Water services with independent providers in peri-urban Maputo: Challenges and opportunities for long-term development

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Abstract

Water service delivery to most residents of peri-urban areas of greater Maputo depends largely on alternative service providers, mostly in the form of small-scale independent providers (SSIPs). This paper discusses the present and long-term challenges facing SSIPs in supplying quality water of sufficient quantity in peri-urban Maputo and possible human health risks associated with the consumption of water provided by SSIPs. Extensive water sampling and analyses were conducted to evaluate the physicochemical and bacteriological quality of water provided by independent providers and the associated human health risks. Borehole pumping tests, the results of which were interpreted using the graphical method of Jacob, were used to evaluate the regional aquifer potential, the long-term impacts of its exploitation and the aquifer vulnerability to external contamination. From the results of borehole pumping tests it was concluded that the present yields are in average 33% lower than estimated safe yields and that larger than present yields therefore can be exploited. The aquifer vulnerability to external contamination (e.g. by *E. coli* and nitrates) is low, mainly because of low hydraulic loads and the existence of a rather thick (10 to 30 m) sandy unsaturated stratum where bacteria die-off and biological denitrification probably occurs. However, the aquifer vulnerability to sea sea-water intrusion is high. Currently, the health risks posed to consumers relying on services provided by SSIPs are small; even so, 13 out of 35 controlled boreholes had either total coliform or faecal coliform levels higher than the WHO standard. In the long run SSIPs may face more serious water quality problems due either to over-exploitation of the aquifer system or increased hydraulic loads resulting from increased population density.

Keywords: water supply services, peri-urban areas, small-scale independent providers, water quality, public health

Introduction

Most cities of developing countries are characterised by two distinct set-ups, namely the formally built 'cement areas' and the nearly rural types of neighbourhoods, the so-called peri-urban settlements, of metropolitan areas. The latter are usually slums, lacking every form of urban planning, where the majority of the urban poor lives. The development of this type of settlements is often not included in the official plans for urban development of the main cities, a fact that often causes difficulties in terms of planning, implementation, provision and maintenance of public services (Bolay and Rabinovich, 2004). To access potable water supplies, most residents of such neighbourhoods rely on alternative service providers such as small-scale independent providers (SSIPs), often acting as investors, developers and/or managers of water kiosks and small-scale piped water systems.

Of the various forms of small-scale service provision, SSIPs have long been accepted by donors and governmental authorities as a viable alternative to developing, managing and expanding service coverage in remote and underserved areas. In the field of water supply, SSIPs are estimated to reach as much as half of the population in some countries (Kariuki and Schwartz, 2005), while up to a quarter of the urban population of Latin America and nearly half of urban dwellers in African countries rely on SSIPs for at least a portion of their drinking water supply (Collingnon and Vézina, 2000). The list of examples in Africa includes the cities of Bamako, Cotonou, Conakry and Dar es Salaam, where SSIPs are reported to be the main source of drinkable water for more than 60% of households, and cities like Abidjan, Nairobi and Ouagadougou, where SSIPs are reported to reach 22% to 28% of unconnected households (Collingnon and Vézina, 2000). The city of Maputo is no exception.

SSIPs have operated in Maputo since the beginning of the 1980s, but they have only become widely established as from 2000. Estimates from a survey carried out on SSIPs in greater Maputo indicate that by 2005, more than 240 groundwater-based small piped systems run by SSIPs existed in the municipalities of Maputo and Matola (Seureca & Hydroconseil, 2005). Around 65% were reported to have been established within the last 5 to 8 years with roughly 43% built between 2002 and 2005 (Fig. 1). During the same period, service levels rose from public taps only to services provided also through house connections, yard taps and private stand pipes (Sal-Consultores, 2005). Today, some 32% of SSIPs are reported to have more than 100 house connections.

Most SSIPs, even though located within the boundaries of greater Maputo and furthermore within the lease area of a private operator – Águas e Moçambique (AdeM) – contracted to provide services to the city of Maputo, are currently not for-

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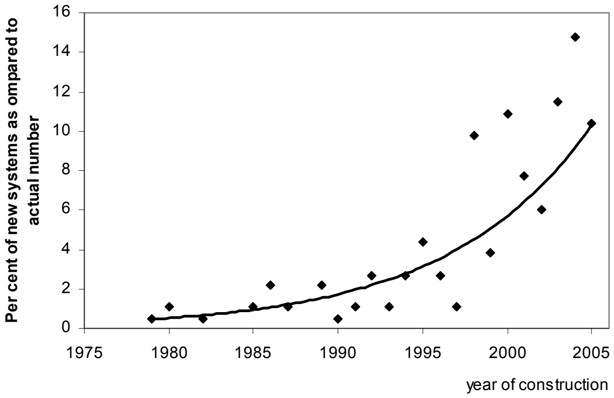

Figure 1
Statistical distribution of SSIPs in Maputo and Matola Municipalities by year of construction (adapted from: Seureca & Hydroconseil, 2005)

mally regulated. This is partially due to the lack of legal bases or legislation frameworks that could be used to issue licences or regulate their activities.

The evolution of household-level water strategies into SSIPs has in most cases been unplanned. Most owners of systems had built those to provide water for themselves, but because of insistence from neighbours they ended up allowing for some private connections or selling water in small quantities (20 to 25 ℓ) and thus slowly developing into water vendors. Also, because the benefits of selling water helped providers offset the investment and running costs (break-even expected within 2 to 3 years), many of them eventually turned into professional service providers.

The rapid increase in SSIP number in the neighbourhoods of greater Maputo has always been driven by demand, particularly in areas where a formal network is lacking. In such neighbourhoods, SSIPs have the dominant role in service provision and are reported to reach as many as 32% of unconnected households (Seureca & Hydroconseil, 2005; Salomon, 2007). This situation is not likely to change in the future, mainly because the physical expansion of the formal network is unlikely to ever match the speed at which new suburbs emerge in the city. Moreover, SSIPs have recently been recognised and accepted as key partners in the recently launched (2006) 'Maputo Water Supply Project', which among other aspects foresees the development of complementary groundwater- based systems and the involvement of small local private operators in the management of service provision.

In this study, the long-term challenges facing SSIPs with regards to supplying quality water of sufficient quantity to unconnected residents of peri-urban Maputo have been assessed based on an analysis of the present situation with respect to the quality of water, the hydrogeological set-up of the aquifer system used by SSIPs and the potential for quality and quantity problems associated with the proliferation of SSIPs. The focus of the study was on the source water quality, potential yields vis-à-vis present and future demands, and the best strategy to locate and monitor boreholes under a scenario of the continuous growth of SSIPs.

Materials and methods

The study area

Maputo is the capital of Mozambique and is situated on the Indian Ocean coastline. The city is characterised by three distinct set-ups, namely the area with high-rise buildings of the so-called old 'cement city', a few inner suburbs built before independence from the Portuguese in 1975, and the outer neighbourhoods consisting mainly of informal settlements.

During the unstable period after independence, exacerbated by the civil war that raged in the country for almost a decade, many families who fled the rural areas in search of security in the cities were allowed to settle in the outskirts of Maputo, where proper urban planning was lacking. With the introduction of municipal reforms in 1998, the city of Maputo was divided into two municipalities namely, Maputo and Matola. Furthermore, the administrative boundaries of the newly created municipalities were re-drawn and most of the neighbourhoods previously considered as informal settlements now became part of the new municipalities.

Without proper planning and investments, however, most of the new neighbourhoods today face severe limitations concerning access to adequate municipal/public services such as water, sanitation and electricity. When it comes to piped water supply, while the residents of the neighbourhoods located near the 'cement city' can still access the piped grid through overstretching the formal network, the residents of the outer neighbourhoods face more restrictions in piped water access, due to lack of pressure in the nearby grid or because the network cannot be sufficiently extended to reach their neighbourhoods.

These problems have not only led to enormous disparities concerning the access to piped water supply but also prompted the emergence of alternative service providers (e.g. SSIPs) who presently constitute the most reliable sources of water for the majority of the under-served urban poor. Today, roughly 38% of households in Maputo rely either on SSIPs (32%) or other types of alternative sources (6%) for their water supply, compared to the roughly 62% of households supplied through the formal network (Gumbo, 2004; Seureca & Hydroconseil, 2005).

Pumping tests and water quality measurements

Pumping tests

Borehole pumping tests were performed to assess the hydrogeological potential of the aquifer system used by SSIPs. A total of 10 pumping tests were performed on an equal number of boreholes distributed within the study area. Attempts were made to establish an evenly distributed grid of test boreholes covering the entire study area. Some problems arose while performing this task, i.e.:

- **Access limitations**. Owners were requested to interrupt their services temporarily to allow for installation of flow meters and other equipment required for the tests, and to run the actual tests. Due to possible disturbances to their services, some owners were not willing to participate; thus, new boreholes had to be identified near to previously selected boreholes in order to maintain the desired level of coverage of the study area.
- **Poor system condition**. In many cases the pipe casing was poorly done, making it difficult and costly to install the equipment for running the pumping test. Therefore, all tests were carried out using pumps already installed in the boreholes. This also limited the possibilities of running the tests with a three-stage pumping rate as is common practice. Instead, a single-stage pumping rate followed by a recovery test was used.
- **Reliability of power supply**. The area suffered from frequent power outages. The borehole locations thus had to

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be chosen on the basis of power reliability. Boreholes reported to be located within an area subject to a high rate of power cuts, as indicated by the owners, were not included in the list of test sites.

Despite the above-mentioned constraints, 10 different sites for the pumping tests were identified. The pumping tests consisted of a well drawdown test with a single stage pumping rate followed by recovery tests. Water levels were measured by divers in all tested wells with an accuracy of ± 1 cm. Discharge rates were determined using a flow meter connected to the rising main of each well. The test results were used to determine the aquifer transmissivity, the borehole-specific yield and borehole productivity.

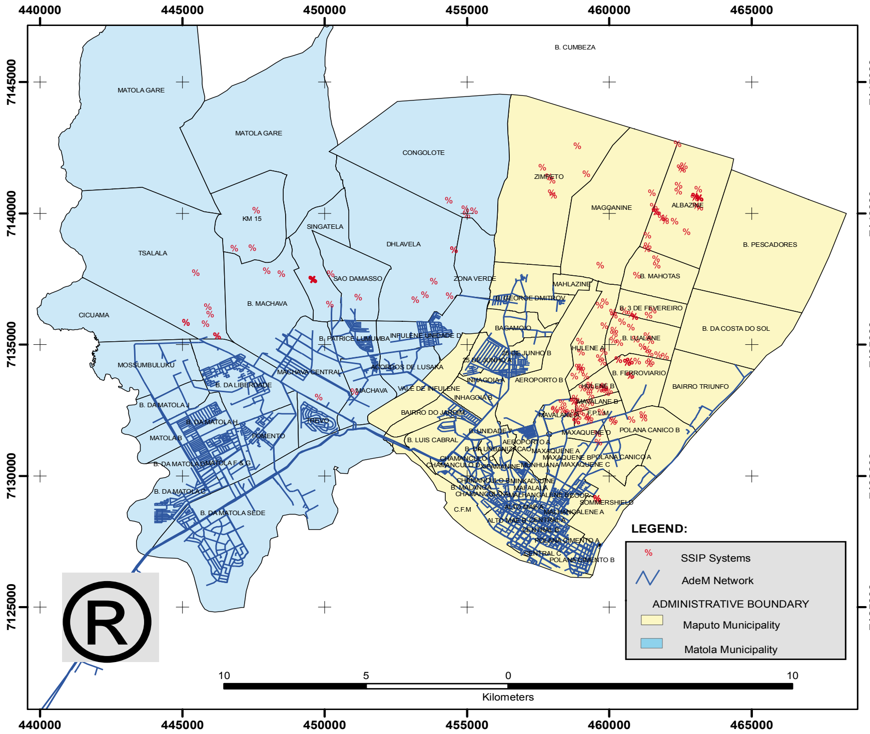

Figure 2
Distribution network of greater Maputo and distribution of water systems run by SSIPs

Water quality measurements

Thirty-five sampling wells were used to assess borehole water quality. Samples of borehole water were collected and further analysed for nitrates and bacteria (*E. coli* and faecal coliforms).

EC (electrical conductivity) and pH were measured in the field using handheld digital meters from Wagtech International Ltd., and temperature was measured using a standard mercury type thermometer. EC measurements were carried out with the purpose of evaluating the influence of sea-water intrusion on the quality of borehole water.

Nitrates and bacteria were analysed at the AdeM laboratory following procedures described in *Standard Methods* (1995). Bacteriological analyses were carried out using the membrane method. Although a total of 35 boreholes were used to investigate borehole water quality with respect to nitrates, the results from just 12 boreholes were used, due mainly to unreliable results obtained from one of the laboratories involved. The nitrate concentrations reported by Avignon Hydrogeological Laboratory in France were the results used in this study.

Results

Present condition of peri-urban water supply services

The Maputo water supply system is presently run by AdeM, a private operator rendering services through a 15-year lease signed in 1999 as part of the implementation of the framework for delegated management of water supply (Zandamela, 2002; Gumbo et al., 2003; Gumbo, 2004). As a consequence, FIPAG (Fund for the Investment and Property of Water supply) was created to take over as owner of the fixed assets of water supply of 5 major cities of the country; also CRA (the Water Supply Regulation Council) was created for regulation of private sector contracts within the framework. The lease area of AdeM spans across the entire area of the two municipalities while the existing network is limited to the most urbanised areas (Fig. 2).

Demand for services provided by SSIPs

From Fig. 2 it is evident that the lack of formal services in large areas of peri-urban Maputo has prompted the proliferation of private service providers who operate either as the sole service providers in their neighbourhoods or in competition with AdeM. In a survey conducted as part of this study, some 187 SSIPs of Maputo and Matola, who were reported to be responsible for some 192 small-scale piped systems, were interviewed. About 84.4% of providers interviewed said they offered services through house connections and yard taps while 15.6% offered services through standpipes.

The density and distribution of SSIPs in peri-urban areas of the city more or less follows the population density (see Fig. 2). The highest population densities are in the north-eastern part of the city (in the neighbourhoods of Albazine, Mahotas, Hulene, Laulane and Mavalane) and in the new expansion zones located north-west of the city, namely in Zimpeto, Ndhlavela, Bunhiça, Singatela and Tsalala.

The quality of services provided by SSIPs is highly appreciated by residents of peri-urban areas; therefore, the demand for their services has always been high. This has been confirmed through studies carried out for CRA in 2005 (Seureca & Hydroconseil, 2005) and further updated in 2006 (Salomon, 2007); these studies indicated that more than 75% of consumers interviewed were satisfied with the services offered by SSIPs.

SSIPs source water potential

Geological settings

The study area is part of the large Meso-Cenozoic sedimentary basin which covers the area south of the Save River and is related to the rift system between Madagascar and Africa. This system extends from Port Dundford in South Africa to Quelimane in the central part of Mozambique. Karoo basalts and rhyolites, dated Permic and Jurassic, form the basement of the system. Cretaceous to Tertiary flat deposits or deposits with nearly horizontal slopes overlay the Karoo sediments. These deposits are mostly of marine origin and were formed during transgression periods. Sand dunes or quaternary sand deposits cover the entire study area.

Characterisation of the aquifer system

The aquifer system of the region of Maputo is divided into two major units: the sandy aquifer or phreatic aquifer and a deep aquifer of sandstones and limestone with fresh- water, regarded as having good hydraulic potential (Burgeap, 1961). At a local level, the aquifer potential is substantially different for the two aquifers; however, the deep aquifer is the best in terms of strategic groundwater exploitation. The separation between the two aquifers is not clearly defined but for large-scale exploitation of groundwater, the two aquifers can be regarded as a single unit according to findings of IWACO (1983) later confirmed by studies by IWACO (1985), Juizo (1995) and Sweco & Associates (2004).

Groundwater potential

The results of the borehole pumping tests are presented in Table 1. The pumping test results were interpreted using the graphical method of Jacob (Kruesman and Ridder, 1991). The objective was to infer the following parameters characteristic of the groundwater potential: aquifer transmissivity, borehole specific yields and borehole productivity.

For all tested boreholes, the plotted drawdown curve adjusted to the semi-log law (Table 1). This indicates that the aquifer system should be classified as a porous media aquifer in which fractures do not play an important role in the overall aquifer permeability. The aquifer transmissivity was found to be between 40 and 520 m^2/d, which is a reasonably high value for a single sandy aquifer with a depth to the water table of between 10 and 30 m (Table 1).

Borehole specific yield depend on the aquifer setup, but also on the borehole equipment (length and other characteristics of filter screens) and the quality of the gravel pack. Specific yield (discharge for a 1 m^3/h yield) values calculated for the 10 tested boreholes are also presented in Table 1. These were further compared to historical data of the same boreholes and also from nearby boreholes in order to identify possible yield reductions with time. According to the results in Table 2, estimated specific yields for all tested boreholes were found to be within the range of 0.2 to 4.0 $m^3/h{\cdot}m$; these are rather high values for sand aquifers and for low-cost boreholes probably constructed without a gravel pack. The long-term productivity of the tested boreholes calculated from the aquifer transmissivity and borehole specific yields is also shown in Table 1. An estimated borehole lifetime of approximately 3 years and a continuous pumping rate of 24 h/d with a maximum drawdown tolerance of ± 10 m were assumed. The results indicate that all tested boreholes can be exploited to a higher yield than the present one without running into risks of over-exploitation of the aquifer system. The total potential yield for the 10 tested boreholes was 1 772 m^3/d. Eighty per cent of the tested boreholes could be exploited within the range of 100 to 300 m^3/d.

Water quality assessment

Microbial contamination

A total of 35 samples were taken from water provided by SSIPs and analysed for microbial contamination. Results of bacteriological analysis for those sites where bacteria counted in excess of recommended guidelines are resumed in Table 2. Accordingly, 14 out of the 35 sites investigated revealed total coliform counts above prescribed guidelines for human consumption (<3 cfu/100 mℓ), while at four sites, total counts of *E. coli* and faecal coliforms indicated moderate to high levels of contamination by faecal bacteria. In these, faecal bacteria counts were reported to range from as low as 10 cfu/100 mℓ to as high as 240 cfu/100 mℓ, while *E. coli* was found to be present at least at three sites.

The sites with the highest incidence of contamination with faecal bacteria were located in two neighbourhoods north-west of the study area (Sigantela and São Damaso) but also in one neighbourhood located north-east of the study area (Albazine). The results of the microbial analysis with respect to total coliform counts were further mapped (Fig. 3) to indicate the spatial dispersion of contaminated boreholes within the study area. Accordingly, the borehole at Singatela was the one showing the most critical situation in terms of bacterial contamination.

TABLE 1
Productivity and potential yield of tested boreholes

Ref. site	Total depth (m)	Depth to water table (m)	Discharge testing (m^3/d)	Measured drawdown (ΔS; m)	Spec. yield 10^3 sec (S_{1000s})	Trans-mis-sivity (m^2/d)	[a]Qexpl $_{10\ m}$ (m^3/d)
Site 1	25	9.9	32	0.133	6.38	44	41
Site 2	30	12.3	64	0.137	2.46	85	145
Site 3	55	16.9	74	0.120	5.35	113	106
Site 4	30	17.3	77	0.123	1.43	115	245
Site 5	30	16.2	55	0.083	3.58	122	104
Site 6	48	27.4	59	0.073	2.81	147	130
Site 7	35	6.7	28	0.022	0.24	232	304
Site 8	48	27.1	89	0.067	2.50	243	211
Site 9	44	24.6	30	0.017	1.07	332	131
Site10	45	18.5	66	0.023	0.75	518	355
Present yield (m^3/d)			**575**	Potential yield (m^3/d)			**1 772**

[a] *Safe yield for 10 m drawdown after 3 years of continuous pumping*

TABLE 2
Microbial contamination analysis results of boreholes from which positive counts were reported

Ref. site	Location	Bacteria counts (cfu/100 mℓ)			Guideline standard (MISAU, 2004)	
		Total coliforms	Faecal coliforms	*E. coli*	Total coliforms	Faecal coliforms
Site 1	Romão	9	0	0	< 3	0
Site 2	Albazine	4	0	0		
Site 3	Abazine	43	9	0		
Site 4	Albazine	460	28	4		
Site 5	Albazine	4	0	0		
Site 6	Zimpeto	15	0	0		
Site 7	Dlavele	39	0	0		
Site 8	Dlavele	20	0	0		
Site 9	S. Damanso	150	28	1		
Site 10	Singatela	240	240	13		
Site 11	Tsalala	4	0	0		
Site 12	M. Socimol	23	0	0		
Site 13	Khongolote	4	0	0		

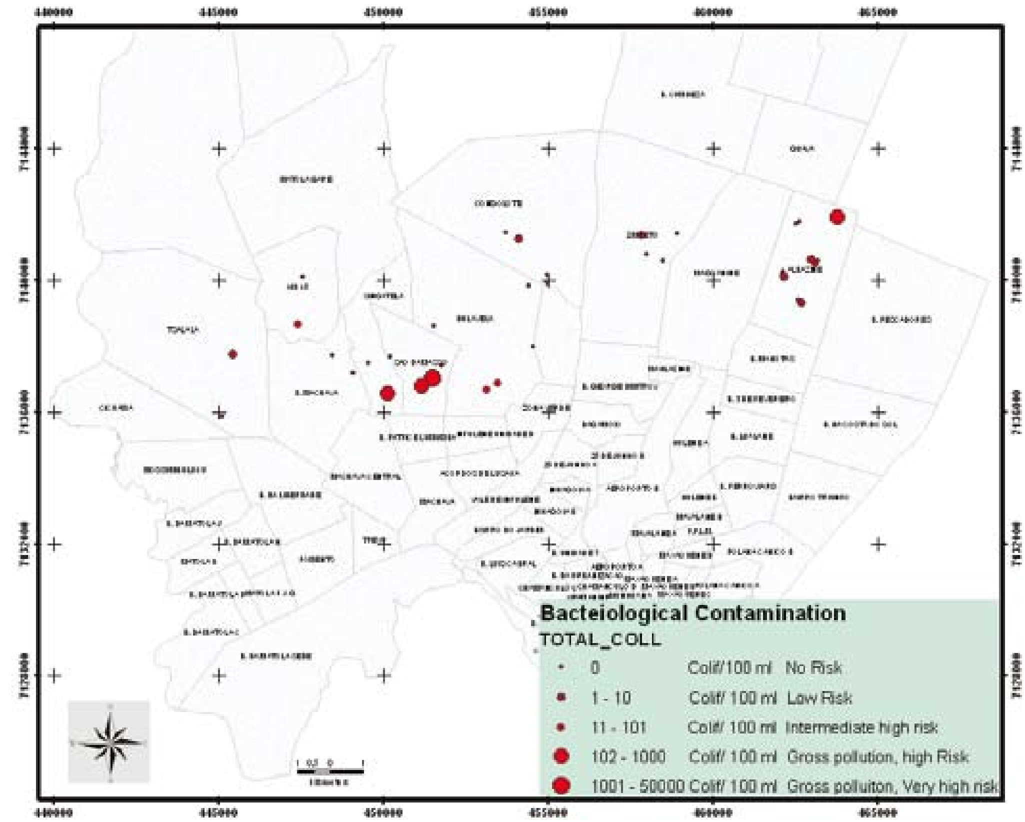

Figure 3
Bacteriological contamination analysis results (total coliforms) of the tested boreholes

Contamination with nitrates

To assess the degree of borehole water contamination with nitrates, results from 12 tested boreholes were used. The locations of sampled boreholes were mapped in Fig. 4. Accordingly, nitrate concentrations in all sampled boreholes were rather low and below the target limit of 45 mg/ℓ set in the guidelines for drinking water quality (WHO, 2004). Reported concentrations ranged from values as low as 3 mg/ℓ to a maximum of 31 mg/ℓ for all tested wells.

The highest nitrate concentrations were reported in boreholes located in areas long established as residential areas (suburbs) of the city of Maputo and thus having moderate to high population densities. These are areas where sanitation is mostly provided by means of cesspits and dry-pit latrines. The area north of the dotted line in Fig. 4 shows the new expansion zones of the cities of Maputo and Matola, and is therefore characterised by low population densities. Here, sanitation is also offered in the form of cesspits and pit latrines. The analysis of the spatial distribution of nitrate concentrations as indicated in Fig. 4 suggested the existence of three distinct areas, namely:

- An area with the lowest levels of nitrates (< 6 mg/ℓ), located mainly in neighbourhoods with low population densities (the northern part of the study area, consisting of the neighbourhoods of Congolote, Zimpeto, Singaleta, São Damasso and KM 15). This also includes areas reported to have a rather shallow groundwater table where the unsaturated zone is relatively thin.
- An area with medium levels of nitrates (10 to 20 mg/ℓ), located mainly in neighbourhoods with moderate to high

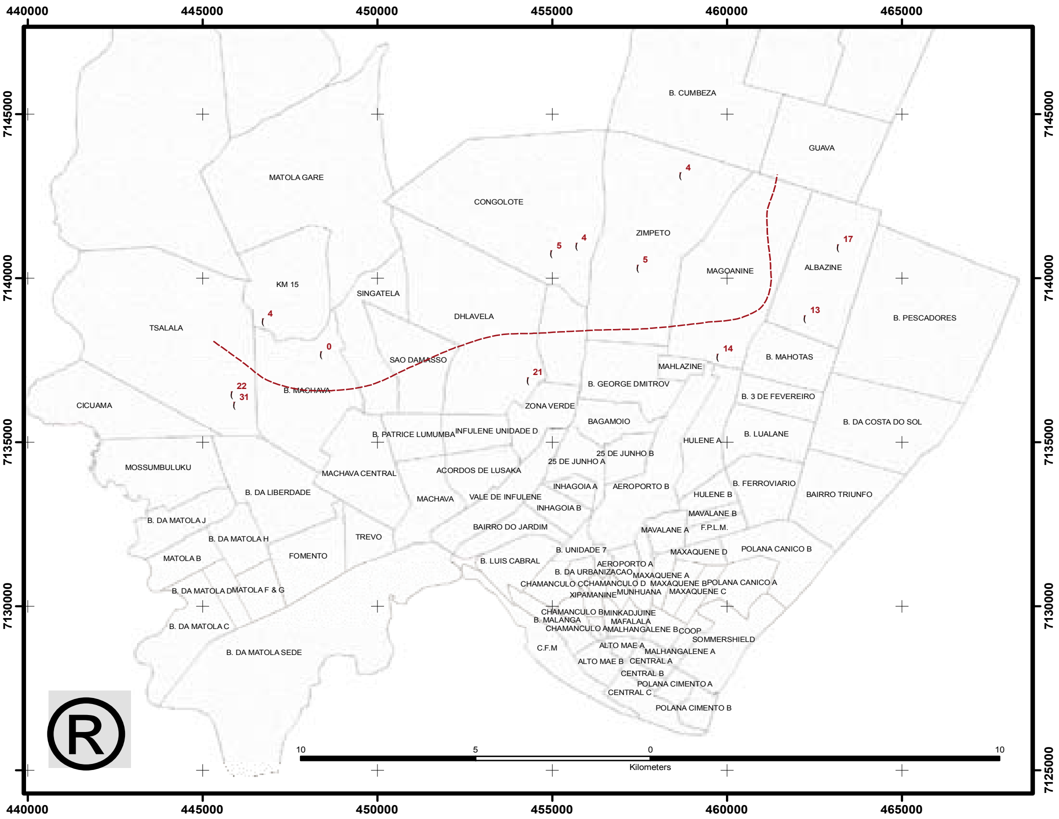

Figure 4
Nitrate concentrations (mg/ℓ) within the study area

population densities (namely the north-eastern neighbourhoods of Magoanine and Albazine), in the aquifer of which a relatively thick unsaturated zone and depth to the water table are reported to exist.

- An area with the highest nitrate levels (20 to 32 mg/ℓ) located mainly in densely populated neighbourhoods (Dlavela and Tsalala).

Electrical conductivity and water salinity

Sea-water intrusion is a very common problem when it comes to groundwater extracted in coastal areas. When aquifers are depleted by high-yield exploitation, sea-water intrusion may occur and the quality of water with respect to its taste is thus compromised. When sea water invades coastal aquifers, the interface position between fresh and brackish water is a function of aquifer properties, pumping rate and aquifer recharge potential. In order to assess the levels of salinity of borehole water used by SSIPs, EC measurements were carried out on samples from 35 boreholes located further north of the study area. The results were mapped and are presented in Fig. 5. Accordingly, only 3 sites were reported to show EC levels in excess of the guideline for drinking water of 1 500 mg/ℓ and hence potentially to contain brackish water. Two sites were located north-west of the study area while the third was located to the north-east.

Discussion of results

Because of the formal water network not reaching most of peri-urban Maputo, SSIPs have, over the past few years, become an integral part of the supply chain of services to the suburbs of greater Maputo. They play the predominant role in service provision to such areas, and the quality of their services is highly appreciated by consumers. Most independent providers operating in greater Maputo are currently unregulated, but important steps have already been taken to change that situation. These include studies commissioned by CRA for the development of regulatory tools to frame their activities, and the joint efforts by CRA and municipal authorities for the formalisation of independent providers (OECD, 2007). SSIPs have also been included as key partners in the recently launched ‘Maputo Water Supply Project’. The demand for services provided by SSIPs is therefore not likely to decrease in the near future. Quality and quantity problems associated with future expansion are likely to constitute the main challenges for the long-term sustainability of SSIP activities.

The typical design of water systems run by SSIPs is based on groundwater abstraction. Consequently, the potential of the regional aquifer system is a key element in the long-term planning of intervention of SSIPs. From the results of borehole testing presented in Table 2, it is clear that most boreholes used by SSIPs are of limited depth (< 60 m) and also, that they tap water at relatively shallow depths to the water table (< 30 m), probably from within the sandy aquifer. The pumping test results also indicate that present yields are generally lower than estimated potential yields (0.2 to 0.4 m^3/h.m); consequently, borehole water can be exploited at even higher yields without risking over-exploitation of the aquifer system. This implies that, within reasonable limits of expansion of small-scale service providers and proper location of boreholes, the risks of an eventual depletion of the aquifer system are small. Also, because the two major units comprising the aquifer system of Maputo can be regarded as one unit (IWACO, 1983; IWACO, 1985; Juizo, 1995; Sweco & Associates, 2004), the yield properties in case of larger abstraction rates will also be determined by the deeper aquifer, which is regarded as having better hydraulic properties and being suitable for large-scale exploitation. In fact, the deeper aquifer is regarded as the main supplementary source for the water supply

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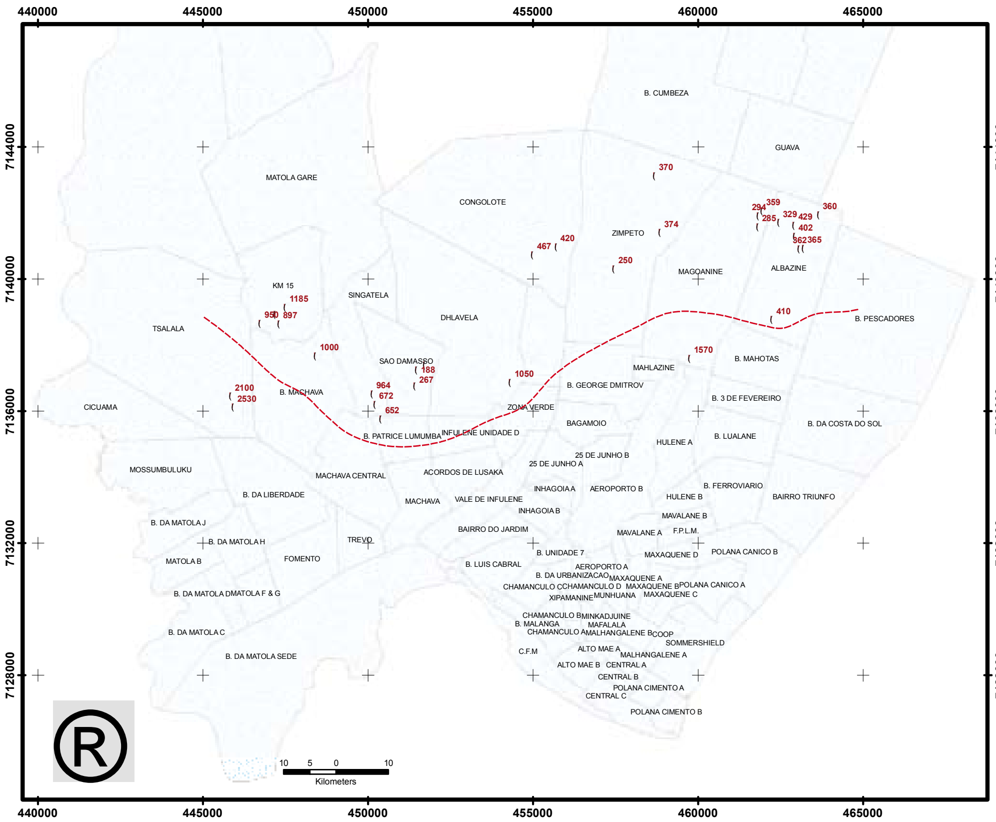

Figure 5
EC levels within the study area (µS/cm). The dotted red line represents the 1 200 µS/cm boundary. All areas located north of the dotted line are suitable for borehole installation.

to the city of Maputo, particularly to the neighbourhoods located north of the city centre.

The results of groundwater quality assessment suggest that, as for today, the quality of water tapped by SSIPs generally conforms to guideline standards (MISAU, 2004; WHO, 2004) with respect to the parameters investigated and therefore poses no constraints on use at domestic level. Yet, none of the independent providers said they treated the water, except when instructed due to problems detected during monitoring intermittently conducted by the Ministry of Health via its Food & Hygiene Department. In fact, the Ministry of Health (MISAU) has in its database about 220 boreholes, the water quality of which is to be regularly monitored; 83 of these are private boreholes run by SSIPs.

The analyses of microbiological quality indicate that, with few exceptions, water from the majority of privately owned systems is virtually free from faecal contamination, as proven by the absence of *E. coli* as well as faecal coliforms in more than 90% of samples investigated. This suggests that as for today, there is no widespread bacterial contamination of the aquifer system used by SSIPs.

Most SSIPs are located within moderately to densely populated residential areas, where sewers do not exist and sanitation is mainly provided through septic tanks, cesspits and dry-pit latrines; therefore, seepage from on-site sanitation represents the most widespread and serious source of pollution (both point and diffuse) to the aquifer system. Since pathogens can survive for many days while percolating the unsaturated strata and eventually through the aquifer system (Sugden, 2006), the major concern regarding poor sanitation is direct migration of pathogenic bacteria and viruses to underlying aquifers and neighbouring groundwater sources (Lewis et al., 1981).

The extent and risk of groundwater contamination depend, however, on many factors, one of which is the degree of pathogen attenuation during percolation through the unsaturated zone and, eventually, through the aquifer system. Some studies (Sugden, 2006; Argoos, 2001; Schmoll et al., 2006) indicate that pathogen attenuation is generally most effective in the uppermost layers of the unsaturated zone, where biological activity is greatest and where the presence of protozoa and predatory organisms, rapid changes in soil moisture and temperature as well as competition from established microbial communities help reduce the level of pathogens in that particular zone and, consequently, in the groundwater.

The distance between the base of pit latrines and water table (also known as soil infiltration layer) plays an important role in the die-off of pathogens. As noted by Sugden (2006) and Schmoll et al. (2006), a soil infiltration layer depth of between 5 and 10 m is sufficient for reducing contamination of the water table by pathogens to acceptable levels.

Because most SSIPs tap their water at depths to the water table of greater than 10 m and pit latrines are built with depths of 1.0 to 1.5 m, sufficient depth is maintained through the unsaturated zone to prevent pathogens from reaching the groundwater table. The horizontal distance between pit latrines and water wells will also have an impact on levels of contamination.

The soil type and permeability characteristics of the unsaturated zone and aquifer system are also important factors, since they impact residence times in the unsaturated zone and prevent the passage of bacterial pathogens into the subsurface. High soil permeability is associated with high risks of pathogens reaching the groundwater table. According to the literature (Schmoll, 2006; Lee and Bastermeijer, 1991), residence times of about a month are long enough to free groundwater sources from pathogens naturally. Long residence times in the unsaturated zone are associated with low risks of groundwater contamination. Seasonal variations of the groundwater table, e.g. due to rainfall, increase the risk of pathogens seeping into the groundwater. Godfrey et al. (2004), Pujari (2007) and Howard et al. (2003)

have all reported significant increases in faecal contamination of groundwater following rainfall events.

Construction and completion details of boreholes are also crucial factors in that they may increase the risk of groundwater contamination by creating localised pathways for ingression of pathogens (Schmoll, 2006; Godfrey, 2005) or by shortening the distance and time required for pathogens to reach the groundwater table (Argoos, 2001). The deeper the filter screen, for example, the longer the time required for pathogens to reach the aquifer system and the higher the die-off rate.

The results of the geohydrological characterisation of the aquifer system used by SSIPs in Maputo suggest that the aquifer system does not have any natural barrier against pollution; this means that contaminants disposed of on the surface or seeping from pit latrines can percolate relatively freely across the unsaturated stratum and readily reach the groundwater system. The results of this study indicate, however, that the incidence of contaminated wells is rather limited, which suggests that either the load of contaminants is rather limited or that the ingress of pathogens is still being sufficiently attenuated in the unsaturated strata underlying the aquifer system. Yet, 13 out of the 35 tested boreholes had either total coliform or faecal coliform levels higher than the WHO standard which suggest that other paths of contamination may probably have occurred.

The most critical situation with respect to faecal contamination was found to be related to an open hand-dug well (in São Damanso) where faecal coliform counts as high as 240 cfu/100 mℓ were reported. Open hand-dug wells are usually constructed in areas with relatively shallow groundwater tables, where the proximity of the groundwater table facilitates the transport of contaminants; consequently, contamination with bacteria could be widespread. For example, a study conducted in rural Zimbabwe (Dzwairo et al., 2006) has shown that pit latrines constructed at less than 2.0 to 3.0 m above the water table affected the groundwater quality at lateral distances of up to 25 m. However, it appears as though this is not necessarily true; in the very few cases where contamination with bacteria was reported, the problem appeared to be related to borehole construction and siting rather than to percolation of contaminants. This is in line with findings from a study by Howard et al. (2003) on water quality variations in shallow protected springs in Kampala, who concluded that improving the sanitary finishing of wells and of local environmental hygiene is more important to protect groundwater quality than controlling wide-spread construction of on-site sanitation facilities. The situation of the contaminated wells identified in this study should therefore not be considered as representative of all SSIPs located within the study area, nor as a common critical aspect of this type of water systems.

The area located north-east of the city (Albazine) where moderate to high levels of bacterial contamination were also reported, is a densely populated area. The depth to the water table, as measured in nearby boreholes where pump tests were performed (sites 8 & 9), suggests that rather thick strata of the unsaturated zone exist (> 25 m). The problem here is attributed either to poor borehole construction or high hydraulic load from pit latrines. Improper location of pit latrines may also be a contributing factor. The area also experiences high recharge conditions and relatively good permeability rates (IWACO, 1985); hence, there is a high potential for bacterial contamination due to percolation. Low living standards, poor borehole construction and high hydraulic contaminant loads are therefore the most probable causes of the high incidence of bacterial contamination reported in these boreholes.

The presence of nitrates is a common groundwater problem (WHO, 2004). Although nitrogen may occur naturally in groundwater, the main sources of groundwater pollution are human activities such as agriculture, sanitation (pit latrines) and accumulation of organic material from improper solid waste handling (Boulding and Ginn, 2003; Schmoll et al., 2006; WHO, 2004). The WHO guideline for the presence of nitrates in drinking water is 45 mg/ℓ. The peri-urban area of Maputo is lacking formal waste collection services and sanitation is mainly provided by dry-pit latrines. Dwellers, on the other hand, usually burn their waste in the garden, thereby reducing the source of diffuse pollution from solid waste handling and leaving seepage from pit latrines as the main source of nitrogen that could potentially pollute the groundwater.

High levels of nitrate are a major problem for bottle-fed infants, as the risk of methaemoglobinaemia increases when nitrate concentrations rise above 50 mg/ℓ (WHO, 2006; Thompson et al., 2007). Factors such as hydraulic loads, soil type and depth to the water table determine the rate and extent of nitrate transport into the groundwater. Sandy soils are particularly vulnerable to nitrate leaching into the groundwater because of the limited attenuation they provide (Thompson et al., 2007). Rainfall also affects nitrate transport into aquifer systems. If the water table is too shallow, there is a great risk of high concentrations of nitrate occurring after a relatively short time, particularly after heavy rainfall.

The results of nitrate analyses for sampled boreholes (Fig. 4) suggest that nitrate levels were always below the WHO guideline value of 45 mg/ℓ for drinking water. Accordingly, three distinct areas can be distinguished:

The area north of the study area where the lowest nitrate concentrations (< 6 mg/ℓ) were reported, covers mainly neighbourhoods with low population densities and thus with relatively low hydraulic loads potentially harmful to the groundwater. It includes zones where the unsaturated zone is rather thin (less than 10 m) and so features a limited capacity for attenuating any nitrate loads leaching from pit latrines. This leaves hydraulic loads as the main factor determining the levels of nitrates in the groundwater, thereby supporting the idea that, presently, levels of groundwater contamination in this area are determined principally by population density.

The area with moderate concentrations (10 to 20 mg/ℓ) is located mainly in neighbourhoods with moderate to high population densities and where a relatively thick stratum of the unsaturated zone exists. The moderate levels of nitrates observed in this area are probably the result of moderate hydraulic loads from pit latrines, combined with a rather limited capacity of the unsaturated zone for preventing the ingress of pollutants due to its relatively high permeability. The area with the highest nitrate concentrations (20 to 30 mg/ℓ) is located in densely populated neighbourhoods. High hydraulic loads from cesspits and pit latrines are certainly the major nitrogen contributor to the groundwater system.

The spatial distribution of nitrate concentrations in the study area thus suggests that population density and the characteristics of the unsaturated zone are the main factors determining present nitrate levels in the groundwater. Present contamination levels were still below critical levels for safe use of the groundwater, a state of affairs that was believed to result from:

- Still limited hydraulic loads due to low population densities (< 100 persons/ha) even in areas considered as densely populated
- Relatively thick soil infiltration layers in areas where the majority of boreholes were located and where biological denitrification may possibly occur.

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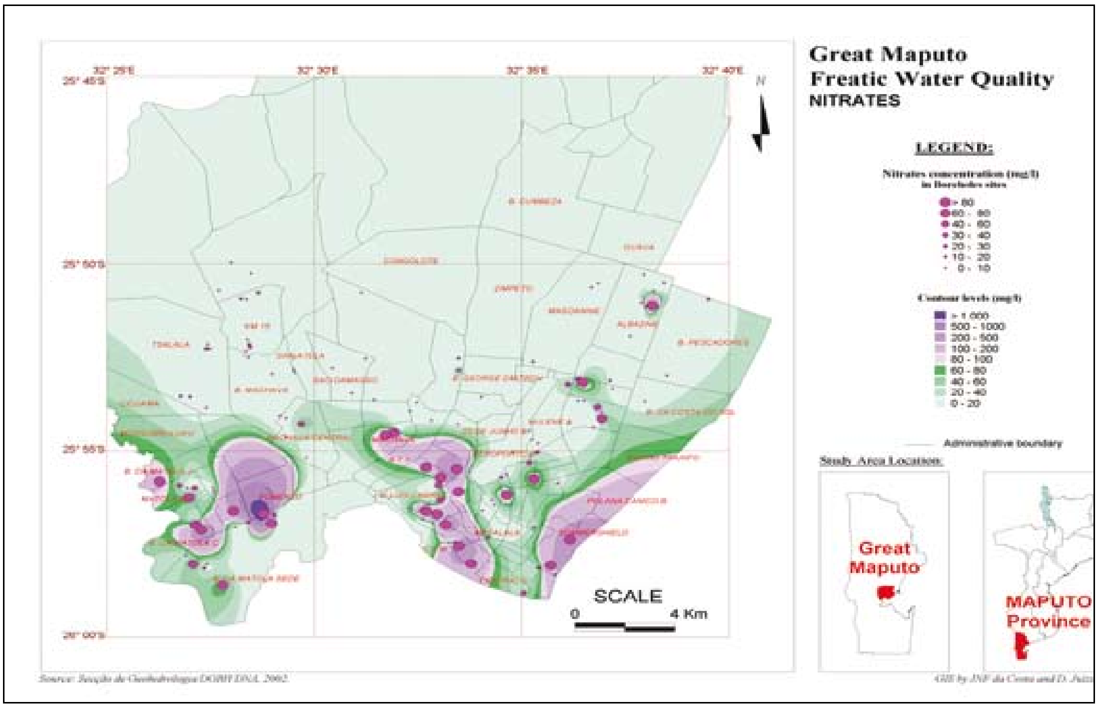

Figure 6
Nitrate concentrations in the neighbourhoods of Maputo based on historical data

An analysis of the spatial distribution of nitrate concentrations based on historical data collected in other, more densely populated neighbourhoods of Maputo (Fig. 6) indicates that nitrate levels in groundwater can be as high as 500 mg/ℓ, which means that contamination by nitrates is a real threat in some neighbourhoods. This is also confirmed by results of similar studies done in other parts of the study area (IWACO, 1984; Juízo, 1995) where nitrate levels of as high as 300 mg/ℓ in the groundwater were reported.

Sea-water intrusion is a common groundwater quality problem in coastal areas. The WHO guideline for EC in drinking water is 1 500 as/cm. Studies with the purpose of assessing the problem of sea-water intrusion in the Maputo and Matola areas (IWACO, 1985) have concluded that such problems are more severe in the south-western part of the city (Matola, Fomento, Cicuama) than in other parts of the city. The occurrence of brackish water has, however, been recorded in some other areas located north-east of the city and close to the Maputo bay, namely the 'bairros' Pescadores, Costa do Sol and Hulene A. While the results of the present study suggest that, as for today, the majority of surveyed sites do not face problems with brackish water, the nature of the geological formations suggests that the area is vulnerable to sea-water intrusion, particularly if the aquifer system should become over-exploited.

Conclusions

SSIPs have become an integral part of the water services delivery chain to the peri-urban areas of greater Maputo, where they are reported to reach as much as 32% of the population. They are presently expanding rapidly to cover new or already established neighbourhoods, not only because of increasing demand resulting from the lack of formal services in such areas but also because they have recently been recognised as important partners for expanding service coverage to reach unconnected residents. The expansion of services with the help of both self-financed and formally delegated small-scale service providers, however, comes with a number of issues deserving urgent attention, among which their capacity for providing quality water of sufficient quantity in the long run.

An analysis of the potential of the aquifer system from which SSIPs tap water to render their services suggests that present yields in general are lower than estimated safe yields and that borehole water can be exploited at higher than the present yields without running into risks of over-exploitation of the aquifer system. This implies that, within reasonable limits of expansion and proper location of boreholes, the expected increase in the number of SSIPs will not lead to an eventual depletion of the existing aquifer system. Yet, care must be taken to ensure that quality problems will not arise due to increased abstraction rates.

So far, the quality of water used by SSIPs to provide services has been virtually free from microbial and organic contamination. Two major factors contribute to this, namely limited hydraulic loads due to low population densities and relatively thick strata of the unsaturated zone, where attenuation of contaminants still occurs at sufficient levels. Yet, 13 out of 45 tested boreholes had total coliform levels above the WHO recommended standard and 4 had faecal coliforms in excess of the standard. Low living standards, poor borehole construction and high hydraulic loads were the probable causes of the high incidence of bacterial contamination in those boreholes.

Nitrate concentrations in all boreholes tested were below the recommended standard of 45 mg/ℓ. However, the situation may change in future, either due to over-exploitation of the aquifer system or to increased hydraulic loads resulting from increased population density.

No problems with brackish water were reported in large parts of the studied area, but in future this could become a serious problem because of the high vulnerability of the aquifer system (coastal aquifer) to sea-water intrusion.

While the potential for development of SSIPs is high, based on demand and the characteristics of the aquifer system, the long-term sustainability of their activities require that efforts be put in place to speed up the already initiated attempts at formalising small-scale independent providers and to establish regulatory tools to frame their activities. In doing so, pressure must be put on authorities to establish mechanisms that will ensure the adoption of more stringent protective measures for boreholes constructed to provide public services, including:

- Regulated procedures for borehole design and location in order to minimise risks of contamination. Special emphasis should be put on aspects such as wellhead protection, positioning of filter screens and the location of boreholes in relation to existing pit latrines. A minimum radius of influence 25 m away from pit latrines is generally accepted in Mozambique.
- Mandatory rules for direct protection of boreholes used as drinking water supply (e.g. a 5x5 m surrounding fence)
- Mandatory rules for SSIPs regarding chlorination of the water before distribution.

Because most independent providers tend to tap water at relatively shallow depths to minimise investment costs, enforcement rules regarding minimum depths of abstraction could also be put in place.

Overall it can be said that SSIPs provide a valuable contribution to overcoming the problems with drinking water supply to peri-urban areas experiencing rapid growth; however, it is imperative that the governmental institutions and already established regulatory bodies put in place mechanisms to reduce the possibilities of future public health risk associated with these systems.

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