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THE EFFECTS OF INTERMITTENT SUPPLY AND HOUSEHOLD STORAGE IN THE QUALITY OF DRINKING WATER IN MAPUTO

Förändringar i dricksvattenkvalitet i Maputo på grund av intermittent försörjning och tanklagring i hushållen

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Abstract

A serious problem arising from intermittent supplies is the associated high level of contamination and public health hazards resulting either from ingress of contaminated water or from prolonged storage. This paper discusses the overall condition of the drinking water quality of intermittent water supplies in Mozambique. The network of Maputo is used as an example. Records of water quality determinations from different locations in the network are used to assess the final quality of water at consumer's taps. Chlorine residual levels measured in reservoirs and results of bulk chorine decay tests performed with samples of treated water are used to estimate chlorine decay constants (kb) at different locations of the network and to predict the influence of retention time in the final quality of water. Presence of bacteria, low disinfection capacity and long residence times in the network and reservoirs are the main factors affecting the final quality of distributed water. Post-contamination due to ingress of contaminated water and prolonged storage in reservoirs is high. The intermittent operation of the distribution network is therefore inadequate to guarantee safe drinking water.

Key words – intermittent water supply, household storage, chlorine decay, water quality Maputo

Sammanfattning

Ett allvarligt kvalitetsproblem vid intermittent dricksvattenförsörjning kan kopplas till kontaminering och folkhälsofaror som orsakas antingen av inläckande kontaminerat vatten i de trycklösa markförlagda ledningarna eller av lång lagringstid i reservoarer i nätet respektive hushållstankarna. Denna artikel redovisar den generella situationen för dricksvattenkvalitet i Moçambique vid intermittent försörjning. Maputos dricksvattennät används som exempel. Analyser av dricksvatten från olika provtagningsplatser i nätet används för att bedöma vattenkvaliteten hos konsument. För att uppskatta betydelsen av uppehållstid i ledningsnät och för att bestämma sönderfallskonstanten för klor (kb) i vatten mättes restklorhalter i reservoarer och gjordes sönderfallsförsök av klorhalter i dricksvatten från olika platser i Maputo. Bakterieförekomst, en låg desinfektionskapacitet och en lång uppehållstid i ledningsnätet är de viktigaste faktorerna som påverkar den slutliga vattenkvaliteten i det distribuerade vattnet. Efterkontamineringen är hög på grund av inträngande vatten i trycklösa ledningar och en förlängd uppehållstid i nätets reservoarer och i hushållstankar. Den intermittenta försörjningen med uppehåll i vattendistributionen är därför otillräcklig för att garantera säkert dricksvatten i Maputo.

Introduction

The provision of safe drinking water is essential in maintaining the quality of life in all communities. During the last decades, the demand for improved supplies in the Third World has been increasing considerably due to rising per-capita incomes, rising standards of living, and population increase (Reweta and Sampath, 2000). While the pressure on existing supplies increased with time, the development of additional sources and/or extension of existing supplies have been an unrealistic option for many places of the developing world due to financial constraints.

The solution frequently applied in such places is the adoption of intermittent supplies. Intermittent supplies, however, are associated with quantity and quality problems, occasionally linked to fatal health hazards (Totsuka et al., 2004). Despite considerable negative impacts, intermittent supplies are used in many parts of the world, especially in arid and densely populated areas of the developing world.

Totsuka et al., (2004) point out that more than 90 % of the population served by piped water supply in South Asian countries receives water during less than 24 h/day. In most African countries, conditions are worse. According to the same author, in Zaria (Nigeria), only 11 % of consumers with a piped supply receive water one day in two while, in Mombasa (Kenya), the average number of service hours is of about 2.9 hours/day. For Dar es Salaam (Tanzania), Reweta and Sampath (2000) indicate that the main supply to the town provides less than 1 % of the required demand, forcing residents to depend heavily on alternative supplies. The long list of examples also includes many countries in The Middle-East.

The most critical consequence of intermittent supply is the risk of water contamination due to ingress of contaminated water and the consequent public health hazards. Other consequences include, inequitable water distribution, inconveniences to consumers and added costs of water supply due to the need of additional facilities such as storage tanks and pumps (Totsuka et al., 2004).

Unequal distribution of water forces consumers to find their own ways to cope with intermittency by constructing household tanks. However, contamination of drinking water in household tanks is a second important health risk. Totsuka et al. (2004) report water quality tests carried out in Istanbul (Turkey) which revealed that 24 % of samples taken from consumer storage tanks were found positive for coliforms compared to only 4 % positive samples taken from the pipe network. Tokajian and Haswa (2003), reporting results from a controlled study in Beirut (Lebanon), have found a positive correlation between mean bacterial counts and pH, temperature and storage time.

Intermittent supplies can also promote bacterial regrowth in the network during stagnant hours and consequent biofilm detachment when the supply is reestablished. These events were found to greatly impact the water quality distributed in a controlled study run in a suburb of Nablus Palestine, Coelho et al. (2003). Bacteria counts were about eight times higher during the first five minutes of supply compared to the overall water quality.

Water supply and distribution in a large number of Mozambican cities and villages is also intermittent. Existing transport and distribution networks are old; suffer from high levels of leakage, limited hydraulic capacity and limited coverage, caused by city demand increases and city growth. The average number of supply hours in the majority of the cities is of less than 12 h (Gumbo et al., 2003). The purpose of this paper is to evaluate the effect of intermittency and household storage on the quality of drinking water distributed in Maputo.

Materials and methods

The study area

Maputo is the largest city of Mozambique and the city capital of the country. The town is supplied by piped water from a system consisting of a single source in the Umbeluzi River, treatment by conventional treatment, transport through a 28 km transmission main, and distribution through a reticulated network of approximately 840 km (Gumbo, 2004). Five distribution centres (DCs) exist of which three are located in series along the main supply line (Matola at about 10 km from the water works, Chamanculo at 20 km and Maxaquene at 28 km). The others are Machava DC located some 17 km from the water works, and Alto-Maé DC located at about 24 km.

The supply from the water works is done 24 h per day, but the distribution to the different consumption zones is intermittent because of low pressure in the system and the need to minimize losses (Gumbo et al., 2003). Many consumers of the city of Maputo have therefore, built extra household tanks to cope with water shortages. A large proportion of these tanks are built on ground level from where stored water is further pumped to roof tanks or supplied directly to taps in the households.

Data collection

The drinking water quality in Maputo was investigated through analysis of data provided by the service provider and data collected through fieldwork. The data from the service provider covered the period 2001–2004 but only data from 2004 was used for the analysis. Due to incompleteness of the data with respect to bacteriological data, the analysis of bacteriological aspects of distributed water was done using data from 2003.

Residual chlorine, bacteria, turbidity and solids are the parameters used for the analysis of the water quality in the network. Temperature, residence time and the condition and treatment of reservoirs and household tanks are used to make the final assessment of the quality of drinking water in Maputo. Reference locations are: the water works (treated water), distribution centres (DC), household tanks and taps in the network.

Fieldwork took place during 7 weeks in November/December 2004. Water samples taken from different locations in the network were analyzed for physic-chemical and bacteriological characteristics. During the fieldwork, samples were collected twice a week (Mondays and Wednesdays) usually between 7.30 a.m. and 2.00 p.m. Four sampling points were visited each day where, water samples were collected pair wise on taps located before and after household tanks. The taps used to collect samples for bacteriological analysis were cleaned with cotton and ethanol before sampling. In addition, the taps were left open for about 1 min before sampling.

During sampling of household reservoirs, the condition of the tanks was assessed through observation and interviews to owners. Aspects of interest included, the overall condition of the tanks, construction materials and dimensions, consumers practices regarding the cleaning of reservoirs and consumer's concerns about water quality.

Time dependent chlorine decay tests were performed with samples of treated water. The method used (often referred to as "bottle" or "jar test", Powel et al., 2000) consisted of recording chlorine concentrations at fixed time intervals from bottles previously filled with sample water. The tests were used to estimate the magnitude of chlorine depletion with time and to estimate chlorine decay rates (K_b) for treated water. The results of the tests are compared to results of calculations done with data provided by the service provider and that generated during the fieldwork. Existing or measured data on residual chlorine was used to estimate chlorine decay rates at selected locations of the network with emphasis put on household tanks and reservoirs of distribution centres. Chlorine decay rates estimations where based on a first order decay reaction.

Estimates of the total residence times in the network, reservoirs and household tanks are used to discuss the results of calculations of chlorine decay rates.

Measurements

Temperature, pH, TDS, conductivity, free and total residual chlorine, was measured directly in the field while turbidity, bacteria and solids were measured in the laboratory. All Temperature readings were taken with a standard mercury thermometer (accuracy of ± 1°C) and TDS, pH and Electrical conductivity (EC) were measured with pocket Wagtech digital meters. Free and Total residual chlorine (FRC, TRC) were measured with the DPD (diethyl-p-pheneylene diamine tablets) colorimetric method with colour measurement through a portable digital photometer (Wagtech 5000) calibrated at 520 nm wavelength.

Turbidity and alkalinity were measured a few h later in the laboratory. A Hach turbidity meter DR 2500 was used for turbidity readings. Alkalinity was measured with a simplified titration method described in the Standard Methods for the Examination of Water and Wastewater, (1998). All bacteriological analyses were done at the laboratory of the Ministry of Health using the membrane method described in the standard Methods for the Examination of Water and Wastewater. The parameters measured were total bacteria, faecal coliforms and *E.coli*. Sediments sampled in at least three reservoirs were analyzed for solids (total, volatile and fixed solids). The method used for analyzing solids followed the Standards Methods for the Examination of Water and Wastewater (1998).

All pair wise data was checked for its statistical significance. The method used consisted of making a confidence interval for the difference of two expected values $I(\mu_1 - \mu_2)$; if this interval does not cover zero it is regarded to be a significant difference between two homogeneous groups. A 95 % confidence interval ($p=0.05$) was used in all tests.

Chemical and physical parameters measured in samples taken from the network and after household tanks were compared, with an independent sample T-test. The T-test is a parametric comparative test used to show if a difference exists between two homogenous groups. For turbidity, free residual chlorine, total residual chlorine and nitrate the test was not valid since the variance of the two groups were not equal. The Mann-Whitney U-test was used instead. Presence and absence of bacteria in samples taken before and after storage were also compared with a Mann-Whittney U-test. The T-test was also used to compare residual chlorine in samples with and without bacteria.

Results and discussion

Residual Chlorine

For assessing chlorine residual levels in the network of Maputo, about 1192 records of the operator database and 26 records of determinations done during the fieldwork were investigated. The records from the operator database contained only values for TRC while that of the fieldwork included also data for FRC. The results of the assessment for TRC, indicate levels of residual chlorine in the network and water leaving reservoirs of DCs, mostly above the lower limit 0.25mg/l (see Table 1).

Typically, the allowable minimum is 0.2 mg/l (WHO, 2004). The Mozambican standards for total residual chlorine are 0.25–1.0 mg/l in the net and 1.5 mg/l at the

Table 1. *Total and Free residual chlorine and Turbidity in the network, reservoirs of DCs and household tanks of Maputo water supply, from database (db) and field work (fw).*

Location	Residual Chlorine									Turbidity				
	Nr. records	Total Residual chlorine				Free Residual chlorine				Nr. records	Ave.	Max	Min	STD
		Ave.	Max	Min	Std	Ave.	Max	Min	STD					
Treated water (db)	338	1.58	2.49	0.87	0.37					338	3.22	7.64	1.81	0.59
Net (db)	1192	0.69	2.0	0.13	0.32	–	–	–	–	–	–	–	–	–
Net (fw)	27	0.50	1.1	0.08	0.25	0.17	0.68	0.01	0.14	30	2.00	6.00	0.60	1.50
DC-Matola (db)	320	0.98	3.0	0.20	0.44	–	–	–	–	320	2.52	11.20	1.15	0.73
DC-Machava(db)	345	0.97	3.0	0.15	0.40	–	–	–	–	341	2.39	9.19	0.81	0.73
DC-Chamanculo(db)	343	0.98	2.5	0.15	0.41	–	–	–	–	341	2.31	6.99	0.78	0.67
DC4-Alto Maé(db)	343	0.81	2.5	0.15	0.36	–	–	–	–	340	2.30	7.36	1.08	0.58
DC5-Maxaquene(db)	345	0.63	1.9	0.11	0.30	–	–	–	–	342	1.76	6.73	0.79	0.59
H-reservoirs (fw)	26	0.24	0.65	0.06	0.14	0.06	0.29	0.01	0.06	30	1.40	3.50	0.7	0.6

water works (MISAU, 2004). In the specific case of Maputo water supply where a private company (Águas de Moçambique- AdeM) has been awarded a 15 years lease contract to manage the water supply for the city, the contract standards indicate limits only for free residual chlorine between 0.2–1.0 mg/l.

The data on TRC levels of water leaving reservoirs of DCs also show average TRC levels decreasing as the distance from the water works increases even though, the water is re-chlorinated at some DCs located along the main supply line (Matola and Chamanculo).

Analysis of records for TRC and FRC using sampled data reveals much lower values for FRC in the network and household reservoirs with 77 % of samples falling below the target limit of 0.2 mg/l. TRC levels were in general 0.26 mg/l lower after reservoirs while, FRC was 0.11 mg/l lower. A statistically significant difference ($p < 0.01$) between levels measured before and after household tanks has been observed.

Analysis in different parts of the network thus suggests that the disinfection capacity in the network is rather high when evaluated with TRC levels. The same analysis done on basis of FRC suggests, however, a different scenario with chlorine residual levels (0.17 mg/l) very close to the lower limit recommended for an effective disinfection of the water.

Turbidity

The results of the analysis (see Table 1) suggest mean values of about 3.22 NTU for treated water and mean values between 1.8–2.5 NTU for water leaving DCs. The data from the operator's database did not contain data on turbidity levels in the network but the results of the sampled data suggest mean values of 2.0 NTU. From Table 1 it is clear that at all measured sites turbidity levels were most of the times above the WHO desired limit of 1.0 NTU and that in few occasions the WHO limit of 5 NTU was exceeded. The absolute limit of 20 NTU stated in the contractual limits of the water company of Maputo was, however, never exceeded.

Overall, turbidity levels at all investigated sites show rather large variations between extreme values with occasional increases of turbidity levels of the water leaving some of the reservoirs of DCs. This was reported in the reservoirs of the DCs of Chamanculo and Alto Maé but not in the reservoirs of Maxaquene DC.

This suggests the possibility of occasional loads of turbidity-causing particles entering the reservoirs, causing sediments to build up during periods of low demand and further release with the water leaving the reservoir during periods of high demand. Sources of turbidity causing particles can be pipe and fitting corrosion, lining erosion, biological growth, chemical reactions and external contamination that may occur during operations such as pipe repairs (Vreeburg and Boxall, 2007). The formation and growth of particles is, however, a very complex process, which is currently poorly understood but factors such as contact times, contact surface, and hydraulic conditions are likely to play an important role in controlling these processes (Vreeburg and Boxall, 2007).

Bacteria

Presence/absence of bacteria was investigated using records from both the service provider and the additional field survey. The operator's database had records of samples of treated water, reservoirs at DCs and reservoirs and taps of the network. Samples taken during the fieldwork considered two locations at each sampling point namely taps before and after household reservoirs. Around 503 records taken from the operator's database (148 from reservoirs at DCs and 355 from taps and household tanks) were investigated for presence of bacteria. The fieldwork produced another 60 records.

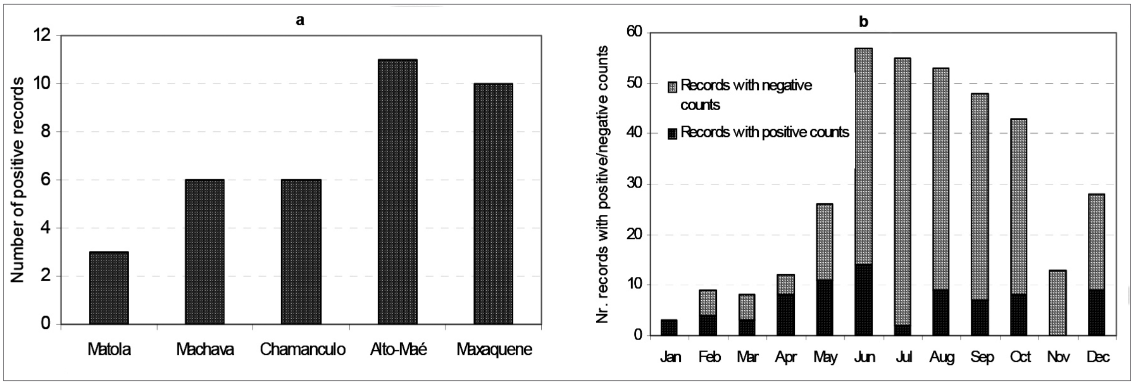

Figure 1. *Incidence of bacteria in reservoirs of DCs (Fig. 1a) and taps of the network (Fig. 1.b).*

The results suggest that both faecal coliforms and *E.coli* were found frequently in reservoirs of distribution centres, network taps and household tanks. The records on treated water did not contain data on presence/absence of bacteria. In the reservoirs of DCs, bacteria were found in about 24 % of the records investigated.

The levels of contamination were generally low (<10 cfu/100 ml), but occasionally reached high values (up to 165 cfu/100ml). Analysis of records from reservoirs of DCs also suggests that the DCs located first along the main line had the lowest incidence of bacteria counts when compared to DCs located further along (Figure 1a).

The data from the operator's database suggest, additionally, that on the network between the DCs and the households tanks, around 20 % of the investigated samples were found contaminated with bacteria. The annual distribution of cases with positive counts of bacteria over the total number of records investigated in the distribution network is show in Figure 1b.

The incidence of positive samples is evenly distributed throughout the year, which suggests that contamination with bacteria is a rather persistent problem in the network. A similar analysis done with records of the fieldwork suggests that coliform bacteria were found in thirteen out of the sixty samples collected (22 % of samples taken). Six out of the thirteen samples found with bacteria had bacteria counts over 100 cfu/100ml. Coliform bacteria was generally found in samples collected after household tanks (Figure 2). Ten out of the thirteen samples found with bacteria were collected after household tanks.

Because these samples were collected from seven different locations in the network, in three cases bacteria were found at least twice during the study. The results of the fieldwork also indicate that bacteria were only found in samples collected from reservoirs with rather low con-

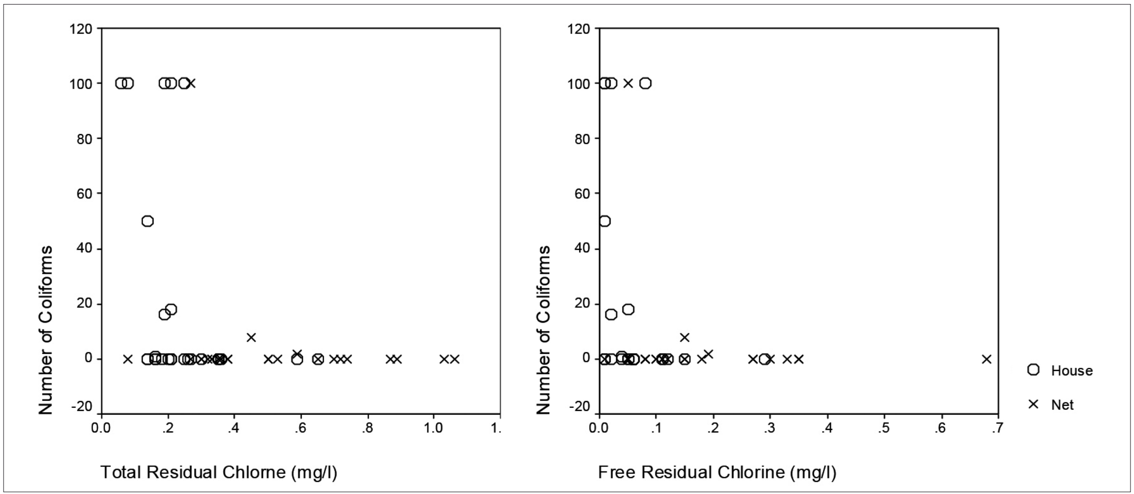

Figure 2. *Presence of Coliform bacteria in samples taken before and after household tanks.*

centrations of residual chlorine (see Figure 2). TRC was generally low in the influent of distribution centres in those days when faecal coliforms were found. *E.coli* was found three times in the network when the concentration of FRC was between 0.05 and 0.19mg/l. These levels of FRC should be sufficient for disinfection (WHO, 2004). This suggests that recent contamination of the drinking water took place.

One of the major reasons for bacterial contamination in pipes and reservoirs of distribution networks is insufficient disinfection capacity due to insufficient residual chlorine. Since chlorine decays over time, increased retention time by either storage or prolonged periods of interruption of supply increases the risk of occurrence of bacteria at points of water consumption. Biofilm formation and bacteria growth may also be occurring during periods of low or no pressure and further biofilm (containing bacteria) detachment when the supply is restart (first flush effect).

The network of Maputo is left under pressurized more often than the transport main between distribution centres (at least once a day), therefore, ingress of contaminated water may occur more frequently. The network is however, left under pressurized only few h/day so, the time for biological growth between flushes is short. Problems with biofilm formation play, therefore, a minor role with respect to contamination with bacteria.

Sediments

Sediments may increase the rate of chlorine decay in pipes and reservoirs, decrease the disinfection capacity and act as a source of nutrients for bacterial growth (WHO, 2004). Sediments resulting from particle accumulation are in fact know to have a relation with biological activity since, 1–12 % of the organic matter in the particles may consist of bacterial biomass. This makes sediments resulting from particle accumulation an important factor in hygienic safety of drinking water (Vreeburg and Boxall, 2007).

Table 2. *Solids concentration in water collected from household reservoirs.*

Reference site	Total solids (mg/l)	Volatile solids (mg/l)	Fixed solids (mg/l)	VS/TS
3	411.0	133.0	278.0	0.32
7	631.0	166.0	465.0	0.26
3	464.0	112.5	352.0	0.24

Sediments taken from few tanks in the network were investigated for factors known to influence chlorine decay rates in the reservoirs and to contribute for microbial growth (Table 2).

The VS/TS fraction is used as an indication for the organic matter content. The results (see Table 2) show amounts of 24–32 % of organics present in the sediments. The organics can potentially serve as nutrients for microbial growth or exert an extra demand of chlorine in tanks and reservoirs. According to findings from literature, the existence of large variations in turbidity will be the predominant causes of sediments build up in reservoirs.

Apart from increasing the rate of chlorine decay, sediments build up in reservoirs decreases the disinfection capacity as bacteria can hide inside the particles and escape from the effect of chlorination. The fact that the water stays relatively long in reservoirs may also increase the potential for biofilm formation (on the walls of reservoirs) and bacterial growth.

Chlorine decay and retention time

Chlorine decay constants calculated according to first order decay models for different parts of the network are resumed in Table 3. Mean values of total residual chlo-

Table 3. *Chlorine decay constants (K_b (l/h)) in different parts of the network.*

Location	Average Chlorine concentration inlet C_0(mg/l)	Average Chlorine concentration effluent C_e(mg/l)	Average retention time (hours)	K_b (1/h)
Treated water [a]	1.58	–	–	0.603
DC-Matola	1.17	0.98	12.5	0.016
DC-Chamanculo	1.20	0.97	37,2	0.006
DC-Alto Maé	0.95	0.81	11.8	0.015
DC-Maxaquene	0.887	0.63	10.1	0.035
H-reservoirs (TRC)	0.5	0.24	48	0.015
H-reservoirs (FRC)	0.17	0.06	48	0.022

Note: [a] obtained from time dependent chlorine decay test R = 0.903

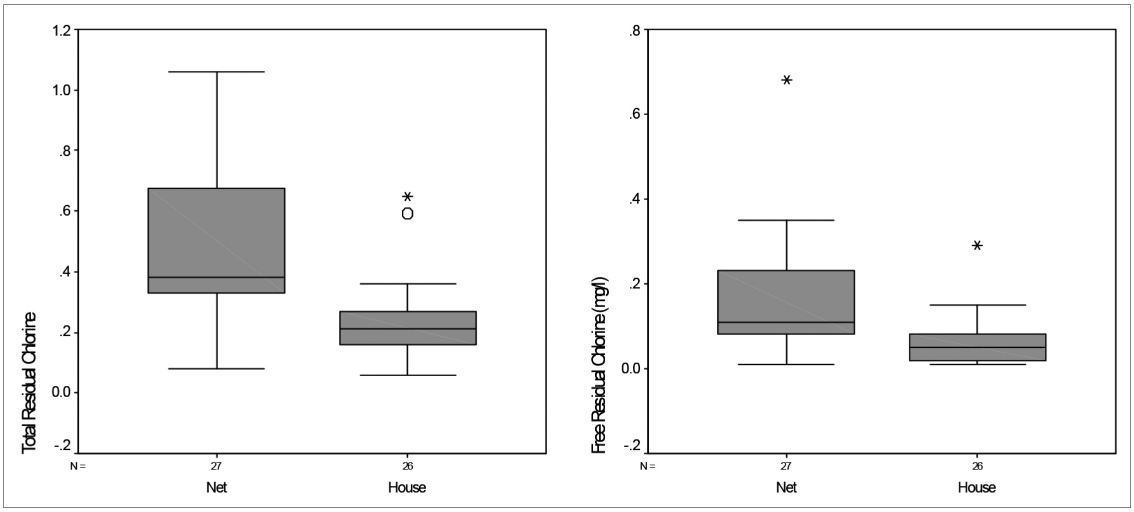

Figure 3. *Total and free residual chlorine before (net) and after storage in household tanks (o=outliers, *=extremes).*

rine in the influent and effluent of reservoirs were used in the calculations. The values of retention time in reservoirs of DCs were calculated from average figures of water consumption as provided by the operator and the net volume of reservoirs of the specific distribution centers.

For household storage tanks, retention time was calculated based on an average daily consumption equivalent to an average of 4.4 persons/house (INE, 1999) and a per capita water demand of 120 l/p.day as prescribed in the national standards (DNA, 2003) for water consumption. Though they vary significantly in sizes, household tanks were assumed to have a capacity of 1.0 m^3. Results of calculations of average retention time in reservoirs and estimated constants for residual chlorine decay are resumed in Table 3. Chlorine decay rates vary significantly in different parts of the network which suggests that the extent of chlorine decay varies in the system.

The results of chlorine residual tests performed with samples of treated water are also resumed in Table 3. Compared to the results obtained for different reservoirs in the network, the rate of chlorine consumption in the treated water is much higher than that observed in reservoirs of DCs and households. This is expected pattern since, the treated water is re-chlorinated in two points along the main line (Matola and Chamanculo) before reaching the reservoirs at DCs located downstream. According to findings from Kiéné et al. (1998) and Fang et al. (2000), chlorine decays more rapidly in freshly chlorinated water when compared to water that has been re- chlorinated.

The rate of chlorine decay in DCs and household reservoirs appears to be generally high and to vary significantly (between 0.006 and 0.035 l/h). This suggests that there may be external factors (e.g. biomass builds up, particles mixed with turbidity) that influence the decay rates.

Condition and treatment of household tanks

The materials mostly used for construction of household storage tanks is concrete, plastic (pre-fabricated black-PVC tanks) and asbestos cement. The capacity of concrete and asbestos cement tanks ranges from 0.25–4.5 m^3, while that of plastic tanks ranges from 0.5–1.5 m^3 (Table 4). The maintenance of the tanks is often poor, cleaning and disinfection is hardly done and in many of them lids was missing or was locked for long periods meaning that they are hardly opened for cleaning, maintenance and repair work.

Most of the tanks are oversized for the average demand/family, which, according to estimations based on an average of 4.4 persons/household @ 120 l/p.day, lies between 0.5 and 0.6 m^3/day. This result in relatively long storage times, excessive depletion of residual chlorine and the possibility of bacterial growth and biofilm formation due to insufficient disinfection capacity and bad condition of tanks.

According to results of this study, the average free residual chlorine levels downstream household tanks showed a decrease (Figure 3) of about 60 % during storage (from 0.167 to 0.061 mg/l).

Free residual chlorine in the majority of household reservoirs is therefore far lower than recommended lim-

Table 4. *Location, condition and treatment of household tanks.*

Ref. house	Location	Net volume (m^3)	Average number of users	Average retention time (days)	Material	Physical condition	Encountered maintenance problem
1	Ground	2.0	6	2.7	Asbestos cement	Fairly good	Tank cover broken. Ingress of contaminants possible.
2	Roof	0.5	5	0.8	Plastic	Good	Lid locked. Access for cleaning and maintenance limited
3	Roof	0.5	7	0.4	Plastic	Good	Lid locked. Access for cleaning and maintenance limited
4	Roof	1.0	6	1.4	Plastic	Good	Lid locked. Access for cleaning and maintenance limited
5	Under ground	6.0 (2x3.0 m^3 e.a.)	8	6.3	Concrete	Fairly Good	One tank with a broken lid. Second tank with lid locked. Access for cleaning and maintenance limited. Ingress of contaminated water possible.
6	Underground	4.5	10	3.8	Concrete	Good	Lid locked. Access for cleaning and maintenance limited
7	Roof	3.0	5	5.0	Concrete	Good	None.
8	Ground	1.0	5	1.7	Asbestos cement	Bad	Tank cover heavily corroded. Ingress of pollutants and contaminated water possible
9	Roof	1.0	6	1.4	Plastic	Good	Lid locked. Access for cleaning and maintenance limited.
10	Roof	1.0	6	1.4	Asbestos cement	Good	None
11	Roof	1.0	7	1.2	Asbestos cement	Good	Dirty inside the tank. Biofilm developing on the walls of the tank
12	Ground	1.0	6	1.4	Asbestos cement	Fairly good	Cover missing. Exposed to ingress of contaminants
13	Ground	0.5	6	0.7	Asbestos cement	Good	Cover missing. Exposed to ingress of contaminants
14	Ground	2.0 (2x1.0 m^3 e.a.)	10	1.7	Asbestos cement	Fairly good	One tank with a broken cover. Second tank with cover locked. Access for cleaning and maintenance limited. Ingress of contaminated water possible.
15	Ground	0.5	7	1.2	Asbestos cement	Fairly good	Tank cover heavily corroded. Ingress of contaminants possible
16	Ground	0.5	6	0.7	Plastic	Good	Lid locked Access for cleaning and maintenance limited
17	Roof	9.0 (6x1.5 m^3 e.a.)	30	2.5	Concrete	Good	Access ladder heavily corroded. Access for cleaning and maintenance limited
18	Ground	2.0 (2x1.0 m^3 e.a.)	6	2.8	Asbestos cement		Covers missing. Exposed to ingress of contaminants.
19	Ground	1.0	5	1.7	Asbestos cement		Cover missing. Exposed to ingress of contaminants

its. This finding is in line with conclusions from earlier studies by Coelho et al. (2003) and Tokajian and Haswa (2003), who found a strong relationship between storage time and bacterial growth as residual chlorine decreased. The combined effect of intermittency and household storage usually increases retention times, with the observed consequences for chlorine concentrations and occurrence of bacteria.

Conclusions

The results of this study suggest that the drinking water quality in Maputo is generally not safe for human consumption due to the presence of bacteria. The water quality deteriorates gradually, from the treatment works to the distribution centres, further on into the network, and finally in the household tanks. The reason is a combination of factors such as condition of pipes, ingress of contaminated water when the network is without pressure, long retention times in the network and reservoirs, and condition and treatment of storage tanks.

Both faecal coliforms and *E.coli* were found frequently in reservoirs of DCs and in the network. Apparently, some contamination occurs before or at reservoirs of DCs, which suggests contamination due to ingress of contaminants during periods of low or no pressure. The intermittent mode of operation of the network of Maputo water supply is therefore, pointed as the most critical factor causing contamination in the network.

Storage is influencing the water quality either because of retention time or because of poor management and ingress of contaminants. Long storage times seem to be the major factor of water quality deterioration, particularly in household tanks. Storage increased the risk of occurrence of faecal coliforms in the water with more than 100 %.

Though based on a limited number of samples, sediments in household tanks are found to potentially contribute to water quality deterioration. Turbidity of the water entering the reservoirs is generally high. Because the majority of household reservoirs are over-dimensioned and the network is operated intermittently, conditions exist for the settling of turbidity-causing particles and sediments build up. The combined effect of sediments and low disinfection capacity and long retention time, results in favourable conditions for bacterial growth.

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