. Salinity classification and calculation of Sodium Absorption Ratio (SAR)[1] served to determine the suitability for irrigation purposes.

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1. SAR = Na^{2+} / $\sqrt{((Ca^{2+} + Mg^{2+})/2)}$, where Na^{2+}, Ca^{2+} and Mg^{2+} represent the concentrations, in

Table 5.1 *Classification of water on the basis of TDS by catchment area**

Type of water	Recommended TDS range in ppm.	distribution Diani %	Msambweni %	Tiwi %
Fresh	below 1,000	63	96	81
Brackish	1,000 - 10,000	35	4	19
Salty	10,000 - 100,000	2	0	0
Brine	above 100,000	0	0	0
		100	100	100

* Modified from Davis and Dewiest, 1970

RESULTS[2]

WATER QUALITY

The distribution of the sampling sites is shown in Fig 5.1 & 5.2. According to the classification in Table 5.1, most areas have fresh waters. Diani catchment has the highest percentages of brackish water. Most of the parameters were below the maximum permissible levels for drinking water apart from conductivity, total dissolved solids, sodium, chloride, magnesium and total hardness which, in some cases had very high values (Table 5.2).

Most of the boreholes with high levels of TDS are quite close to the ocean. Conductivity, TDS, Na and Cl show great variation between individual boreholes. This suggests that the factors influencing these parameters are not uniformly distributed in the area and do not necessarily derive from the geology of the area because this is the same throughout the study area.

The pH in the study area ranges between 6.5 and 8.18 while the means were 7.26, 7.15 and 7.28 for Diani, Msambweni and Tiwi respectively. The pH values in the three aquifer systems indicate generally neutral waters and within the range of most groundwater as reported by Hem (1978). The fluoride concentration was generally below the maximum permitted value of 1.5 ppm (WHO, 1987) with a mean value of 0.3, 0.2 and 0.3 ppm for Diani, Msambweni and Tiwi respectively. These results indicate that the water is generally suitable for drinking purposes. However, the water has limited use due to the general hardness.

About 90 per cent of the samples from Msambweni had conductivity less than 1000μs. The lowest value was recorded at Makalani and Chungwani 'B' (520μs) while the highest was 2600μs at Bahani. In Tiwi, about 53 per cent of samples had conductivity of less than

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milliequivalents per litre of the respective cations.

2 . Detailed results are presented in Anyango (1995).

1000μs. The lowest value recorded was 400μs (at Kombani) while the highest was 4800μs at Kayatiwi secondary school. Diani had the greatest variations resulting in the mean being even less than the standard deviation. About 57 per cent of the samples had conductivity of less than 1000μs. The lowest recorded values was 420μs while the highest was 15000μs at the Grand Reef Hotel in Diani.

Table 5.2 *Physico-chemical parameters by catchment area* (mean ± s.d.)

	Diani N=55	Msambweni N=30	Tiwi N=32
Conductivity (μs)	1701 ± 2259	708 ± 401	1296 ± 915
Depth (m)*	31 ± 12	18 ± 7	33 ± 12
Temp (^{0}C)	30 ± 2	31 ± 2	31 ± 2
pH	7.3 ± 0.4	7.2 ± 0.2	7.3 ± 0.4
TDS (ppm)	1187 ± 1521	598 ± 596	910 ± 634
K (ppm)	10 ± 17	3 ± 3	7.3 ± 5
Na (ppm)	218 ± 461	72 ± 82	167 ± 162
Cl (ppm)	413 ± 809	130 ± 167	287 ± 292
Ca (ppm)	132 ± 52	145 ± 207	115 ± 48
Mg (ppm)	31 ± 31	24 ± 60	24 ± 21
Total hardness (ppm)	436 ± 163	356 ± 41	435 ± 162
F (ppm)	0.3 ± 0.6	0.2 ± 0.4	3.8 ± 21
SiO_2 (ppm)	31 ± 13	30 ± 14	38 ± 15
HCO_3 (ppm)	332 ± 95	323 ± 40	341 ± 71

* N=46; 25; 28 respectively

Table 5.3 shows the results of the comparison of the values in 1987 when the boreholes were dug with the results of the present study, in 1993. The figures confirm that the waters have become more saline and that there are significant changes in Conductivity, TDS and Na concentrations.

Analysis by means of the trilinear method (piper diagram) indicates that in Msambweni, 50 per cent and above of the water is dominated by calcium cations while 10 per cent of the samples have sodium as the dominant cation. For the anions 81 per cent of the water samples form a cluster indicating 50 per cent and above of bicarbonates as dominant and 10 per cent of the remaining waters have chloride as the dominant anion. In Diani about 42 per cent of the water samples form a cluster indicating 50 per cent and above of the waters is dominated by calcium while 35 per cent of the waters have sodium as the dominant cation. For the anion 55 per cent of the water samples form a cluster indicating 50 per cent and above of bicarbonate as dominant and 38 per cent of the remaining waters have chloride ion as the dominant anion. In Tiwi about 36 per cent of the water samples form a cluster indicating that 50 per cent and above of the water is dominated by calcium

while 30 per cent of the waters have sodium as the dominant cation. For the anion 39 per cent of the waters samples form a cluster indicating that 50 per cent and above of bicarbonate as dominant and 39 per cent of the remaining waters have chloride as the dominant anion.

Table 5.3 *Results of selected parameters for boreholes measured in 1987 and 1993* (mean ± s.d.)

	N	1987	N	1993	p= *
Conductivity	68	876 ± 572	68	975 ± 574	.03
TDS	65	579 ± 416	65	688 ± 401	.001
Na	45	86 ± 91	45	115 ± 104	.003
Cl	65	170 ± 192	65	186 ± 177	.13

* paired t-test; one-tailed

VARIATION OF CHLORIDE CONCENTRATION

Figures 5.1 & 5.2 show the concentration of chloride in various boreholes in the study area and also indicate the possible trend of Cl-ions which is related to sea water intrusion. There is an indication of inward movement of the sea water/fresh water interface. The chloride contour line gives the probable area of sea influence. The 200ppm value was chosen because water with higher values normally starts having a salty taste.

TIDAL AND WATER DEPTH VARIATIONS

These indicate that the wells have direct linkage with the sea, even though there is a time lag of one and a half hours between lowest tide and lowest height (Fig 5.3). When it is high tide the water rest level is increased. The effect is less and time lag greater (up to eight hours) for fresh water boreholes nearby. But the effect is greatest in boreholes near the ocean.

Table 5.4 *Distribution of SAR values by catchment area* (%)

	Diani N=50	Msambweni N=30	Tiwi N=32
0.0 - 0.9	40	40	6
1.0 - 1.9	20	40	22
2.0 - 2.9	4	3	28
3.0 - 5.9	20	7	31
6.0 - 8.9	12	10	10
9.0 +	4	0	3
	100	100	100

SODIUM ABSORPTION RATIO

Elevated sodium in certain soils can degrade soil structure thereby restricting water movement and affecting plant growth. Results for the sodium-absorption rate calculations for the three water catchment areas are presented in Table 5.4. Although the values are higher in Tiwi than in the other catchment areas there were no observations above the critical value of 18 (Driscoll, 1986). All samples have low values which makes the water suitable for irrigation purposes.

Discussion

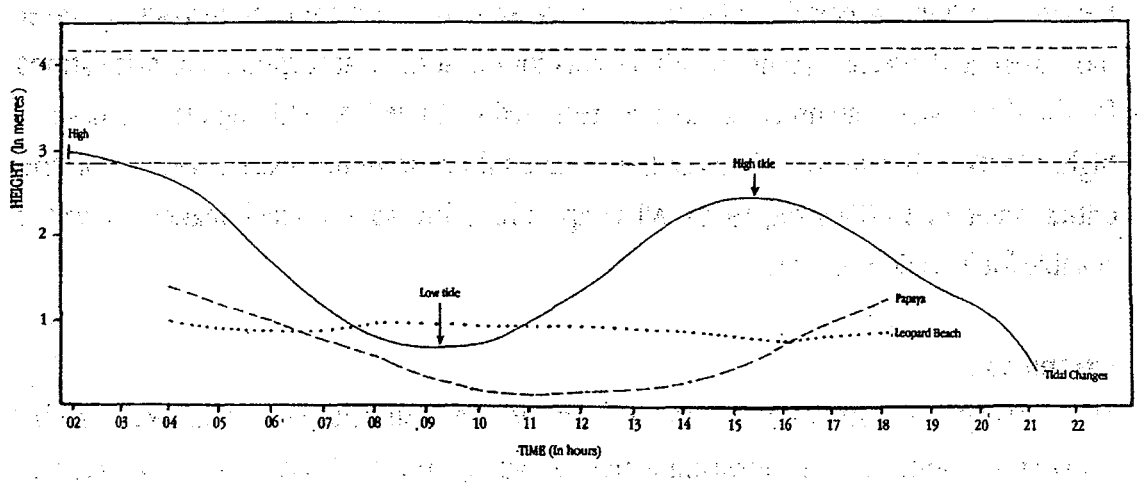
The results of the water samples indicate that the chemical nature of groundwater in the study area is influenced by environmental factors e.g. the geology, chemical processes, climate and hydrological factors. This was also noted in studies by Maina (1981) and Ongwenyi (1973). The water in the study area can be classified into four types, calcium bicarbonate, calcium chloride, sodium bicarbonate and sodium chloride type of waters.

The fluoride concentration was generally below the maximum permitted value of WHO (1.5ppm) with a mean value of 0.3, 0.2 and 0.3 for Diani, Msambweni and Tiwi areas respectively. This indicates that the water presents no danger due to fluorides. Fluoride mobility in water depends to a large extent on the Ca^{2+} ion concentration since fluoride forms low solubility compounds, with divalent cations. This explains why the water in the study area may have low fluoride concentrations.

The cases with Na^{+} as the dominant cation can be attributed to the influence of the sea, through the process of sea water intrusion. Examples are boreholes at Jumapili, Baharini and Mkaliatsi in Msambweni; boreholes at Maweni, Bwagamoyo at Jadini hotel in Diani; and boreholes at Sparki, Shukrani and Tawakal in Tiwi (Fig 5.1). In Msambweni a tongue of sea water seems to be coming in from the south (Mto Kivinje, Fig 5.2). In Tiwi and Diani several tongues of sea water intrusion were observed at Bowa, Kibwaga, Mwakamba, Magutu among others.

Compared with measurements that were taken in 1987 when the boreholes were sunk, the present study, in 1993, found no significant changes in Conductivity, TDS, Cl and Na concentrations, although there is a general trend towards greater salinity in the boreholes. According to Freeze and Cherry (1979), the rate of groundwater extraction that causes groundwater 'mining' is not necessarily the same as the rate that causes contaminant intrusion. In coastal areas for example a certain rate of groundwater extraction, even without causing over withdrawal, can lead to sea water intrusion.

Figure 5.3 *Tidal variations* as compared to the well water rest levels*



* The wells were monitored over 12 hours when no drawing of water occurred

There is a significant difference in the chloride concentrations in Diani & Tiwi compared to Msambweni. The reason might be due to more extensive borehole extractions compared to the Msambweni area. The Diani/Tiwi area has a higher population density with higher number of boreholes belonging to hotels and other private owners. These boreholes use electric pumps, thus extracting more water than the handpumped boreholes do. Some of the beach hotels have obtained the right of extracting water from boreholes further inland with fresh water and this has resulted in some of these boreholes becoming saline e.g. boreholes sunk by South Palms and Leisure Lodge around Diani and Mvumoni respectively.

In Msambweni, the extraction still seems not to have had effect on the aquifer except at Msambweni Hospital and near the creek at Shirazi and there are no signs of sea water intrusion. Fresh water springs in the intertidal zone have been observed in the Msambweni area, confirming a high fresh water recharge. Such a phenomenon can no longer be observed in Diani or Tiwi.

In Diani, some boreholes are already highly saline, especially those being operated by the hotels, but no precautionary measures have been taken to protect the nearby boreholes that are producing fresh water. This can encourage the sea water/freshwater interface to move further inland. Some wells have become saline to the extent that the water is no longer being used for domestic purposes (e.g. Kwa Mzee Juma Makalani in Diani).

The study established that the sea water/freshwater interface varies along the coast but it ranges from 1.5km to 6.5km from the shoreline in the Mwabungo-Waa area. In the Msambweni area, the waters are safe for drinking up to the shoreline except adjacent to Msambweni hospital and south Kigwede in the Shirazi area.

The study indicates that wells have direct linkage with the sea, even though there is a time lag of one and a half hours between lowest tide and lowest height. When it is high

tide the water rest level is increased, the effect is less and the time lag greater (up to eight hours) for a freshwater borehole nearby. But the effect occurs only in some specific boreholes near the ocean.

Without the threat from sea water intrusion, it is evident that the freshwater in the area is generally potable and suitable for domestic use. The water has also low SAR value and therefore suitable for irrigation. However, sodium sensitive crops may accumulate injurious sodium concentrations and Driscol (1986) recommends that most of these waters are used on textured organic soils with good permeability.

Conclusion

This study has shown that the sea water intrusion is significant at the present level of groundwater extraction. A good groundwater management plan should be developed for these major aquifers. The following measures can be useful in the conservation and proper utilisation of these resources:

- Determination of aquifer safe yields;
- Monitoring of groundwater levels and well allocation, spacing and construction guide lines;
- Records of water use rates, quantities and quality should be maintained by large scale users such as hotels and even the National Water Pipeline and Conservation Corporation. Such records can help water managers to decide (where the safe yield of an aquifer is already determined), whether or not withdrawal is excessive so as to take appropriate measures, such as reducing the quantity under the license;
- Discourage hotels from using fresh groundwater in the area, and propagate other methods like desalination (some are already doing it e.g. Jadini) and roof catchment;
- Encouraging rainwater harvesting in general, much more than has been done so far. This can reduce the pressure on the limited groundwater resources, and provide a long term solution for the area.

However, enactment of good regulations and subsequent enforcement are fraught with difficulties involving political, economic and sociological factors that are hard to overcome.

Abstract

This work describes the results of water quality analysis carried out along the coastal plains of Kwale District, to determine the influence of sea water intrusion, the relationship between tidal changes and water quality in boreholes close to the sea shore, and the effectiveness of the hand pumps in the provision of potable waters in the study area.

Four types of waters were found in the study area; calcium bicarbonates, sodium bicarbonate, sodium chlo-

ride and calcium chloride waters. Total Dissolved Solids (TDS) in sodium-rich waters varied from 800ppm to 10,000ppm with most of the TDS concentrations being below 1000ppm (recommended concentration limits for drinking water). The salinity hazards for the water are greater than 750μs/cm at 25^{0}C. Consequently this water has limited practical use.

A salt tongue (sea water intrusion) was detected covering a distance ranging from 1.5 to 6.5km from the shoreline in Mwabungo-Waa area. But in the Msambweni area, sea water intrusion is still limited and waters are safe for drinking up to the shoreline except adjacent to Msambweni hospital and south Kigwede in the Shirazi area.

During periods of high tide some wells exhibit higher levels of water and higher salinity than during the time of low tides. This effect decreases with distance away from the seashore.

Acknowledgements

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References

Anyango S O (1995). *The chemistry and management of the ground water resources in Kwale District, Kenya, with reference to sea water intrusion*. M.Phil. thesis. Moi University, School of Environmental Studies.

Balek L (1983). *Hydrology and water resources in tropical regions*. New York: Elsevier

Camponera D (1979). *Water law in selected African countries*. Rome: FAO.

Chapman D (1992). *Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring*. London: Chapman and Hall.

Davis S N & Dewiest R J M (1970). *Hydrogeology*. New York: John Wiley.

Driscol F G (1986). *Groundwater: water and wells*. 2nd ed. St. Paul (Minnesota.): Johnson.

Freeze R A and Cherry J A (1979). *Groundwater*. Prentice Hall.

GOK (1989). *Kwale District development plan 1989-1993*. Nairobi: Government of Kenya, Government Printers.

Hem D J (1978). *Study and interpretation of the chemical characteristics of water*. United States Department of the Interior, 1473.

Maina J W (1981). *Groundwater chemistry of the area to the immediate North of Nairobi conservation area*. M.Sc. thesis. University of Nairobi.

Ongwenyi G S (1973). *The significance of the geographic and geologic factors in the variation of groundwater chemistry in Kenya*. M.Sc. thesis. University of Nairobi.

WHO (1987). *GEMS/Water operational guide*. Geneva: World Health Organization.