Conditions In Shallow Wells In The South Coast Region Of Kenya

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ABSTRACT

Groundwater conditions in the South Coast Region of Kenya are examined in terms of the quantity and quality of the water derived from boreholes in the region. Both the quality and quantity are found to be generally acceptable for expected uses in the area. A new parameter used to define the degree and sensitivity of violations in the quality conditions is introduced and demonstrated.

INTRODUCTION

Background

There has been a realization in Kenya that the provision of clean potable water to the rural population is best achieved by the development of shallow wells which are constructed and maintained to prevent contamination. Under previous conditions most of the wells in the rural communities were very shallow, hand-dug wells which were uncovered and rarely provided sufficient water. In 1982, the South Coast Hand Pumps Project was initiated with the aim of providing clean water to the rural communities. The project, which was sponsored by the Swedish International Development Agency, has since been successfully completed, and 127 wells have been drilled. Most of the wells were found to have good water with a quality suitable for domestic purposes.

It is the intention of the Government of Kenya's Ministry of Water Development to provide potable water to every community by the turn of the century. Encouraged by the success of the South Coast project, two more similar projects, the Kwale Hinterland Sanitation Project and the South Nyanza Shallow Wells Project, have been started.

It is the intention ... to provide potable water to every community by the turn of the century.

This study, however, examines the variations in the quantity and quality of water in the wells associated with the South Coast Hand Pumps Project, and suggests a new measure for assessing the quality of groundwater derived from the wells in the region. This new measure, described later in the paper, is based upon parameters derived from limits of general acceptability and highest acceptable limits defined by the World Health Organization (WHO).

Location of Project Area

The South Coast Hand Pumps Project is situated in the coastal province of Kwale, approximately 500 km SSE of the city of Nairobi and about 40 km south of the port of Mombasa. The location of the project area within Kenya is shown in Fig. 1, while Fig. 2 shows the locations of a number of the groundwater wells in the region. The well names associated with these well numbers are given in Table 1.

Hydrogeology of Project Area

The coastal region has a geology which consists of beach sands, a coral reef complex, and sandstones. Interspersed between the sandstones are layers of clays and

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shales. The area receives about 1200 mm of rainfall annually, mainly from convectional storms, and a significant amount of local recharge takes place through the highly permeable sands to become groundwater. Wells dug into the coral limestones yield hard but potable water mainly derived from solution channels within the rocks. This supply from the coral limestones is, however, limited by the close proximity of the sea with the consequent risk of contamination by sea water.

The sands are highly pervious due to their lack of consolidation, yield fair quantities of good quality groundwater at relatively shallow depths. Large diameter boreholes drilled to about 60 m below surface in the Tiwi and Ukunda areas, if properly gravel-packed, can yield large amounts of groundwater (> 80 m^3/hr) for municipal supplies. Very deep boreholes in the coastal zone may, however, result in tapping mineralized water from the shales. The wells which are drilled into the sandstones are liable to be saline, as these series were deposited in a land-locked basin under conditions of semi-aridity. This led to the evaporation of the water with consequent precipitation of the mineral salts.

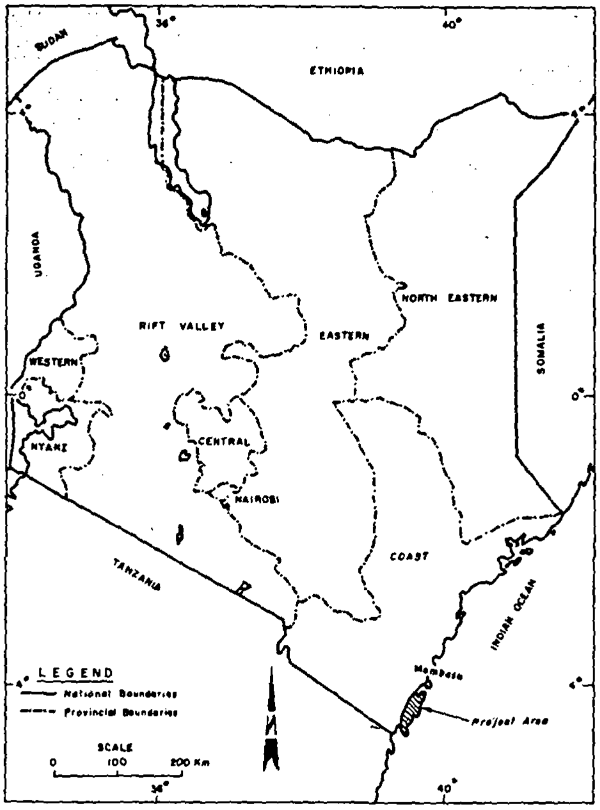

Figure 1. Location of South Coast Region within Kenya.

Table 1. Well numbers and names

Well[1] Number	Well Name	Well Number	Well Name
1	Milalani II	20	Magutu
2	Milalani III	22	Shamu
3	Mwabungo I	23	Msambweni
4	Kinondo	25	Mwachande
5	Mbuani	26	Kilole
6	Gandini	27	Mabokoni
7	Gazi	36	Kingwendel1
8	Vingujini	37	Kingwendel2
9	Ngaja	38	Kingwendel3
10	Kidzumbani	39	Munge1
11	Muhaka	40	Munge2
12	Mafisini	41	Mwabungo II
13	Vindungeni	42	Shirazi

[1] Note that wells and boreholes are different in this paper. Hence the well numbers in this table do not correspond to the borehole numbers in Table 3.

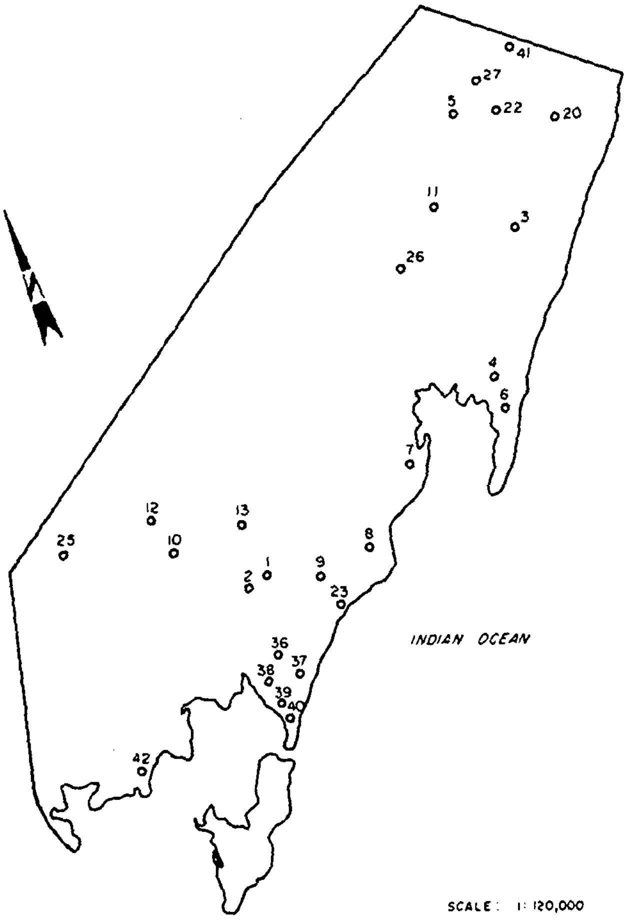

Figure 2. Location of some of the groundwater wells in the South Coast Region.

QUANTITY-WATER LEVEL CONDITIONS

Data giving water level fluctuations for wells at Milalani, Msambweni, Gazi, Mwabungu, Shamu and Magutu over a period of 16 months are available. During the 16 month period, the highest fluctuation in water levels was 5.84 m at Milalani well, which had its highest water level of 8.20 m on September 2, 1984, and a lowest water level of 14.04 m on April 24, 1984. The lowest water level fluctuation of 0.45 m (11.43 cm) was recorded at Mwabungu well. It had its highest water level of 19.20 m on June 3, 1983 and a lowest water level of 19.65 m on January 11, 1983. Of these six wells, four (Msambweni, Gazi and Shamu) had the lowest water levels recorded in April. At the other two (Mwabungu and Magutu), the lowest water levels were recorded in January and February, respectively. This temporal pattern of low water levels is expected, as January through mid-April are the hottest months in the region, and groundwater recharge is minimal.

The highest water levels were recorded in July in two wells (Magutu and Gazi), in September in two other wells (Milalani and Shamu), while the other two wells, Msambweni and Mwabungu recorded the highest water levels in May and June, respectively. The long rains in this region come between mid-April and June, while the short rains are in September and October. It is reasonable, therefore, that the wells register the highest water levels during or immediately after the rains.

It is not clear why differences in the times when the highest (or lowest) water levels occur. One of the possible contributions may be the fact that the aquifer is not continuous. In a sedimentary basin like this one, various impermeable clay layers interspersed in between the sands may be expected. These clay layers thus create several localized aquifers instead of one regional aquifer. Because recharge in this area can also be very localized, wells within the same "local" aquifer will tend to show high or low water levels at about the same time. Msambweni, Milalani and Gazi wells, for example, are wells which are close together and all show the lowest water levels in April. The highest water levels, however, were registered in May, July and September, respectively in the three wells. Since these wells are close together and have their lowest water levels at the same time, it might have been expected that the highest water levels would also be coincident in time. The discrepancy is attributed to the fact that all three wells are drilled to different depths (Milalani 28 m, Msambweni 25 m, and Gazi 12 m), and some wells would therefore tap different aquifers.

Another possible reason for the differences between the times of highest and lowest water levels is that the data used were taken over a period of only 16 months. It is possible therefore that should the data have been for several years, most of the wells would have shown the highest and lowest water levels at more or less the same period. Water-level monitoring within the region is still continuing and it is recommended that after sufficient data have been collected, water level graphs be reexamined to establish periods of high and low water levels and consequently advise on the withdrawal rates.

Rapid fluctuations of water levels through vertical distances of several metres are primarily due to pumping.

Changes in storage obviously account for the greater part of fluctuations in wells. During the rainy seasons, which are in April-June (long rains) and October-November (short rains) in Kenya, the water levels are considerably higher than in the drier months in which there is no recharge but continuous withdrawal. Rapid fluctuations of water levels through vertical distances of several metres are primarily due to pumping. Seasonal trends show several months of rise followed by a fall in response to pumping.

These variations are not surprising, however, as water levels in "shallow" aquifers (15-20 m deep), often fluctuate through a wide range in response to seasonal rainfall variation and in response to periods of above and below normal precipitation. An indication of the sensitivity of the well levels in the region can be obtained by examining the distribution of rainfall for the relevant time periods in the area.

As expected when the rainfall is highest, the groundwater level is also the highest and when there is little rainfall the water level in the wells is low. During this time only wells which are deep enough and which tap good aquifers are left with water while most of the other shallower wells dry up or produce so little water that after pumping for a few hours a wait of several more hours is necessary for the water to trickle down into the well from the surrounding sediments. This latter condition occurs because as most of the wells are water table aquifers which receive recharge directly from local precipitation and because this precipitation is very low, the withdrawal from the wells intermittently exceeds recharge. Under these conditions, the reservoir is being emptied of water that may have taken some time to accumulate, and there is no possibility of a continuous supply until the next rains. However, for the small quantities of water used for domestic purposes (20 litres per day per capita), these wells appear to be satisfactory for local needs, at least in terms of quantity.

In the very dry basins, the groundwater reservoir may not receive any recharge at all in a year of normal precipitation, because all the moisture is dissipated from the soil zone into the atmosphere. Recharge to those aquifers occurs only during years of exceptionally heavy rainfall.

In addition to the issues associated with aquifer replenishment, the slow movement of water within an aquifer is also a problem. Yield data are avilaable for 127 "shallow" boreholes within the south coast region. Fifty-three of the boreholes within the region can be considered as "high" yielding for rural water supply purposes, producing over 3 m^3/hr. Apart from relatively shallow wells at Gazi which are 14 m, 17 m and 12 m deep, respectively, and quite productive (over 6 m^3/hr), all the other boreholes with a yield of over 3 m^3/hr have been drilled to depths of 20 m to 40 m. Yields of between 2-3 m^3/hr are considered to be quite adequate for domestic purposes in rural areas, but not necessarily for urban requirements and more than half of the boreholes (69) have yields greater than 2 m^3/hr. Eight of the boreholes had exceptionally good yields of over 6 m^3/hr. With the exceptions of the three wells at Gazi where the water was struck between 10-12 m, all the other boreholes struck water at levels between 18 m and 24 m, and a water-rest level of between 10-15 m. The boreholes at Gazi also had water-rest levels of around 9 m. From the close proximity of these boreholes and the similar water-struck and water-rest levels, it would be reasonable to assume that they all tap water from the same aquifer. Although the Gazi boreholes show a discrepancy among themselves, as far as the "water struck" levels are concerned they show more or less the same water-rest levels. These boreholes may have tapped a shallower aquifer at 12 m which is underlain by an impervious layer of clay shielding the main aquifer at 18 m from the top aquifer. A geoelectrical sounding is, however, necessary to confirm this and to ascertain the thickness of the clay layer. It is also important to note that only two bore-oles, namely, Mbuani Sham and Tsimba were either dry or ad insufficient water for practical use.

The wells in the northern part of the project area seem to
tapping an aquifer which is much more deep-seated (one
ell had a water struck level of 40-44 m), but still the yields
reasonable. The greater the distance from the coast, the
ore deep-seated the aquifers become, and pumping with a
d pump, as proposed within the project, may be diffi-
t.

ALITY CONDITIONS

roundwater in Kenya, once considered relatively pol-
-free, is being increasingly polluted locally by mu-
al and industrial wastes. Examination of the existing
in the region of the project revealed that most of the wells were unlined and uncovered. These wells posed a health hazard to the population using them for their water supply. Furthermore, although some of the wells had been equipped with hand pumps, due to lack of maintenance none of the pumps were working and well users had broken the concrete plates covering wells and reverted to drawing water from the wells using a rope and bucket. This maintenance problem is common in environments similar to this area and must be considered in the well designs.

Pumping with a hand pump, as proposed within the project, may be difficult.

The slow movement of water within an aquifer is also a problem.

In order to assess the quality of the groundwater under these conditions, water from 42 wells in the region was analyzed and the results compared to the quality guidelines recommended by the World Health Organization (WHO). A list of the particular chemical parameters examined and their corresponding limits as set by the WHO is given in Table 2. The results of the chemical analyses are shown in Table 3. Examination of Table 3 shows very clearly the difficulty of obtaining an overall indication of the quality at a particular location. All values of each constituent at each well should be compared to the various limits suggested by the WHO. Traditional measures to perform these comparisons, e.g., numerical comparisons along the lines of that in Table 3, pictorial diagrams such as bar or pie charts, and multivariable graphs do not easily permit the evaluation of all parameters relative to their WHO limits.

In this study, a different procedure was used to display the relative values of each constituent and to indicate clearly the extent to which the limits are violated. An underlying principle of the procedure and, in particular, the means of displaying the results, is that the mere fact of violating a particular limit is not the only critical issue. The extent of the violation is also very important. The WHO guidelines for quality recognize this issue in that limits are specified as "general acceptability concentration" and "maximum allowable concentration," rather than absolute boundaries. The problem that exists even with these boundaries can be best explained by a simple example. Consider the chemical constituent iron. The maximum allowable concentration for iron is 1 mg/*l*. However, an iron concentration of 1.2 mg/*l* is a violation that is far more serious than the violation of 1.05 mg/*l*. The absolute accuracy of the analysis becomes an issue. The boundary should therefore be recognized as being "fuzzy" rather than precise, with "distance" from the boundary being a central issue. Similar issues exist with the strict levels of general acceptability concentrations.

Table 2. International standards for drinking water (WHO)

Substance	Limit of General Acceptability	Maximum Allowable Limits
Toxic Substances		
Lead		0.05 mg/*l*
Arsenic		0.05 mg/*l*
Selenium		0.01 mg/*l*
Chromium (Cr Hexavalent)		0.05 mg/*l*
Cyanide		0.20 mg/*l*
Barium		1.00 mg/*l*
Radionuclides (gross beta activity)		10 μμ/*l*
Components Hazardous to Health		
Nitrate as NO_3		45.0 mg/*l*
Fluoride		1.5 mg/*l*
Chemical Substances Affecting the Potability of Water		
Total dissolved solids(TDS)	500 mg/*l*	1500 mg/*l*
Colour	5 units*	50 units*
Turbidity	5 units**	25 units**
Taste	Unobjectionable	-
Odour	Unobjectionable	-
Iron (Fe)	0.3 mg/*l*	1.0 mg/*l*
Manganese (Mn)	0.1 mg/*l*	0.5 mg/*l*
Copper (Cu)	1.0 mg/*l*	1.5 mg/*l*
Zinc (Zn)	5.0 mg/*l*	15 mg/*l*
Calcium (Ca)	75 mg/*l*	200 mg/*l*
Magnesium (Mg)	50 mg/*l*	150 mg/*l*
Sulphate (SO^{2-})	200 mg/*l*	400 mg/*l*
Chloride ($Cl^{\underline{4}}$)	200 mg/*l*	600 mg/*l*
pH range	7-8.5	>6.5 & <9.2
Magnesium + sodium sulphate	500 mg/*l*	1000 mg/*l*
Phenolic substances (as Phenol)	0.001 mg/*l*	0.002 mg/*l*
Carbon chloroform extract (CCE) (Organic Pollutant)	0.2 mg/*l*	0.5 mg/*l* ***
Alkyl benzyl sulphonates (ABS) (surfactants)	0.5 mg/*l*	1.0 mg/*l*

* Platinum-cobalt scale

** Nephelometric turbidity units

*** Concentrations greater than 0.2 mg/*l* indicate the necessity for further analysis to determine the causative agent.

Table 3. Results from chemical analyses of the water from 42 wells

Borehole[1] No.	Name	Substance Concentration (mg/l)													Remarks
		NO_3^-	HCO_3^-	Cl^-	SO_4^{2-}	F^-	Na^+	Ca^{2+}	Mg^{2+}	Mn^{2+}	Fe^{2+}	Zn^{2+}	pH	TDS	
1	Milalani II	1.25	246.0	21.4	nil	0.58	16.0	96.0	1.96	nil	nil	0.05	7.7	286	Free from organic pollution
2	Milalani III	0.35	290.0	35.7	10.0	0.58	32.4	30.4	44.16	nil	nil	0.25	7.3	322	Neutral and soft
3	Vidungeni	0.54	92.0	28.6	8.00	0.60	20.0	23.1	13.92	nil	nil	0.20	6.8	102	Free from organic pollution
4	SBH 5	0.30	312.0	28.6	9.00	0.65	28.0	54.4	32.64	nil	nil	0.12	7.2	345	Free from organic pollution
5	Mbuani	*	45.6	170	1.00	0.03	NA	6.1	5.00	1.7	1.0	*	5.9	54	calcated
6	Kibarani I	NA	187.2	29.0	3.00	0.30	NA	132	21.00	0.1	2.2	*	8.2	162	Organic matter present, hard
7	Mwangoloko	NA	341.0	50.0	16.00	0.20	NA	114	43.00	0.1	0.6	*	7.7	360	Moderately mineralized
8	Kibarani II	NA	305.0	0.10	12.0	NA	NA	99	34.00	0.1	0.3	*	7.5	330	Hard with organic matter
9	Kibarani III	NA	14.4	11.0	1.50	0.06	NA	3.1	2.50	0.1	0.3	*	6.7	30	Low mineral and organic matter
10	Mkuakwani	NA	441.6	61.0	2.50	0.20	NA	140.0	56.0	0.1	0.2	*	7.9	480	Slightly hard and alkaline
11	Mtambwe Muhaka	NA	12.2	13.0	0.38	0.04	NA	55	3.90	0.8	0.5	*	5.5	42	Slightly acid and corrosive
12	Kibarani IV	NA	385.2	5.7	1.12	0.20	NA	138	30.0	0.1	2.5	*	7.5	420	Slightly hard
13	Kibarani V	NA	307.2	99.0	11.3	0.20	NA	112	44.0	0.3	0.3	*	7.9	420	Slightly hard
14	Kibarani VI	NA	348.6	22.0	1.75	0.17	NA	127	9.0	0.1	0.6	*	7.5	360	
15	Bongwe	NA	441.6	32.0	1.25	0.20	NA	118	56.0	0.1	0.1	*	7.9	420	Slightly hard and alkaline
16	Kibarani VII	NA	19.2	23.0	3.35	0.2	NA	110	60	0.1	0.1	*	6.2	360	Good quality
17	Chalo	NA	448.6	0.39	165	NA	NA	380	-	124	0.1	*	8.2	3300	Highly saline and hard source
18	Mwalibema	NA	273.0	66.0	9.25	0.2	NA	118	33	0.1	0.6	*	8.5	384	Mildly hard and turbid organic matter
19	Lunga Lunga	NA	429.1	NA	144	0.42	NA	186	225	1.0	0.5	*	7.9	480	Hard, high concentration of sulphates
20	Magutu	NA	326.7	22.0	1.5	0.20	NA	100	39	0.1	0.4	*	7.8	300	Slightly hard water
21	Mwamaguo	NA	21.94	19.0	5.0	0.04	NA	1.3	.9	0.3	1.6	*	5.8	48	Slightly acidic - needs filtration
22	Shamu	NA	4.87	39.0	0.8	0.04	NA	1.7	1.1	0.1	1.0	*	5.4	72	Slightly acidic - needs filtration alkaline
23	Msambweni I	0.06	192.0	60.0	nil	0.65	51	50.4	22.6	nil	nil	0.06	7.5	610	Moderate mineral constituent
24	"No name"	0.51	130.0	34.0	3.0	0.65	19	84.0	nil	nil	nil	0.07	7.6	382	Chemically suitable
25	Bomani	0.02	130.0	48.0	29	0.65	26	94.0	8.6	nil	nil	0.2	7.4	268	Free from organic pollution

Table 3. Results from chemical analyses of the water from 42 wells (Continued)

Borehole[1] No.	Name	Substance Concentration (mg/*l*)													Remarks
		NO_3^-	HCO_3^-	Cl^-	SO_4^{2-}	F^-	Na^+	Ca^{2+}	Mg^{2+}	Mn^{2+}	Fe^{2+}	Zn^{2+}	pH	TDS	
26	Ngaja	0.007	160.0	104	27	0.40	49	113.0	8.6	nil	nil	0.14	7.3	812	Fairly mineralized
27	Milalani I	0.3	130.0	34.0	nil	0.65	24	88.0	0.96	nil	nil	0.14	7.9	220	Soft and neutral
28	Munge I	nil	116	28.	nil	0.7	20	62	10.56	nil	nil	0.1	7.8	174	Soft and neutral
29	Munge II	0.12	148	32.	nil	0.7	24	85	10.56	nil	nil	0.14	7.5	256	Chemically suitable
30	Munge III	0.2	168	100	28	0.3	114	36.8	17.3	nil	nil	0.1	7.6	476	Moderate mineral composition
31	Ndzovuni	0.12	138	32.	nil	0.3	19	43	3.8	nil	nil	0.08	7.6	120	Neutral and soft
32	Kingwende I	0.05	128	26.	nil	0.6	18	85	1.9	nil	nil	0.08	7.8	234	Moderate with favourable mineral composition
33	Msambweni II	0.5	50	28.	33	0.85	22	24	nil	nil	nil	0.02	7.5	150	Slight organic pollution
34	Milalani IV	0.02	136	16.	nil	0.2	18	39	5.8	nil	nil	0.11	7.8	132	Favourable mineral constituent
35	Mbatani	0.1	156	22.	nil	0.65	16	94	7.68	nil	nil	0.1	7.2	368	Fit for domestic use
36	Kingwende II	0.03	150	40.	nil	0.30	25	58.4	3.8	nil	nil	0.07	7.4	376	Fit for domestic use
37	Kinwende III	0.3	140	20.	nil	0.35	18	48	48.	nil	nil	0.07	7.5	462	Fit for domestic use
38	Kingwende IV	0.15	140	42	1	0.75	28	83	35.5	nil	nil	0.02	7.8	392	Fit for domestic use
39	Munge IV	0.1	150	92.	nil	0.3	51	47	15.4	nil	nil	0.1	7.3	446	Fit for domestic use
40	Munge V	nil	180	148.	nil	0.75	91	99	17.2	nil	nil	0.13	7.5	408	Fit for domestic use fairly mineralized
41	Kiriogo	0.28	144	22	nil	0.2	26	48.8	1.4	nil	nil	0.08	7.4	138	Soft and suitable
42	Shirazi	0.06	156	54	16	0.7	7.8	26.4	14.8	nil	nil	0.05	7.6	462	Soft and suitable

* Not analyzed

[1] Note that wells and boreholes are different in this paper. Hence, the well numbers in Table 1 do not correspond to the borehole numbers in this table.

The mere fact of violating a particular limit is not the only critical issue.

Furthermore, a violation of 1 mg/*l* in the iron concentration is far less significant on a relative basis than the violation of 1 mg/*l* for magnesium. In the case of iron, the violation is 100% of the maximum allowable concentration, while the magnesium violation is only 2% of the maximum allowable concentration. Thus, an additional parameter defining the severity of a unit, say 1 mg/*l*, violation lies in the relative size of the violation and the difference between the maximum acceptable concentration and the generally acceptable concentration.

The proposed methodology for examining water quality is aimed at addressing these issues. In essence, the procedure measures the extent to which a particular constituent concentration is greater than the generally acceptable level measured as a proportion of the difference between the maximum and generally acceptable concentrations. This difference will henceforth be referred to as the band width for that particular constituent. Thus, if the concentration of the particular constituent is less than the generally acceptable level, it will have a value of less than 0. If the concentration lies between the generally acceptable and maximum limits, it will have a value lying between 0 and 1, and any concentration above the maximum acceptable will have values greater than unity. The value of the parameter, if it is greater than unity, will indicate the extent to which the maximum allowable concentration is violated in terms of the band width.

The mathematical statement of this measure is

$$VP_i = \frac{AC_i - GA_i}{MA_i - GA_i} \qquad (1)$$

in which

VP_i = violation parameter for constituent i
AC_i = actual level of constituent i
GA_i = generally acceptable level for constituent i
MA_i = maximum allowable level for constituent i

Another advantage of this parameter is that it is easily used in a graphical mode to show relative levels of a particular constituent at all wells, and the relative levels of all constituents at a particular well. In the first case, it is possible to easily identify groups of wells with similar problems. In the second, the water quality at individual wells can be easily classified according to its general suitability for human consumption according to the number and degree of the violations for a range of parameters of interest.

Example Use of Parameter

All the information necessary to produce these graphs is given in Table 3. However, rather than producing graphs for all pollutants in all boreholes in a short paper, only one pollutant in one well is examined, namely, iron, for all boreholes. The graphical display of the measures is given in Fig. 3. (Note that the borehole numbers refer to the borehole numbering in Table 3 only, and there is no spatial relationship in the numbering system). Examination of Fig. 3 shows clearly how the method identifies boreholes with problems and the extent of those problems.

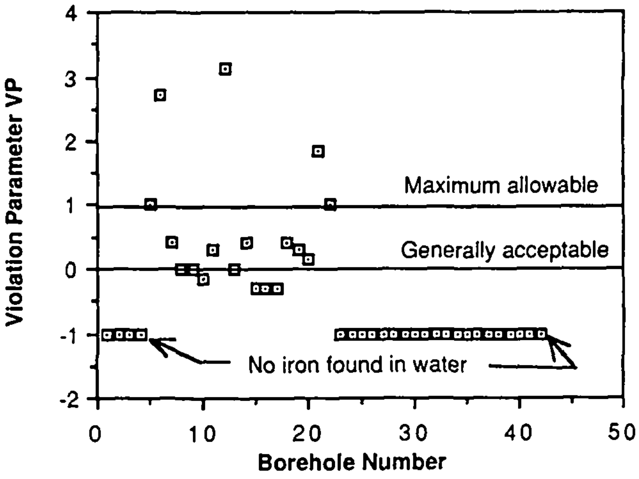

Figure 3. Example use of violation parameter, VP, for iron in all boreholes.

The boreholes can also be arranged on the abscissa according to a spatial system. In this way, areas or regions in which problems exist are easily identified. For a single borehole and a range of constituents, the constituents are simply marked on the abscissa and the same type of graph results. In this case, types of pollutants or groupings of pollutants for a single borehole are examined rather than violations for one pollutant in individual boreholes or regions.

Another advantage of this approach is that overlays, one for each constituent of concern, can be easily utilized to identify boreholes or regions which are characterized by a range of quality problems or types of constituents of concern.

Areas or regions in which problems exist are easily identified.

Specific Analysis of Water Quality in the Region

Although not all violation graphs are presented in this paper, examination of them revealed the results summarized in Table 4. The relatively low number of boreholes in the table shows that most of the wells have a constituent level below even the generally acceptable limits. In fact, only four constituents are noted in the table as having values above the generally acceptable value, and of these four constituents, the largest number of wells with a problem with any one constituent (calcium) is 23 out of a possible 42, i.e., 55%. (The next largest number, iron, is only 11 out of 42 boreholes, i.e., 26%.) There is, therefore, evidence that the quality of the groundwater in the region is generally very good. This conclusion is further supported by the very small number of occurrences (6 out of all constituents and boreholes) of violation parameters with values greater than one.

Table 4. Boreholes with constituent above limits of general acceptability.

Constituent	Borehole Name	Absolute Extent of Violation	Band Width	Violation Parameter	Comments
Iron	Mbuani	0.7	0.7	1.0	Reasonably good water
	Kibarani I	1.9	0.7	2.7	Excessive
	Mwangoloko	0.3	0.7	0.43	Reasonably good quality
	Muhaka	0.2	0.7	0.29	“ ”
	Kibarani IV	2.2	0.7	3.14	Excessive
	Kibarani VI	0.3	0.7	0.43	Reasonably good quality
	Mwalibembo	0.3	0.7	0.43	“ ”
	Lungalunga	0.2	0.7	0.29	“ ”
	Magutu	0.1	0.7	0.14	“ ”
	Mwamaguo	1.3	0.7	1.85	Excessive
	Shamu	0.7	0.5	1.0	Reasonably good water
Magnesium	Mkuakuani	6	100	0.06	Reasonably good water
	Bonqwe	6	100	0.06	“ ”
	Kibarani	10	100	0.10	“ ”
	Lungalunga	175	100	1.75	Excessive
TDS	Chalo	2800	1000	2.80	Excessive, very saline
	Msambweni I	110	1000	0.110	Moderately saline
	Ngaja	312	1000	0.312	“ ”
Calcium	Milalani II	21	125	0.17	Reasonably good water
	Kibarani I	57	125	0.46	“ ”
	Mwangoloko	39	125	0.31	“ ”
	Kibarani II	24	125	0.19	“ ”
	Mkuakuani	65	125	0.52	“ ”
	Kibarani IV	63	125	0.50	“ ”
	Kibarani V	37	125	0.30	“ ”
	Kibarani VI	52	125	0.42	“ ”
	Bonqwe	43	125	0.34	“ ”
	Kibarani VII	35	125	0.28	“ ”
	Chalo	305	125	2.44	Excessive
	Mwalibembo	43	125	0.34	Reasonably good water
	Lungalunga	111	125	0.89	“ ”
	Magutu	25	125	0.2	“ ”
	“No-name”	9	125	0.07	“ ”
	Bomani	19	125	0.15	“ ”
	Ngaja	38	125	0.30	“ ”
	Milalani I	13	125	0.10	“ ”
	Munge II	10	125	0.08	“ ”
	Kingwende I	10	125	0.08	“ ”
	Mabatani	19	125	0.15	“ ”
	Kingwende IV	8	125	0.06	“ ”
	Munge V	24	125	0.19	“ ”

One of the water quality parameters frequently discussed in relation to potable water and not discussed above is hardness. Analysis of the water does, however, show that hardness is a concern in 8 of the boreholes. The results of this analysis for the cations related to the hardness are shown in Table 5. Examination of the data in Table 5 indicates that most of the wells have bicarbonate water, the principal cations being calcium and magnesium, the high concentrations of which cause hardness. Most of these wells are drilled in coral limestones which are predominantly composed of calcium carbonate. All hardness found in the wells is temporary hardness, i.e., caused by the bicarbonates of calcium and magnesium. Note that calcium is the constituent having the greatest number of violations above the generally acceptable level, so the hardness is no real surprise. The sulphate ion, which is responsible for permanent hardness, is present in only very small amounts (less than 20 meq %) in all wells but one, Msambweni, which has 29 meq % of sulphate ion. However, in the interpretation of the chemical analysis, the meq % can be misleading, especially when the total meq/*l* of cations and anions is less than 5 [1].

In this case, the actual concentration of the ions in mg/*l* should be used and compared to the limit of general acceptability as stipulated by WHO. For the case of Msambweni II, it shows that the meq % of the sulphate is 29%, while the actual concentration of the sulphate ion is 33.0 mg/*l*, a figure well below the limit of generally acceptability of 200 mg/*l*.

As noted above, the hardness can be attributed to the high concentrations of calcium ion and the bicarbonate ion, especially in the wells in coral and coral breccia which are predominantly composed of limestone ($CaCO_3$) and dolomite ($MgCO_3$). The relative proportions of these ions depend on the source of the sediments. In the south coast, the sediments usually come from the erosion of the igneous intrusions which form isolated hills within the Digo Settlement areas and which contain more calcium and magnesium minerals. Jombo and Mrina Hills are covered by a thick layer of distinctive red-brown soil caused by the weathering of the manganese and iron ores [2]. The effects of these ions is to make the water objectionable by imparting some colouration on it. Three wells, Kibarani I, Kibarani IV, and Mwamaguo, were found to have objectionably high quantities of iron while none of the wells had concentrations of manganese high enough to affect the potability. Water from these wells is, however, likely to stain laundry and is therefore undesirable in this respect.

Water from these wells is . . . likely to stain laundry and is therefore undesirable.

Table 5. Boreholes with hardness problems

Borehole Name	Constituent Concentration (mg/*l*)		
	Calcium	Magnesium	Bicarbonate
Kibarani I	132.0	21.0	187.2
Mkuakuani	140.0	56.0	441.6
Kibarani IV	138.0	30.0	385.2
Kibarani V	112.0	44.0	307.2
Bongwe	118.0	56.0	441.6
Chalo	448.5	-	380.0
Mwalibemba	118.0	33.0	273.0
Lungalunga	100.0	39.0	326.0

SUMMARY AND CONCLUSIONS

Quantity and quality characteristics of water from boreholes in the South Coast Region of Kenya were examined. Results from the analysis show that both quantity and quality of groundwater in the region was adequate to good for the rural water supply purposes. The quality of the borehole water was also examined using a new parameter which is able to recognize the severity of violation of both the generally acceptable and the maximum allowable limits set by the World Health Organization. The parameter also recognizes the sensitivity of the water quality to changes in the absolute value of the parameters through normalization of the constituent concentration on the basis of the difference between the appropriate generally acceptable and maximum allowable values. The nature of the parameter enables it to be used in a graphical mode which clearly displays the "normalized" extent of any violation, thereby permitting easy identification of boreholes with particular quality problems with a range of constituents. If displayed in a slightly different fashion, the parameter can also identify groupings of wells with quality problems derived from the same constituent. The fuzzy nature of any water quality standard is also able to be addressed indirectly through the use of the parameter, particularly when it is displayed graphically.

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