

Full Length Research Paper

Groundwater quality degradation due to salt water intrusion in Zanzibar Municipality

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Saltwater intrusion problems are widespread where there are over pumping of groundwater from coastal aquifers. Water samples were collected from production boreholes in Zanzibar municipality and analyzed for salinity indication parameters comprising of chloride, electrical conductivity, total dissolved salts and percentage salinity levels. Historical water quality data of boreholes were also collected and used to establish trends. The water quality results indicated that the groundwater from the boreholes is progressively becoming more saline against the pumping age. The increase in salinity indicates progressive saltwater ingress in the aquifers. These trends show that saltwater intrusion is still limited around the shoreline areas especially Beit-el-Ras and Mweni. The aquifer under the historic Stone Town area is also showing high potential for saltwater intrusion for which increased pumping of groundwater may render it saline. To curb this problem, controlled groundwater pumping and establishment of a long-term monitoring programme have been recommended.

Key words: Zanzibar, groundwater, saltwater intrusion, water quality, Tanzania, stalinization

INTRODUCTION

Saltwater intrusion is a common problem in coastal areas where over-pumping of groundwater occurs. It results in salinization of fresh groundwater tapped in wells and boreholes and therefore rendering it unsuitable for domestic supplies and other uses. Saltwater intrusion is not reversible, once it happens, the wells will be abandoned and the aquifer cannot readily be used (Black, 1977). This is a waste of resource that leads to scarcity of water for the people and increased costs for water. For municipalities in developing countries, like Zanzibar, provision of alternative water source could take many years due to inadequate financial resource. This could mean suffering on part of the communities and other water related health problems arising from using

water sources of inferior quality. The normal control mechanism for saltwater intrusion problem is to maintain the proper balance between pumping rates and aquifer recharging capacity. This works only where groundwater monitoring is practiced, otherwise in its absence, the intrusion could happen without notice.

The Zanzibar Municipality relies on groundwater as a sole source of water supplies. The public water authority meets only about 62% of the water demand which is estimated at 45,000 m³/day, the remainder being sourced from private boreholes and shallow wells (Revolutionary Government of Zanzibar, 2004). About 30% of the water is lost in the distribution system before reaching the consumers. The State of Environment Report

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Table 1. Existing boreholes serving Zanzibar Municipality (Zanzibar Water Authority, 2009).

Water source	Water production (m ³ /day)
Springs	
Mwanyanya/Bububu	5,000
Mtoni	5,000
Boreholes	
Chunga 1	1,800
Chunga 2	1,800
Chunga 3	1,800
Kaburikikombe 1	2,300
Kaburikikombe 2	2,300
Kianga	2,300
Mbweni	400
Mwembemchomeke 1	2,300
Mwembemchomeke 2	2,300
Mfenesini	1,000
Cave	
Dimani	100
Total production	28,400.00

(Revolutionary Government of Zanzibar, 2004) mentions availability of water among the priority issues of Zanzibar. Since 1950s, the government of Zanzibar has progressively developed systems for groundwater abstraction. There are currently 11 production boreholes with a total water pumping rate of 18,300 m³/day (Zanzibar Water Authority, 2009). The boreholes are located within the urban area and many are close to the Indian Ocean coast. There are also springs and caves providing 10,100 m³/day (Table 1). A thorough assessment to balance pumping rate with aquifer capacity was not conducted. The present increase in population and drive for enhanced tourism on the island is forcing more water production from the boreholes hence posing a potential threat to sea water intrusion in the aquifers. This assessment was conducted to investigate the extent of sea water intrusion in the existing boreholes.

MATERIALS AND METHODS

Description of the study area

This research was conducted in Zanzibar Municipality, Tanzania Islands. Zanzibar is part of the United Republic of Tanzania, East Africa, located within the Indian Ocean and is composed of two major islands of Unguja and Pemba. Zanzibar Municipality is the headquarters of Zanzibar and lies on the Unguja Island (Figure 1). The islands are located between latitude 4°50' and 6°30' South, and longitude 39°10' and 39°50'. Unguja is the largest island occurring at approximate 40 km off the coast of Tanzania mainland. The island is 86 km long and 39 km wide, with an area of 3,354 km² and

population density of 460 persons per square kilometer. Pemba is situated about 40 km to the north east of Unguja, and is 68km long and 23 km wide, with an area of 1,537 km² (Revolutionary Government of Zanzibar, 2004).

According to the 2012 national census, Zanzibar (Unguja and Pemba islands) has a population of 1,303,569 growing at 2.8% per annum (United Republic of Tanzania, 2013). Unguja island had 896,761 and Pemba 406,848 being 68.8 and 31.2% of the population of Zanzibar respectively. The Zanzibar town has a population of 223,000, which is about 24.9 and 17% of the total population of the Unguja Island and entire Zanzibar respectively. Zanzibar islands are bestowed with magnificent coastal areas offering diverse potentials for tourism development. As a result, coastal areas are becoming more populated with intensified socio-economic activities (especially tourism based activities) thus greatly impacting on the natural resources base among of which is the groundwater.

The geological and hydrogeological setting of Zanzibar is characterized by lower Miocene rocks consisting of deltaic sandstones associated with marls and minor reef limestone (Sikat, 2011). The major aquifers occur in the Quaternary limestone (Q2), Quaternary sand (Q3), Miocene limestone (M1) and Miocene sand (M3) (Kent et al., 1971; Sikat, 2011; Vuai, 2012).

Methodology

The study was carried out for six months from January to June 2004. Further updates were conducted between January and June 2009 (Sheha, 2009). A total of 154 boreholes in Zanzibar Municipality were investigated. Water samples were collected from the boreholes and analyzed for salinity linked parameters including electrical conductivity, chlorides, total dissolved solids (TDS) and salinity percentage. Other parameters like nitrogen nitrate and faecal coliforms were also determined. Samples analysis was done in the Environmental Engineering Laboratory, Ardhi University, Dar es Salaam. Historical water quality data of the boreholes were collected from the Zanzibar Water Authority (ZAWA) records. Borehole positions were determined by a hand held GPS. Spatial analysis was done to determine areal extent of the sea water intrusion and to enable determination of longitudinal water quality variation across the municipality. Four longitudinal profiles were used, namely, Beit-el-Ras to Amani (3800 m), Stone Town to Amani (4500 m), Stone Town to Mombasa (4800 m) and Chukwani to Mombasa (1620 m).

RESULTS AND DISCUSSION

Groundwater abstraction

Sustainability of the present water sources for the Zanzibar municipality is not quite understood. Groundwater is the sole source of water supply, abstracted through boreholes, springs and caves. There are 13 water sources of which 30% are located within the urbanized area. Although more than 70% of the municipality residents are connected to public water system, it does not meet the demand (Table 1) and as such there are many private operated boreholes. There are observed water decline from the spring sources (Table 2) signaling further water scarcity and more private borehole drilling. There is no registration or monitoring of boreholes drilling and/or operation (control

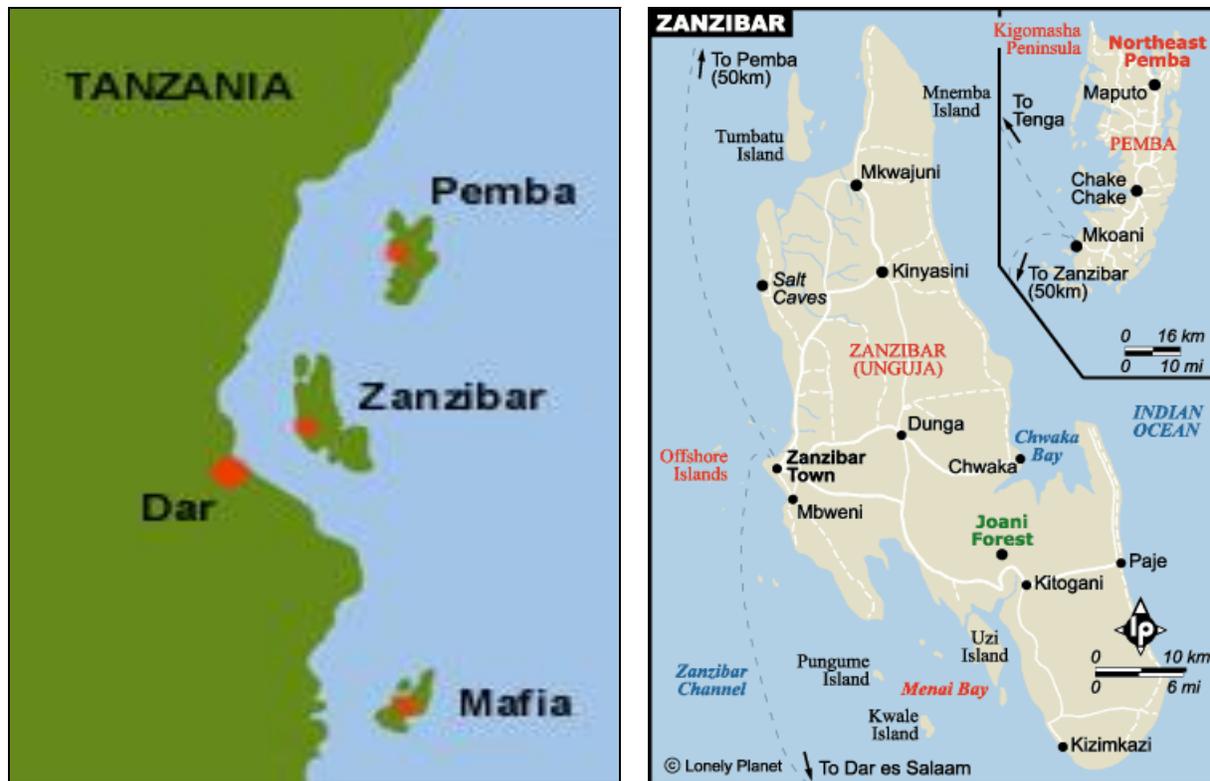


Figure 1. Location map of Zanzibar (Department of Survey and Urban Planning-Zanzibar, 2007, cited in Sheha, 2009).

Table 2. Average daily water production from spring sources in Zanzibar Municipality (Source: Zanzibar Water Authority, 2009)

Year	Mwanyanya or Bububu springs (m ³ /d)	Mtoni springs (m ³ /d)
1993	4,820	5,327
1994	5,010	4,900
1995	4,700	5,300
1996	4,500	4,300
1997	4,200	4,000
1998	4,200	4,000
1999	4,000	3,500
2000	4,000	3,400
2001	4,000	3,400
2002	3,700	3,400
2003	3,400	3,100
2004	3,400	3,100
2005	3,400	3,100
2006	3,400	3,100
2007	3,000	2,980
2008	3,000	2,980

of pumped water) and hence groundwater withdrawal rates are not known. Many surveyed boreholes in this study are privately owned located at business premises

or institutions. Boreholes have been drilled from a distance of less than 70 m from the Indian Ocean shoreline (Beit-el-Ras) to more than 3 km (Kaburikikombe) within the municipality boundaries. Coast areas like Stone Town (the historical town), Beit-el-Ras, Mtoni and Mbweni have many shallow and boreholes apart from being connected to central water articulation system. Continued unregulated boreholes drilling and groundwater abstraction in the municipality thus threatens the seawater/freshwater balance in the underneath aquifers with consequential seawater intrusion. With the advent of present drive towards tourism sector expansion and rapid population increase in Zanzibar more stress on the aquifer is anticipated that may result into complete aquifer degradation from saltwater intrusion if groundwater abstraction will not be checked.

Water quality changes indicating saltwater intrusion

The results of laboratory analysis and historical water quality data of the boreholes in Zanzibar Municipality are shown in Tables 3 and 4, respectively. Available water quality data obtained at Kaburikikombe boreholes span from 1988 and was used to track saltwater intrusion trend. About 97% of boreholes analyzed show a positive trend in conductivity, salinity, TDS, and chloride levels.

Table 3. Representative analyses for groundwater from boreholes in Zanzibar Municipality.

Number	Name	Borehole details				Conductivity	Salinity	^a TDS	Chloride	^b N-Nitrate	^c FC
		Drilling date	Diameter mm	Depth (m)	Yield (m ³ /h)	µs/cm	ppm	mg/L	mg/L	mg/L	No./100 mL
BH1	Kaburikikombe	1996	254.0	50.00	126	1044	500	520	284	3.41	0
BH2	Kaburikikombe	1988	250.0	42.00	120	1056	500	528	324	4.23	0
BH3	BOT	2000	152.4	29.50	13	444	200	222	64	1.38	0
BH4	Zainab bottler	2203	150.0	10.00	15	720	200	365	130	1.66	0
BH5	M.matrecta	1990	130.0	22.00	12	679	300	340	140	3.57	0
BH6	Ngozi	2003	101.0	20.00	5	368	200	183.8	176	1.65	0
BH7	Gongoni	1996	143.0	17.00	29	2080	1100	1039	1040	4.92	5
BH8	Soda	2001	101.6	18.00	4	1054	500	527	204	2.45	0
BH9	S.S.beit-el ras	2002	150.0	19.00	5	8360	5607	4880	4460	4.4	0
BH10	S.R. mombsa	2000	145.0	20.00	8	525	59.01	304	227	1.3	0
BH11	N.S. kilimani	2000	101.0	19.00	5	672	200	390	304	1.6	2
BH12	M.I.barastekipande	1999	150.0	18.00	6	1320	1050	691	512	3.2	4
BH13	H.K.M.Makumbi	2002	101.0	17.00	7	1650	813	604	512	1.5	5
BH14	Migombani	2002	165.0	38.40	2	982	494	532	256	1.6	0
BH15	Amani	2000	105.0	52.97	20	951	215	347	120	2.5	0
BH116	Mpendae	1992	250.0	32.00	7	560	141	450	56.3	2.6	0
BH17	Magomeni	1999	120.0	24.00	10	841	455	287	300	4.1	0
BH18	Kwakhani	1992	135.0	18.00	7	942	420	540	411	2.5	0
BH19	Malindi	1994	101.0	17.00	5	1520	641	754	500	2.8	00
BH20	Baghani	2000	100.0	18..55	7	1447	350	584	600	5.6	0

^aTDS - Total dissolved salts, ^bN - nitrate – nitrogen nitrate, ^cFC - faecal coliform.

Examples of the positive trends are shown in Figure 2 for Kaburikikombe boreholes which are located about 3 km from the shoreline. The data indicate remarkable changes in groundwater quality, especially salinity variations. Increased salinity in groundwater coupled with elevated abstraction rates commonly leads to saltwater intrusion. Unregulated groundwater extraction and increased water demand related to population increase and tourism investment in Zanzibar has been assumed to have triggered salt water intrusion which is reflected by elevated salinity in

boreholes. In this case there are some evidences that the increased salinity may be due to saltwater intrusion. For instance there was a marked chloride changes for BH1 (Kaburikikombe) from 110 mg/l in 1993 to 284 mg/l in 2004 (60% increase) while the nitrate-nitrogen levels remained very low (less than 4 mg/l). Should the sewage disposal in the municipality have an impact on the chloride levels in the water from the boreholes it was expected to have elevated levels of nitrate-nitrogen or at least a positive trend.

Longitudinal variation in water quality was noted

from the sea shore along the four profiles (Figure 3). Generally, boreholes located close to the coastline showed relatively higher salinity, TDS, conductivity and chloride levels than inland boreholes. Chloride concentration of 2000-6500 mg/l and 1000-2000 mg/l were observed in some boreholes located 0- 100m and 100-1000m from the sea line. A steep longitudinal gradient was observed along the Beit-el-Ras to Amani profile where chloride dropped from 4500 mg/l to less than 300 mg/l. The other profiles had a rather flatter concentration gradients in all the four

Table 4. Examples of historical water quality data for the boreholes in Zanzibar Municipality (Source: Zanzibar Water Authority, 2004^a).

BH No.	Location	Sampling date	Conductivity ($\mu\text{s}/\text{cm}$)	Salinity (ppm)	TDS (mg/L)	Chloride (mg/L)	NO ₃ -N (mg/L)	FC (No./100 mL)
BH1	Kaburikikombe	2/11/1998	944	195	472	111	4.1	0
		30/12/99	956	215	600	160	3.87	0
		2/6/2000	966	230	580	167	2.9	0
		5/9/2001	877	224	430	130	2.6	0
		4/9/2002	981	290	504	230	1.2	0
		7/8/2003	965	467	542	222	3.2	0
		11/3/2004	1044	500	520	284	3.41	0
BH7	Gongoni	1/10/2000	1432	751	634	470	4.7	1
		30/6/01	1556	701	624	441	2.8	3
		23/12/02	2001	982	851	842	1.6	1
		2/6/2003	1975	932	823	843	1.4	3
		12/3/2004	2080	1100	1039	1040	4.92	5
BH8	Soda	1/2/2000	611	153.2	301	87.2	4.14	0
		26/1/01	692	193	309	123	1.3	0
		30/7/02	712	209	336	197	3.6	0
		15/6/03	791	307	349	192	1.2	0
		12/3/2004	1054	500	527	204	2.45	0

^aData extracted from working files, Zanzibar Water Authority (2004)

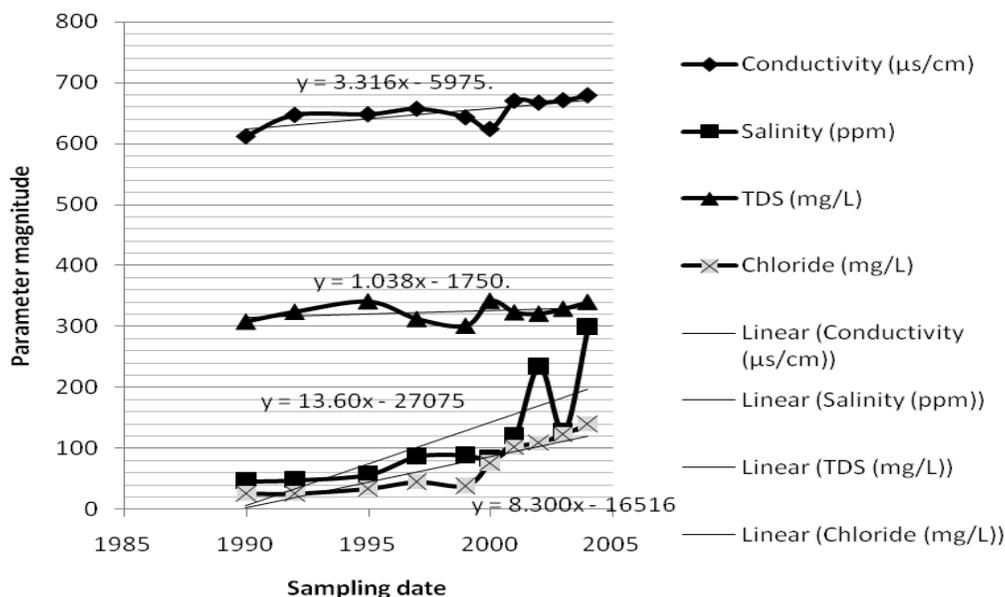


Figure 2. Example of salinity parameters trends in the Kaburikikombe boreholes, Zanzibar Municipality in 2004.

parameters measured.

Generally the water quality data indicate that Beit-el-Ras and Mbweni areas are more threatened with saltwater intrusion problems than the rest of the

municipality beach areas of Chukwani, Mbweni, Kilimani and Stone Town due to more number of boreholes showing progressive increases in salinity levels, many of which exceeded 2000 ppm. These levels are early

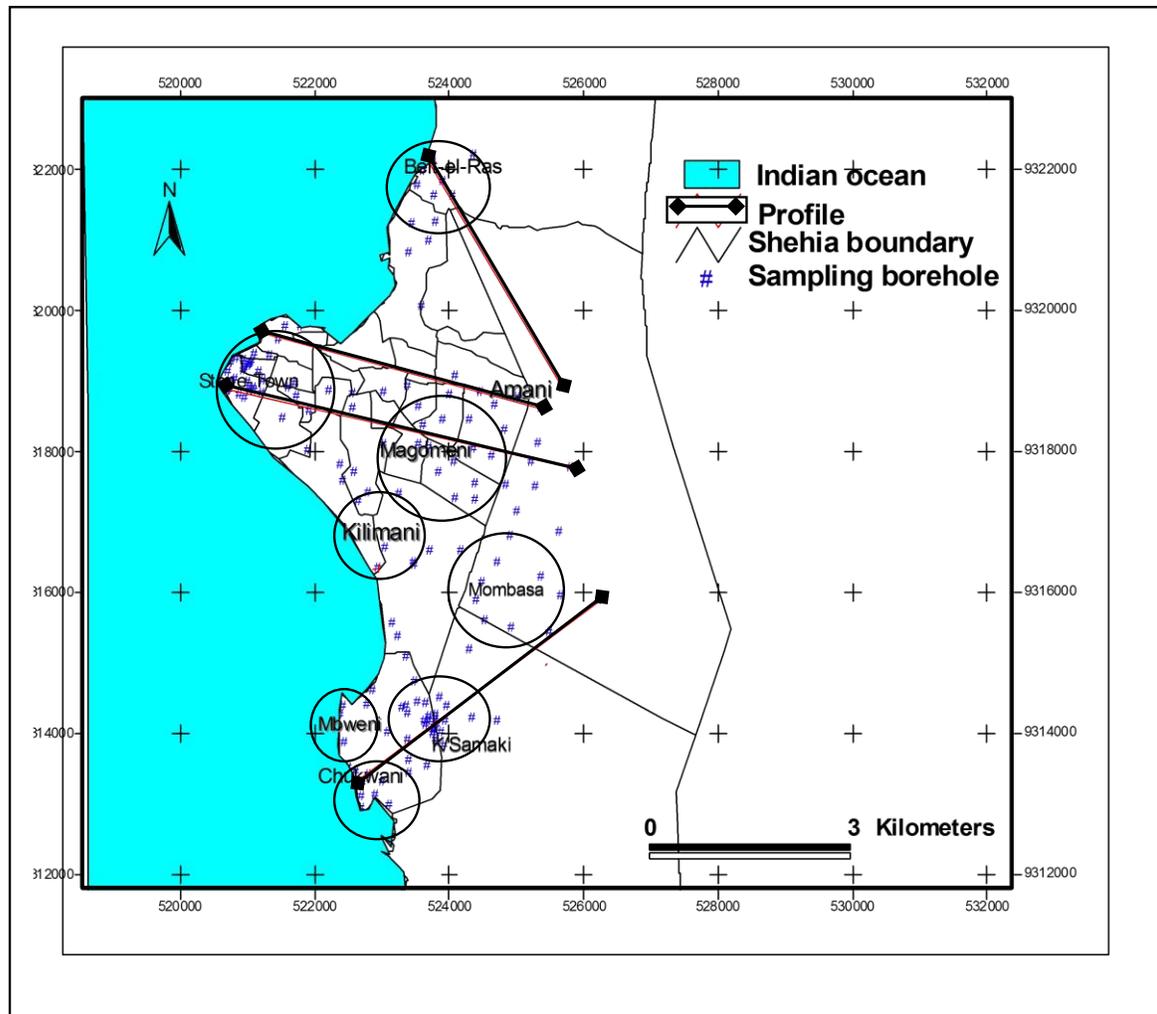


Figure 3. Map of Zanzibar municipality showing locations of some boreholes sampled and longitudinal profiles considered in the study.

indicators of major salt water intrusion problems that could occur should the present uncontrolled groundwater pumping practices continue.

Conclusion

It is quite evident from the study that there are evident signs of saltwater intrusion in the coastal aquifers underneath the Zanzibar municipality. The groundwater salinity increase trend is exacerbated by increased water demand arising from the high population density and expansion in the tourism industry on the island. Uncontrolled groundwater pumping presents a real water resources management problem that could easily deplete the only freshwater resource sustaining the island. Occurrence of saltwater intrusion will increase water scarcity on the island and literally adding more poverty to

the people apart from causing more health related problems. The water resources authorities in Zanzibar should therefore take proactive steps towards curbing the saltwater intrusion threats by controlling the groundwater withdrawal and putting in place long-term monitoring system.

Conflict of interest

The authors did not declare any conflict of interest.

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