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Pollution of groundwater in the coastal Kwale District, Kenya

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Abstract Groundwater is a "last-resort" source of domestic water supply at the Kenyan coast because of the scarcity of surface water sources. NGOs, the Kenya Government, and international aid organizations have promoted the drilling of shallow boreholes from which water can be pumped using hand-operated pumps that are easy to maintain and repair. The shallow nature and the location of the boreholes in the midst of dense population settlements have made these boreholes susceptible to contamination from septic tanks and pit latrines. Thirteen percent of boreholes studied were contaminated with *E. coli*, compared to 30% of natural springs and 69% of open wells. Areas underlain by coral limestones show contamination from greater distances (up to 150 m away) compared to areas underlain by sandstones (up to 120 m). Overpumping of the groundwater has also resulted in encroachment of sea water into the coastal aquifers. The 200 ppm Cl iso-line appears to be moving increasingly landwards. Sea level rise is expected to compound this problem. There is therefore an urgent need to formulate strategies to protect coastal aquifers from human and sea water contamination.

INTRODUCTION

The Government of Kenya and several nongovernmental organizations have long recognized the need to make water more easily accessible to the people in order to improve sanitary conditions, as well as to reduce the time people spend searching for water, so that time can be freed for other productive economic and leisure activities. Given the scarcity of natural surface freshwater sources, efforts have been directed at either the construction of earth dams or the sinking of shallow boreholes where fresh groundwater could be obtained. Among the organizations that have championed groundwater exploitation using community-operated hand pumps have been KENFINCO and LBDA in Western Kenya and SIDA and KWAHO in the Coast Province.

The Kwale Water and Sanitation Project was started in 1985 as an extension of the South Coast Handpumps Testing Programme, with the aim of (a) drilling boreholes and installing handpumps that would be operated by the recipient communities; (b) protecting perennial springs; (c) providing assistance to self help groups on piped water supply schemes; (d) constructing ventilated improved pit (VIP) latrines; and (e) conducting health education campaigns.

This paper examines the quality of some of the groundwater sources developed in the project area, particularly the interaction between pit latrine waste and the groundwater system with respect to the differing geological conditions of the project area. In particular, one of the objectives of the study was to find out whether there were any differences in the extent to which pit latrine waste interacted with groundwater in coral limestone *vs* sandstone lithologies.

Groundwater resources in coastal areas are always in danger of contamination by sea water intrusion. The likelihood of this taking place is increased when rates of extraction of groundwater near the shoreline are raised due to increased demand on fresh water resources. A further cause for concern over coastal water resources has been sea water intrusion due to the predicted sea level rise resulting from global warming. For the Kenyan coast, the likelihood of sea water intrusion is further increased by (a) the highly porous nature of the underlying coral limestone formation; and (b) reduced rates of groundwater recharge as urban centres and roads are paved.

With the above problems in mind, this study was also conducted in order to (a) provide baseline data from which future changes in groundwater salinities in the study area can be gauged; (b) assess the current state of water quality near the coastline, especially in view of sea water intrusion; (c) attempt, with the limited time series data available, to give an early warning of the threat of sea water intrusion along the Kenyan coast; and (d) assess the areas in which the problem of sea water intrusion is most likely to be acute.

THE STUDY AREA

The study area is in Kwale District, Coast Province Kenya (Fig. 1). It is approximately bounded by longitudes 39°22′E and 39°36′E and latitudes 4°9′S and 4°30′S. Close to the Indian Ocean the area is underlain by coral limestones of Pleistocene age (Caswell, 1953). Further inland are the Magarini sands and Mazeras sandstones of the Tertiary and Triassic ages respectively. Study sites were selected to be within the dominant lithologies of coral limestone and sandstone. The Diani, Ukunda, Tiwi, Waa and Msambweni areas (Fig. 1) are densely populated, while Shimba Hills is less densely populated.

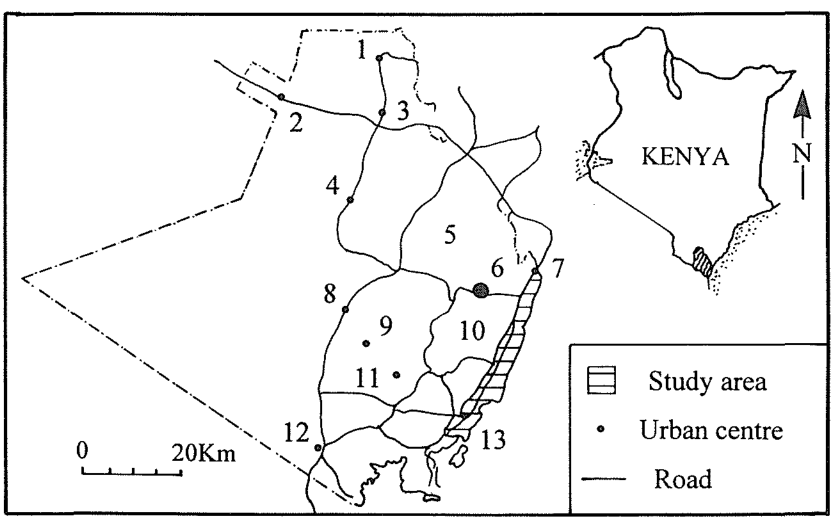

Fig. 1 Study area showing location of sampling stations and major drainage systems (1. Silaloni; 2. Mackinnon Road; 3. Samburu; 4. Kinangoni; 5. Gandini; 6. Kwale; 7. Waa; 8. Gulanze; 9. Mkongani; 10. Ukunda; 11. Lukore; 12. Lunga Lunga; 13. Msambweni).

Previous studies in the area (Caswell, 1953; Gentile, 1965; Austromineral, 1980; Adam, 1982; Majanga, 1987) expressed concern that sea water intrusion may be imminent, and recommended that groundwater abstraction should be limited and further drilling controlled. Gichaba *et al.* (1992), however, state that there seems to be no problem of sea water intrusion in the study area further inland.

Due to increased demand, the Kwale Water and Sanitation Project has been undertaking drilling of boreholes and installation of community owned and operated hand pumps within the study area through funding from the Kenya Government, SIDA (Swedish International Development Agency) and KWAHO (Kenya Water for Health Organization). Tourist hotels in the area have also, due to increased demand, sunk a number of private boreholes from which large quantities of water are withdrawn using electrical and/or diesel pumps. The National Water Conservation and pipeline corporation operates the Tiwi boreholes which withdraw water from the Tiwi aquifer for consumers in Mombasa. All these put a strain on the fresh groundwater resources in the area, and increase the possibility of sea water intrusion.

RESEARCH METHODS

Available data on boreholes drilled by the Kwale Water and Sanitation Project on water quality at the time of commissioning of the wells (1987) were obtained from the project files (Baseline Survey Team, 1989). Field data were collected during this study in boreholes drilled by the project, but also from hotel drilled boreholes and open wells to extend the data base for future time series analysis, and to map out more accurately the sea water intrusion contour. A total of 125 stations were sampled.

Two wells were selected for monitoring the effect of tidal fluctuation on the water rest levels in the wells when no pumping/withdrawal of water was taking place (over a 24 h period). Samples were collected in duplicate. The parameters which could be determined immediately, i.e. pH, temperature and conductivity, were determined *in situ*. pH was measured using a Jenway model 3100 pH meter, while conductivity was measured with a Jenway 4070 conductivity meter. Both meters had automatic temperature compensation. Samples were collected into polyethylene bottles which had previously been cleaned with metal-free nitric acid and rinsed several times with distilled water. Just before collection of the sample, each container was rinsed three times with the water about to be sampled. Borehole waters were allowed to flow freely for some time while the pumps were in operation to remove all the water contained in the casing and to obtain fresh samples from the aquifer. No preservation of samples was attempted as the samples were analysed within 48 h of collection.

In the laboratory, the chemical analytical methods used were those established for the Government Chemist in Mombasa. Sodium and potassium were analysed using a flame photometer; calcium was determined by titration with EDTA using Eriochrome black T as indicator. Total hardness was determined using EDTA titration; magnesium was estimated as the difference between total hardness and calcium concentration; carbonate and bicarbonate were determined by titration with H_2SO_4, using phenolphthalein and methyl orange indicators respectively; chloride was determined by titration with silver nitrate, using potassium dichromate as indicator; fluoride and silica were determined colorimetrically using zirconium-alizarin and ammonium molybdate respectively. Total dissolved solids (TDS) were measured by evaporation of 100 ml of sample.

Coliform counts were determined by the most probable number method, after incubation of MacKonkey broth-treated samples for 48 h at 37 °C (WHO, 1984). Culture in bile broth was used to determine the most probable number of *E. coli* (WHO, 1984).

RESULTS

For statistical data analysis the data were grouped into three: those for Tiwi, those for Ukunda-Diani, and those for Msambweni. Such grouping shows that the Msambweni area had the best quality of water (96% of the sample points had freshwater), followed by Tiwi (81% of the sample points had freshwater), while Ukunda-Diani had the worst quality water (only 63% of water points had freshwater). The mean TDS in the Ukunda-Diani area was 1187 ppm (413 ppm Cl); that in Tiwi 910 ppm (287 ppm Cl); and in Msambweni 598 ppm (130 ppm Cl).

Comparison of initial borehole data with those obtained in this study (only boreholes drilled by the Kwale Water and Sanitation Project had previous data that were accessible to the study) indicated that most of the boreholes have had an increase in salinity in the period from 1987 to 1993. A few showed no change, while for some there was a decrease in salinity between 1987 and 1993, which was a rather surprising outcome. The differences were significant at the 90% level for Na, but only at the 50% level for Cl.

Figure 2 shows that there is a hydrological connection between some of the wells/boreholes and the sea. The effect was greater in this case for the Papaya well, which has saline water, than for the Leopard Beach hotel borehole which produces freshwater. Based on a 200 ppm Cl value (the approximate Cl value at which a salty taste begins to be felt by the human tongue), the extent of possible sea water intrusion effects in 1993 are given in Fig. 3.

Statistical treatment did not reveal any significant differences in the means of parameters between the wet and dry season, although there is a trend towards a slight

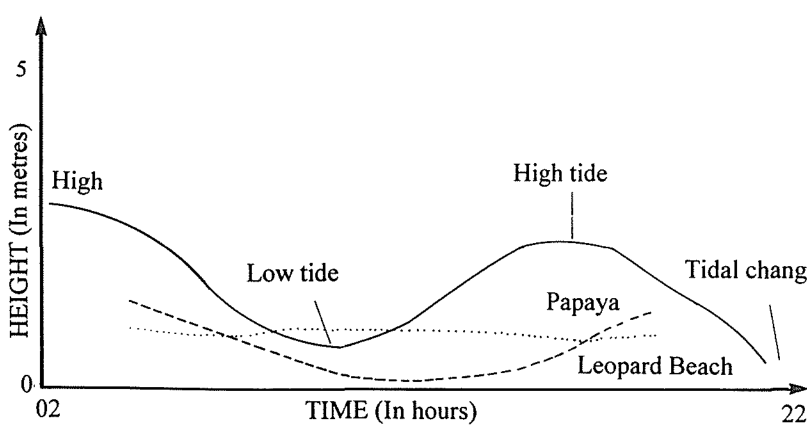

Fig. 2 Tidal variations compared to the well water rest levels. The wells were monitored over 12 h when no drawing of water was occurring.

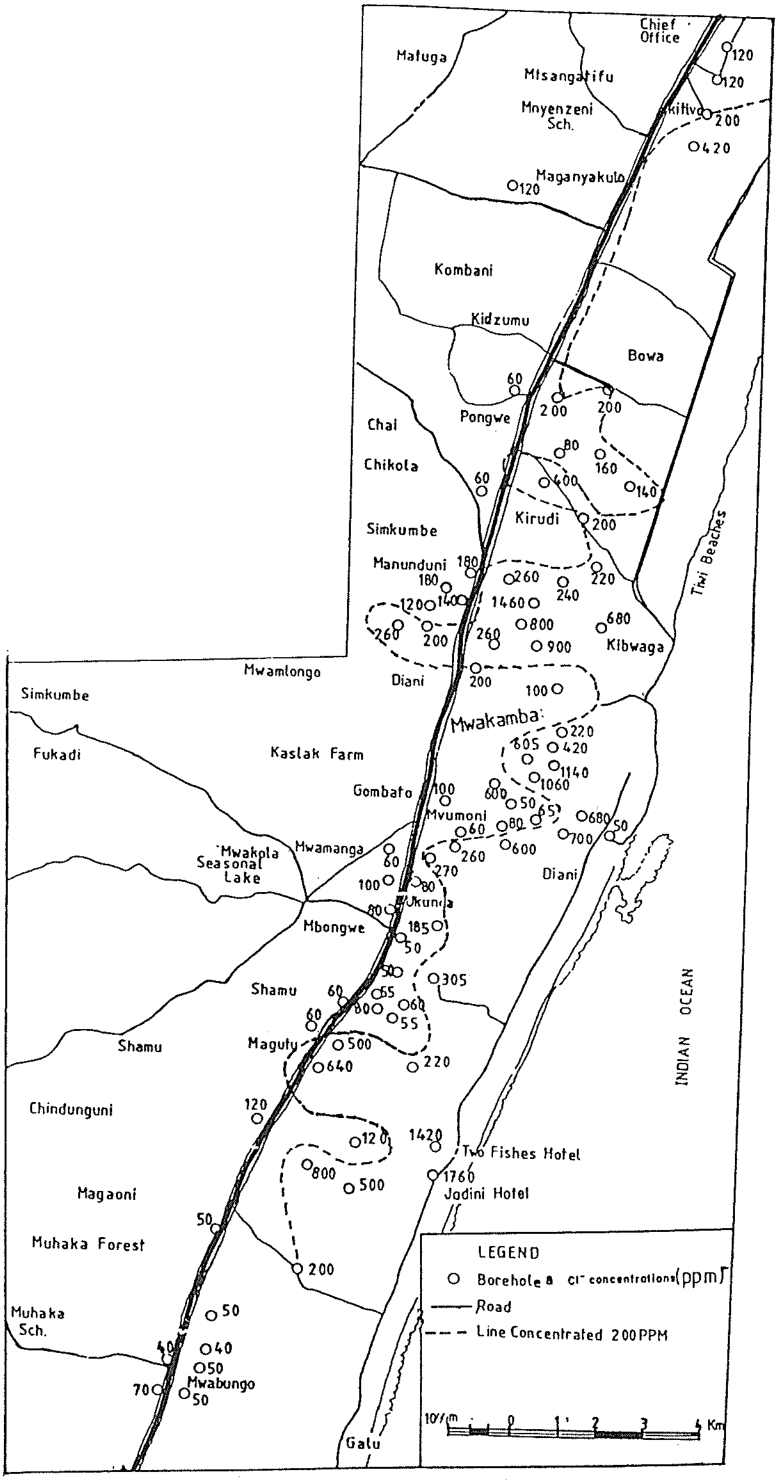

Fig. 3(a) Salt water incursion in the Tiwi-Diani area.

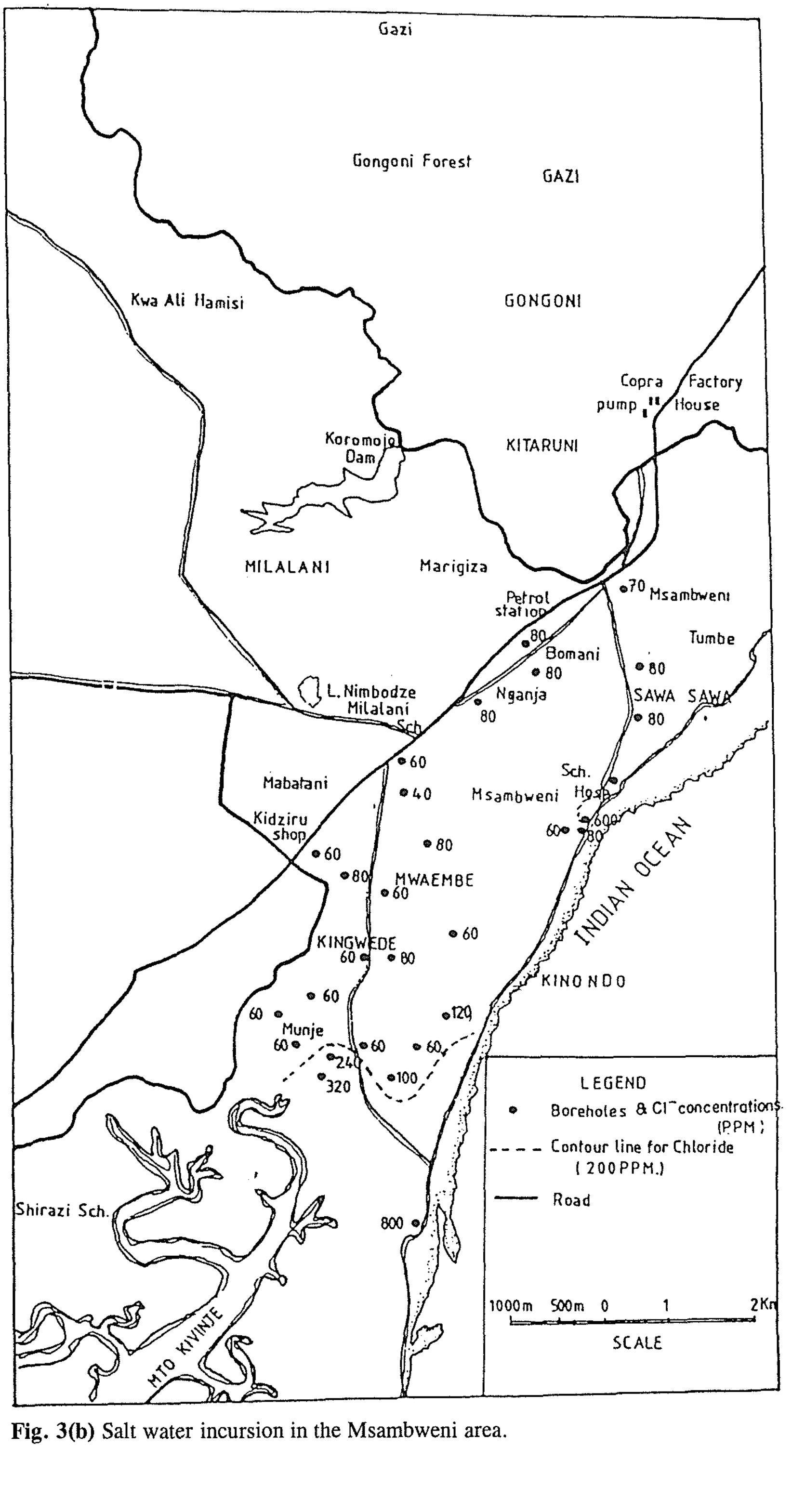

Fig. 3(b) Salt water incursion in the Msambweni area.

increase in mean concentrations during the dry season for conductivity, TDS, Cl^-, F^-, Ca^{2+}, sulphates, while the parameters dissolved oxygen, COD, BOD and coliform counts showed a slight decrease in the dry season compared to the wet season.

Simple correlation matrices reveal that BOD is related to total coliform counts and *E. coli* counts, even though total coliform and *E. coli* counts are not correlated. pH is correlated with conductivity, TDS, calcium and total hardness. TDS was correlated with chlorides, calcium and total hardness. Calcium was correlated with total hardness, while sodium was (fortuitously?) correlated with distance from the pit latrine.

DRINKING WATER QUALITY

Examination of the data showed that, in terms of rock-derived dissolved materials, most of the waters analysed are suitable for drinking purposes, although some tend to be brackish. The Mzee Juma, Southern Palms and Mwakamba wells in Diani have TDS values which marginally go above the recommended limit (to 1001 ppm TDS) of values greater than 1000 ppm, and are unsuitable for drinking. The Mzee Juma, Southern Palms and Mwakamba wells show significant increases in salinity in the dry season, as compared to the wet season (Mzee Juma from 3600 ppm to 3852 ppm; Southern Palms from 2800 ppm to 2851 ppm and Mwakamba from 1200 ppm to 1508 ppm). These water sources are probably contaminated by sea water intrusion (Anyango, 1994). The fluoride content of all the waters is below 1 ppm, in agreement with the observed fact that dental fluorosis is not observed in the indigenous residents of the area.

The critical hazard in the drinking water, however, is from *E. coli*. Out of the 13 wells sampled, nine (69%) were contaminated with *E. coli*. The highest *E. coli* count of 50 per 100 ml was observed in the Mayabo Bongwe well. Out of 10 springs sampled, three (30%) showed contamination, with the highest (20 per 100 ml) being Mwagodzo. Of the 55 boreholes sampled in the study area, seven (13%) were contaminated with *E. coli*. Waa Secondary School borehole had the greatest contamination, with an *E. coli* count of 35 per 100 ml of sample during the wet season, which decreased to 4 per 100 ml during the dry season.

The contamination tended to be greater in areas underlain by coral limestone, compared to areas underlain by sandstone. The Diani-Ukunda area had a mean contamination rate of 2.7 *E. coli* counts per 100 ml, followed by Tiwi-Waa region with a count of 1.8 per 100 ml, Msambweni 1.5 per 100 ml and Shimba Hills 0.2 per 100 ml. Shimba Hill wells are in a sandstone aquifer, while Diani, Ukunda, Tiwi and Waa are underlain by coral. Msambweni has a transition zone, with some boreholes in coral aquifers and others in sandy aquifers. It is further observed that the contamination rate in wells is higher (69%) than in springs (30%), both of which are higher than in boreholes (13%). However, these trends are based on a limited number of analyses for both wells and springs. Total coliform counts were plotted against distance to the nearest pit latrine, in an attempt to gauge the "safe distance" between a borehole and a pit latrine. Figures 4(a) and 4(b) show a lot of scatter in the data but indicate that at least 120 m are needed between a borehole and a pit latrine in sandstone areas, while at least 150 m are needed in coral limestone areas.

Sea water intrusion appears to affect the boreholes in the study area. Examples are

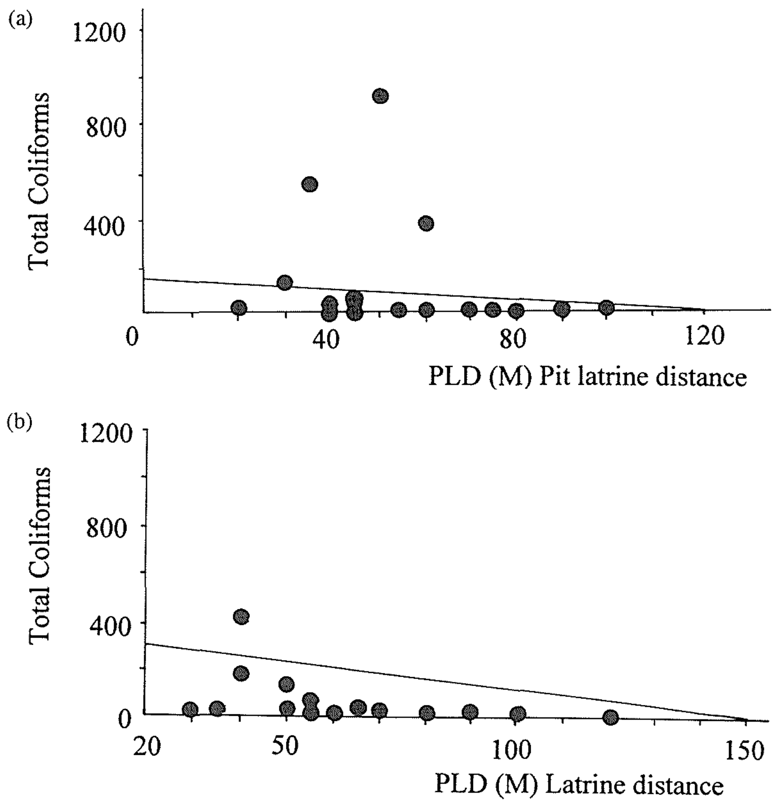

Fig. 4 Total coliform in boreholes in (a) sandstone area and (b) limestone area as a function of the distance form the nearest pit latrine.

boreholes at Jumapili, Baharini and Mkaliatsi in Msambweni, where a tongue of sea water appears to be coming in from the Mto Uvinje creek. In Diani, boreholes at Maweni and Bwagamoyo and the Jadini hotel boreholes have sea water intrusions; as do boreholes at Sparki, Shukrani and Tawakal in Tiwi. Possible paths for these salt water incursions are shown in Fig. 3(a) for the Tiwi-Diani area, and in Fig. 3(b) for the Msambweni area.

It is evident from the maps that the Tiwi-Diani area is totally intruded by sea water for a distance of at least 1 km from the shoreline, and more commonly for more than 2 km. In places, however, the salt water tongues are counteracted by freshwater inputs, the most notable of which are those associated with the Mabu stream, Mwachema River and Muhaka River. There is less sea water intrusion in the Msambweni area except in the very southern part of the area where the Mto Uvinje Creek comes in. This is also the area where there are about three tourist hotels. Otherwise there is freshwater right up to the shoreline for most of the area, except around the Msambweni hospital.

The differences in the groundwater situation at Msambweni and at Tiwi-Diani areas has two explanations. The first is over-exploitation of groundwater resources in the Tiwi-Diani area. In this area there are many tourist hotels which supplement the (frequently unreliable) piped water system with their own boreholes and which use electric pumps for withdrawal of groundwater. The situation is evidently getting worse because when the limited data available from 1987 are compared with those for 1993, it can be seen that conductivity, TDS, Na and Cl have increased significantly to make the water more saline than it was previously. The borehole at Kwa Mzee Juma Makalani, which was previously used for drinking water purposes, had to be shut down due to increased salinity. The owner of the well attributes this to the nearby borehole sunk by a hotel developer.

The second factor is the hydrogeology of the area. The Msambweni area has groundwater recharge from the Shimba Hills, through the Mkurumuji and Ramisi Rivers, two major river systems which converge towards Msambweni, though they do not quite meet. Since the sandstones and shales over which the two rivers flow dip to the southeast, it would be expected that groundwater flow is directed by the bedding planes towards the Msambweni area. Evidence for this groundwater recharge is seen on the beach at low tides, when springs of freshwater are observed to discharge copious amounts of freshwater into the sea just south of Msambweni hospital (Mwangi, 1981). In contrast, the Tiwi-Diani area is mainly recharged through the Mwachema River. The Mabu and Muhaka streams are much smaller water bodies. The authors are not aware of any reported discharges of freshwater into the ocean in the Tiwi-Diani area although this needs to be confirmed by more thorough investigations on the ground during low tide.

There is thus a paradox in that the area where more groundwater is being withdrawn is also the area of relatively little recharge and the area where relatively less groundwater is being withdrawn is the area of abundant recharge. The authors are not aware of any studies to determine the safe yields for the different aquifers in the area. Without such a determination, tourist hotels in the area will continue to be licensed to abstract groundwater, further worsening a bad situation. Whereas the tourist hotel operators have the means to import freshwater into the area using tankers, the local people will be the ones to suffer as their sole supply sources become more and more contaminated with sea water. Rain water harvesting should be encouraged in the area, since there is reduced infiltration into the ground as more of the surface becomes paved. Such harvesting will also help to reduce the environmental hazards of flooding, experienced to an unprecedented scale during the 1994 long rains in the Ukunda-Diani area. Another possible solution is to encourage hotels to desalinate the brackish water close to the shoreline.

IMPLICATIONS FOR WATER SUPPLY PROJECTS

Both governmental and nongovernmental water supply projects have the noble intention of trying to supply clean drinking water to the people, both to improve sanitary conditions and to free labour for other more productive socio-economic activities. However, the results of this study show that these good intentions may inadvertently put people's health at risk, if the water sources are not sited at large distances (greater than 150 m) from pit latrines. This distance will vary with natural groundwater movement rates, rate of withdrawal of groundwater, and rate of pit latrine use.

This has implications for water sources that are located in centres of population such as towns or crowded "rural" areas (Diani, Tiwi and Msambweni all have higher population densities than Shimba Hills). It is in these population centres where provision of water facilities would have the greatest impact in that one point can serve many more people than in a sparsely populated area and yet it is where the greatest risk of contamination exists. In the densely populated areas, it is also difficult to have 150 m separation between the boreholes and pit latrines due to the density of dwellings. It is therefore important that water organizations are aware of this problem and move beyond the provision of water as the primary goal, to provision of safe water. This paper has not addressed contamination from industrial and agricultural chemicals (which are expected to be minimal in the study area) but water supply organizations working in areas where intensive farming and/or industries exist must also address these water quality issues.

In densely populated areas it may be better to pipe in water from elsewhere if deep aquifers cannot be tapped, even though this runs counter to the aims of sourcing waters that can be extracted by the people themselves. Alternatively, roof catchment may provide cleaner water than groundwater sources in areas where there are no air-polluting industries. Since contamination may come long after the boreholes have been commissioned, the organizations that have sunk boreholes should either continuously monitor them or ensure that public health officials do so. Where boreholes are found to be contaminated, constant chlorination of the water should be carried out.

CONCLUSION

In this study it has been shown that in Kwale District the water is generally suitable for drinking in terms of its chemical composition. However, bacteriologically, some springs, wells and boreholes are contaminated with *E. coli*. There is a need to create awareness of this contamination, both within the communities and on the part of the organizations providing water to the people. Analysis of boreholes and wells along the south coast of Kenya has shown that sea water contamination of groundwater resources is becoming a very serious problem in the Tiwi-Diani area. All waters within 1 km of the shoreline, and in some areas as much as 6 km from the shoreline, have a salty taste (>200 ppm Cl). Comparison of limited data from 1987 with data from 1993 shows a significant increase in conductivity, TDS, Na and Cl over the 6 year period. At least one well has been abandoned in recent times because it became too saline for domestic use of the water, after a high yielding borehole was drilled nearby by a hotel developer.

The Msambweni area only has salty waters at Msambweni hospital, and near the tourist hotel developments. It is proposed that the difference in water quality observed at Msambweni and at Tiwi-Diani areas are due to over exploitation of groundwater resources. Another possible explanation is the greater freshwater recharge in the Msambweni area, compared to the Tiwi-Diani area. Since the local people cannot afford to invest in alternative sources of water (unless government provides funding – an increasingly less favoured option), it is recommended that, through appropriate legislation, the onus be placed on hotel developers to desalinate brackish water and/or harvest rain water.

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