Water resources management in Maldives with an emphasis on desalination

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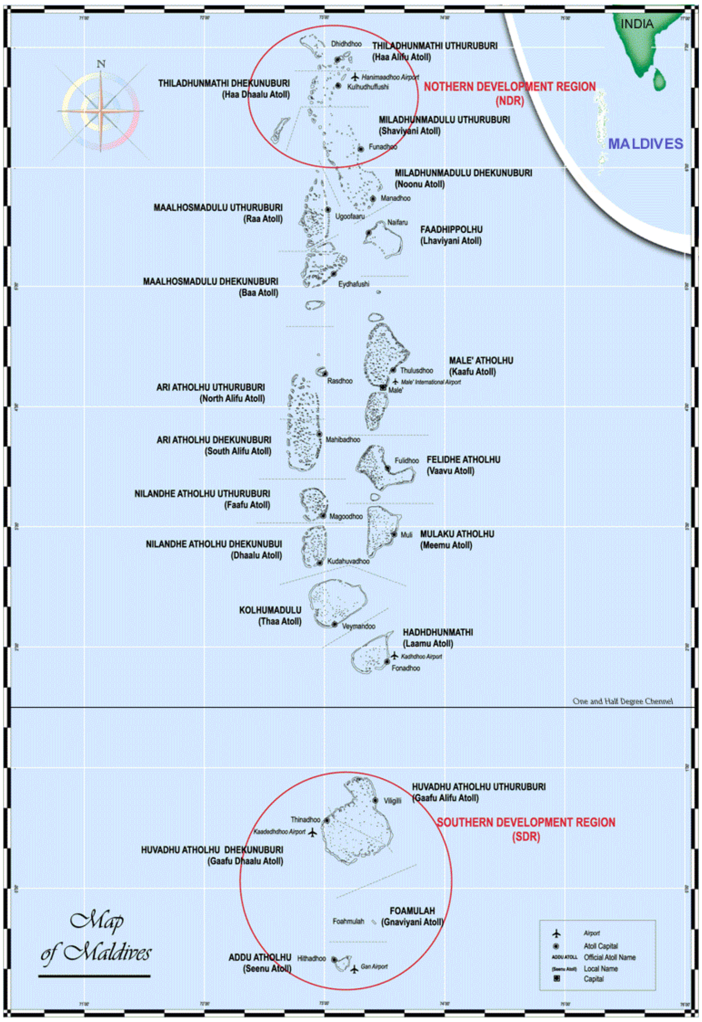
Abstract

A brief introduction describes Maldives geography and water resources and the recent history of water supply and sanitation in both the capital, Male', and the rural islands. The use of rainwater harvesting and the available groundwater resources are described, and the vulnerability of the country's groundwater resources is stressed. Particular emphasis is given to the issues of poor sanitation, highly permeable soils, over extraction and high population densities. The reasons for desalination becoming necessary are made clear, and the experiences with desalination both in Male' and other islands are set out. Finally, the possibility of using desalination as a means of providing safe water on other densely populated islands is discussed.

Introduction

Maldives' geography and water resources



The Republic of Maldives is a chain of nearly 1900 tiny coral islands, which are grouped into 26 geographic atolls that together form a chain 820 km in length and 130 km at its widest point set in an area of more than 90,000km^2 of the Indian Ocean. However, the total land area is less than 300km^2. The island archipelago is located approximately 500km southwest of India. Amongst these only 200 islands are inhabited, 87 islands are used as resorts, a few are used for industrial/agricultural purposes and the rest are uninhabited. The elevation of the highest point in most islands is less than 2m above sea level. The 26 geographic atolls are grouped into 20 administrative 'atolls'. These are labeled in Figure 1. In the top right corner is a map showing Maldives position in relation to India and Sri Lanka.

Figure 1. Map of Maldives

The population of the Maldives is about 270,101 (Census 2000). About a quarter of the population live in the capital island of Male' which has a population of 74,069 and the remaining population is scattered over 199 other islands. In addition to its permanent population, Male' also has a floating population of several thousand who arrive from the outer islands mainly for commercial, education and medical purposes. Maldives' population is growing at an annual rate of 1.9% (Census 2000).

The climate is tropical, warm and humid all year round with a mean annual temperature of 28.0 C and an average relative humidity of 80%. The mean annual rainfall in Malé is approximately 1980 mm. Rainfall is evenly distributed throughout the year, except between January and April when dry periods of two months are common. Open water evaporation and transpiration from vegetation are very high.

There are no rivers or streams in any of the islands of Maldives, and only a few wetlands or freshwater lakes. The country's freshwater resources exist as groundwater in basal aquifers, generally unconfined in nature and extending below sea level in the form of a thin fresh water lens. They are vulnerable to saline intrusion owing to the freshwater-seawater interaction and need to be carefully managed to avoid over-exploitation.

Maldivians depend mainly on rainwater for drinking and groundwater for most other domestic needs. Rainwater is tapped from roofs and collected and stored in various types of tanks. All the islands have individual household as well as community tanks. However, the situation is different in the capital island Male' where the whole population has access to desalinated water distributed through a piped network. In Male' it is common for people to use desalinated water for drinking as well as for domestic purposes due to high contamination of groundwater. As in Male', many islands are now facing groundwater problems caused by human activities such as over abstraction and sewage pollution.

The need to meet water demand by sustainable and affordable means is of paramount importance to the people of the Maldives. However, there are a number of densely populated islands where it may not be possible to rely totally on natural resources and where the need to go for the expensive alternative of desalination to supplement resources may be inevitable. This has been the case in the capital, Male', and in the most densely populated island, Kadholhudhoo.

The development of sustainable water supplies can only be achieved through integrated methods. It will be practically impossible and unsound to rely on only one source. The solution will be a combination of developing groundwater resources and rainwater harvesting. Desalination is considered as an expensive alternative in Maldives, but one that is necessary in some islands. Desalination is widely used in the 87 tourist resorts. These are islands set aside solely for tourists, and each island has its own small desalination plant. This is only an affordable option because the islands are generating substantial revenue from the tourists.

Recent history of water supply and sanitation in Male'

Traditionally, people have used water from mosque wells and other designated wells for drinking purposes. Access to safe water has been a major problem for the people of Maldives. The 19th Century historian H.C.P Bell identified the risk of groundwater contamination due to poor sanitation and recommended the development of rainwater tanks (Bell, 1883). The first rainwater tank for the public was built in Male' in 1906 and a second in 1909 with a total capacity of 96,975 litres. The yield of 1,485 litres per day was sufficient to support the population at that time.

The 1970s

In 1972 the population of Male' was 15,279. Because of the rapid development of Male', with respect to other islands, people from other islands started migrating to the capital resulting in an unnatural population boom. The quantity of water drawn from Male's aquifer increased tremendously, and also with more sewage being disposed off into the ground made it more susceptible to groundwater pollution. Water borne diseases such as diarrhoea, cholera, shigella and typhoid started spreading due to poor sanitary conditions.

In response to this problem, a special office, Maldives Water and Sanitation Authority (MWSA) was established in 1973. By then the population of Male' had increased from 15,279 in 1972 to 29,500 in 1974. A Binnie and Partners (1975) study carried out in Male' for MWSA revealed about 1.3 million litres of water were being used from the aquifer daily, the thickness of the fresh water lens was reduced to about 12m and there was rapid deterioration of the groundwater quality due to this increased population and poor sanitary conditions. Outbreaks of cholera in 1978 and shigella in 1982 claimed many lives. As a result, the Male' Water Supply and Sewerage project was conceived.

The 1980s

Detailed surveys were carried out in 1980/1981 by consulting engineers Binnie and Partners. Subsequently, with assistance from West German Aid, the Saudi Fund for Development and the European Commission, the Government implemented the Male' Water Supply and Sewerage Project in 1985.

Under the project, the following work was carried out in Male' between 1985 and 1988:

?? 8 boreholes were drilled to investigate the aquifer and for subsequent monitoring.
?? Large steel tanks were installed for storage of rainwater with a total capacity of 9900 m^3.
?? Water from these tanks were pumped into a holding tank (600 m^3) and later distributed from a water tower (95 m^3) by gravity and distributed at 30 tap bays free of charge at selected hours.
?? 1154 household tanks were built with a total capacity of 4157 m^3.
?? New wells were sunk in mosques and disinfected well water was fed to tap bays located at the same place, and distributed to the public free of charge throughout the day.
?? A sewerage scheme was built for the whole island of Male'. Sewage flows by gravity to sumps located in 9 areas and is pumped from pumping stations into the deep sea without treatment through 6 outfalls located at 4 different places.

The 1990s

Still the population of Male' continued to grow and increasing pressure was placed upon the island's freshwater lens. Though the new sewerage scheme helped to alleviate the pollution of the lens by septic tanks and soakaways, it contributed to another problem. The increased volumes of groundwater being used to flush toilets were no longer returning to the aquifer but were being discharged to the sea. The salinity of the aquifer increased sharply as a result, limiting its usefulness as a resource. Because the available roof catchment area and the space available for rainwater storage was too limited to provide for Male's increasing population, desalination became one of the few options available for providing sufficient safe water for Male'.

In 1988 the first desalination plant was installed. With assistance from the Danish aid agency, Danida, a reverse osmosis plant with a capacity of 200 m^3/day was installed. More plants have since been installed to cater for the demand and at present there is the capacity to produce 5000 m^3 of desalinated water per day.

In 1995 a joint venture company, Male' Water and Sewerage Company (MWSC) was formed. The responsibility for the operation and management of water supply and sewerage services in Male' was handed over to MWSC. The Maldives Water and Sanitation Authority became responsible for regulating this company, though it retains responsibility for providing services to the other inhabited islands.

Recent history of water supply and sanitation outside Male'

Government has a policy towards ensuring all inhabited islands have water supplies that meet basic requirements. At present investment in the other islands is being made in rainwater collection so as to develop a consistent supply of safe water for drinking and cooking purposes. Efforts are being undertaken to improve the water supply in the atolls mainly by enhancing community rainwater collection and storage facilities and encouraging individual procurement of household rainwater tanks. The objective of the Government is to provide access to 10 litres per person per day (L/p/d) of safe water for drinking and cooking for the whole population and in islands where groundwater is unfit for any potable use to provide 40 L/p/d (Health Master Plan, 1996-2005).

In only one island outside Male' has it been necessary to install a desalination plant. Kadholhudhoo is the most densely populated island in the country, with over 600 persons per hectare. It has experienced similar problems to those in Male'. A freshwater lens polluted by poor sanitation facilities and depleted by over-extraction, coupled with insufficient space to collect enough rainwater for the island's population has left little alternative but desalination. The experience with desalination in Kadholhudhoo has been quite different to that in Male', and this is discussed later in the paper.

In the resort islands, desalinated water has been used since the late 1970's. Each island has its own small desalination plant. Bottled water is generally used for drinking while desalinated water is used for cooking and bathing. Rainwater is sometimes collected for staff to drink, and groundwater is sometimes used for irrigation, though neither resource is used to its full extent. On a few resorts treated wastewater is used for irrigation.

Freshwater Resources: Availability and Vulnerability

The following section of the report focuses on the situation on the inhabited islands outside the capital Male', where the two main water resources are groundwater and rainwater. In these rural islands, people generally use rainwater for drinking and cooking and groundwater for other purposes.

Rainwater Harvesting

Rainwater is collected and stored in different types of tanks (made of steel, ferro-cement, High Density Polyethylene - HDPE and fibreglass) of various sizes. Each islands has both community tanks and private household tanks. The Ministry of Health with the co-operation of various funding agencies has provided since 1984 more than 1,700 ferrocement rainwater tanks of 10 m^3 capacity and more than 3,000 tanks of 2.5 m^3 capacity.

After the introduction of HDPE tanks to Maldives in 1994, these types of tanks have been in great demand due to their ease of maintenance and high durability. From 1994 to December 2001, 785 community HDPE tanks (capacity of 5,000L each) have been provided through government funding and 4,350 HDPE tanks of different sizes (1,500L, 2,000L and 2,500L) have been provided to households on a cost recovery basis under a revolving fund scheme. Following the success of this scheme, HDPE tanks are now being provided by various government ministries and are also available in the market.

Despite the success of this scheme, in some islands many houses still do not have rainwater tanks. The situation varies widely between islands and between regions. Some islands like Muli, the capital of Meemu Atoll in the South Central region, more than 80% of households have rainwater tanks while in others like Ribudhoo, in Dhaalu Atoll less than 100km to the west of Muli only 20% of households have them (MWSA, 2001*)*. In the South region 69% of households have rainwater tanks and in the South Central region the percentage is only 36% (MICS survey, MoH-UNICEF, 2001) Even where rainwater tanks are available there are often problems during the dry period either due to there being insufficient capacity or catchments area being too small.

Beswick (2000) calculated the roof areas and storage volumes necessary to supply 10 L/p/d of water (see Table 1). The calculations were based on 14 years of daily rainfall data and showed that roof areas between 24 and 36m^2 and tank volumes of between 2000L and 4500L could supply household sizes of 4-10. For example a household of 8 people would require a tank of 4000L capacity with a roof area of 36m^2.

Household Size (Persons)	Roof Area (m^2)	Tank Size-(Litres)	Supply (L/p/d)	Percentage of Supply Caught
4	24	2000	10	42%
6	24	2500	10	61%
8	24	5000	10	86%
8	36	4000	10	55%
10	36	4500	10	67%

Table 1. Rainwater Tank Sizing

The values in the table point to the fact that although a significant part of the country’s drinking water demand can be met from rainwater by increasing the capacity of rainwater collected, the vast majority of demand, which is for non-potable use, has to be met from alternative sources, namely, groundwater. These groundwater resources are in fact vulnerable to pollution and to increased salinity. Where these have been depleted and degraded in quality, as the brief history of Male’ illustrates, desalinated water has become necessary.

Groundwater Resources

Although Maldives has few surface water resources, in the form of freshwater lakes known as *kulhis*, and although rainwater is harvested and stored in household and community rainwater tanks, the vast majority of the country’s water resources are stored as groundwater.

The country’s islands are very low-lying – there is no point in the country higher than 2m above sea level – and the water table is found at very shallow depths - usually no more than 2m below the ground surface. In addition, the freshwater lens on each island is usually very thin. The thickness of this lens depends upon the rate at which it is replenished by rainfall, the size of the island, the soil permeability, rates of abstraction and changes in sea level. In Figure 2 below (which shows the approximate relationship between island width and freshwater lens thickness for the 11 islands in the Northern Development Region) we can see that the freshwater lens is rarely more than 12m in depth.

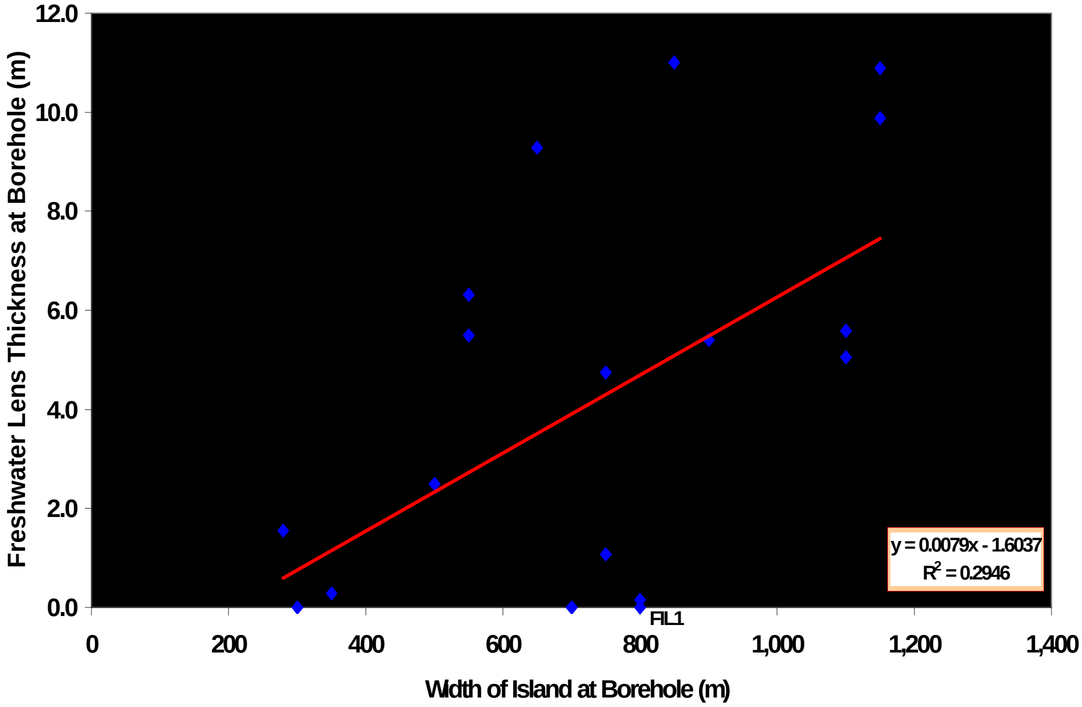


Figure 2. A graph showing the relationship between island width and freshwater zone thickness illustrates the relatively thin freshwater lenses in Maldives' islands (from Falkland, 2001a)

The 11 islands in the Northern Development Region are fairly typical of Maldives' 200 populated islands. The island of Gan in Addu Atoll (one of five islands in the Southern Development Region) has a freshwater lens which is around 20m deep. As Gan is one of the Maldives' largest islands, this is possibly one of the thickest freshwater lenses in the country. On the vast majority of islands, the freshwater lens is less than 12m in thickness. In fact, in populated islands groundwater is often used at a rate which exceeds the sustainable yield. As a result, lenses have reduced to less than 2m in thickness, as is the case in 7 of the 18 boreholes measured in the Northern Development Region and plotted above.

Maldives' groundwater resources are therefore vulnerable in a number of ways. Because the water table is found at such shallow depths, they are particularly prone to pollution from the human activities that take place on the surface. In addition, because the lens is often of very limited thickness, the groundwater resources are prone to increased salinity as a result of over-extraction. In addition, sea level rises which have occurred during the last decade as a result of global warming have also increased the chances of saline intrusion taking place, and therefore pose an increasing threat to Maldives' groundwater resources.

Groundwater pollution from poor sanitation

Maldives' groundwater resources are especially vulnerable to pollution from human activities that are taking place above them. Fortunately, there are relatively few heavy industries outside the capital Male' and intensive agriculture occurs in only a couple of islands. The major source of groundwater pollution is poor household sanitation.

Outside the capital, Male', the majority of households have septic tanks and soakaways. The tanks are often poorly built or have suffered from hydrogen sulphide corrosion and are prone to leakage. In addition, tanks are desludged infrequently. As a result, tanks are often full or nearly full of sludge and have very short retention times. Soakaways are usually deep pits, not shallow trenches. Rather than use the unsaturated soil above the water table to remove at least some of the pollutants from the septic tank effluent, they effectively create a shortcut for septic tank effluent to reach the groundwater below.

These factors combine to cause the contamination of groundwater resources by septic tank effluent. This effluent still has relatively high suspended solids and nutrient concentrations, and contains large numbers of pathogens.

Highly permeable soils encourage pollutant transport

The soils of Maldives' islands are formed in the most part from very permeable coral deposits. Although in vegetated areas the upper parts of the soil profile contain organic material, the areas in which people live and in which poor sanitation systems affect the groundwater have usually been cleared of vegetation. As a result, the soil is a fairly uniform sand, with a very high permeability. In these conditions groundwater movement can be quite rapid, and so pollutants can be transported over large distances.

Each household has its own well. Well water is generally used for bathing but during the dry season, where rainwater storage is insufficient, well water is sometimes used for cooking and drinking too. Where groundwater is commonly found to be polluted by pathogens, this can obviously have a significant impact upon health.

The Government of Maldives has built sewerage systems on several of the most densely populated islands to try and alleviate this problem. Some island communities have built their own sewerage systems. Although these systems have improved the situation, the majority of Maldives' households are still using groundwater polluted by pathogens.

High demand for groundwater leads to increased salinity

As stated previously, Maldives' groundwater is not only vulnerable to pollution but because the lens is relatively thin it is also vulnerable to increases in salinity where over-extraction takes place. Although the problem can be increased by the use of electric pumps, over-extraction can even occur where simple *dhanis* are being used to extract water from household wells. According to Falkland (2001b), water consumption per capita outside of Male' is somewhere between 80 and 110 L/p/d depending on the type of toilet that is used. In Male', according to a report by Carl Bro International (1991), water consumption is approximately 126 L/p/d as a result of water being piped into households. Despite the relatively low consumption for the rural islands, over-extraction can still occur by virtue of the high population densities found on some islands, and increased salinity can result.

Water consumption outside Male’	
Drinking and cooking	10L/p/d (potable)
Sanitary cleaning and toilet flushing	
If pour flush toilet being used:	20L/p/d
If cistern flush toilet being used:	50L/p/d
Bathing	40L/p/d
Dishwashing	6L/p/d
Clothes Washing (average daily)	4L/p/d
Total	**80 L/p/d with pour flush toilet** **110 L/p/d with cistern flush toilet**

Table 2. An estimate of water consumption in the rural islands (from Falkland, 2001b)

During the dry season, which is generally held to last for three months from January to March, there is no recharge by rainfall yet groundwater extraction continues at the same rate. As a result, freshwater lenses are gradually depleted and seawater can often encroach upon the islands periphery. Studies show that the groundwater at the periphery of many islands to be very saline. In some islands this saline groundwater region extends some way inland.

Problems exacerbated by high population densities

The problems of pollution and over-extraction described are exacerbated by the high population densities found on some islands. A rough calculation of the population density which can be supported by a typical freshwater lens in the Maldives is set out below. Assume that:

?? Rainfall is approximately 1,980mm annually
?? Average recharge is approximately 40% of rainfall
?? Sustainable yield, say 30% of average recharge = 238mm per year
?? Sustainable yield per hectare = 0.238 x 10,000 = 2,380 m^3 (=2,380,000 litres) annually
?? If consumption is assumed to be 95 L/p/d (= 34, 675 litres per person annually), then the average island can support a population density of up to 69 persons/ha.

Island	Area (hectares)	Population (2000 census)	Population density (persons/hectare)
R. Kadholhudhoo	4.40	2650	602
Lh. Hinnavaru	7.24	3156	436
K. Male’	187.00	70278	376
B. Thulhaadhoo	4.97	1822	367
Sh. Komandoo	5.96	1526	256
Lh. Naifaru	14.27	3570	250
M. Dhiggaru	4.61	872	189
M. Maduvvari	3.10	455	147
K. Gulhi	5.50	613	111
B. Eydhafushi	22.20	2379	107

Table 3. The ten most densely populated islands of the Maldives

The 10 islands set out in Table 3 have population densities exceeding 100 persons/hectare. Unsurprisingly, these islands have experienced problems with the salinity of their groundwater resources as a result of over-extraction. They have also experienced severe problems with pollution of their groundwater resources from poor sanitation.

In 1974, a study by Binnie and Partners of Male's groundwater found the salinity (measured in electrical conductivity or EC units) to range between roughly 750 µS/cm at the centre of the island and 2,500 µS/cm at the periphery. A 2001 study by MWSA found the salinity to have increased to the point where EC is as high as 35,000 µS/cm (70% seawater) at the centre of the island (see Figure 3). Table 4 shows how the thickness of the freshwater lens depleted rapidly during the relatively short time period between 1983 and 1999. These measurements were taken from the boreholes installed for the Male' Water Supply and Sewerage Project (note that in borehole 5 the thickness was initially greater than the 12m found by Binnie and Partners in 1975).

Monitored borehole	**Thickness of the Freshwater Lens (m)** Where freshwater is defined as EC < 2,000µS/cm		
	1983	**1986**	**1988-1989**
3	2.5	0.8	0.4
4	11.0	6.3	2.7
5	>15.0	8.8	6.7
6	6.7	7.5	2.3
8	3.8	2.6	1.5
9	-	-	1.2
Average	7.8	5.2	2.7

Table 4. Thickness of freshwater lens in monitored boreholes in Male' (from Ranta-Pere, 1990)

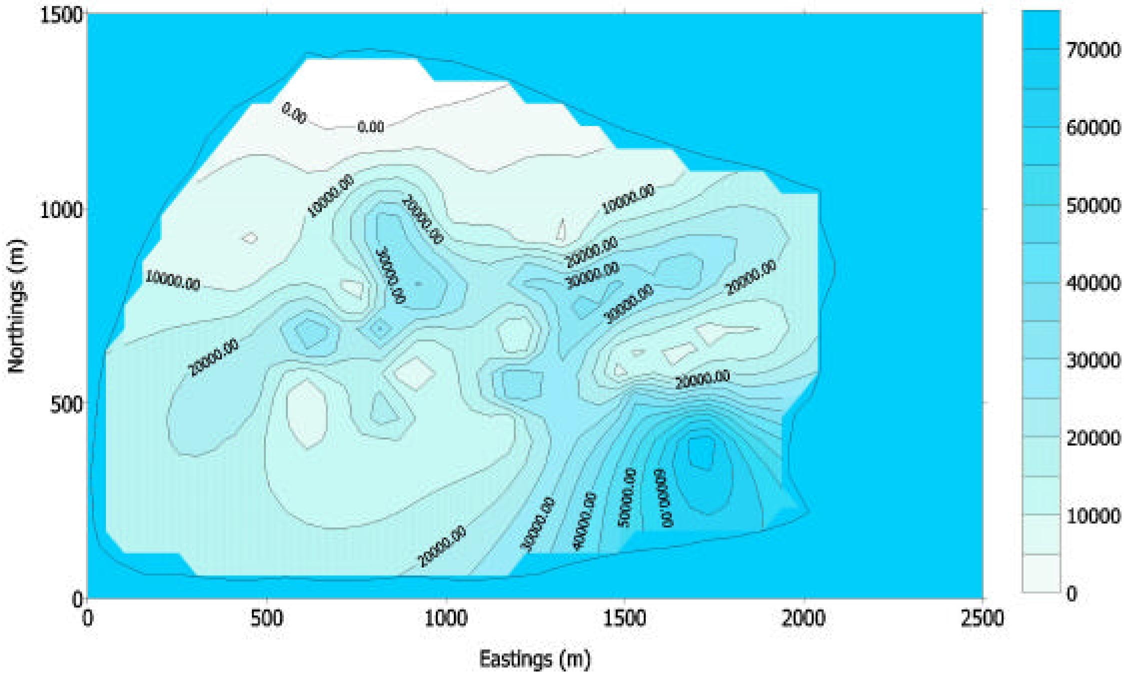


Figure 3. Electrical conductivity of groundwater in Male' (January 2001)

A recent study on the island of Naifaru in Lhaviyani Atoll to the north of Male, the most densely populated island not to have a sewerage system, found 80% of the household wells tested to contain faecal coliforms. The majority contained more than 100 faecal coliforms per 100ml. This situation is common in the more densely populated islands. Nutrients and coliforms are still found in the less densely populated islands, both indicating pollution from sewage.

Infrastructure provided to address these problems

The above islands are by no means the only ones which are having these problems. Elsewhere, factors other than population density influence the vulnerability and degradation of groundwater resources. Geographical factors such as a particularly high water tables or a particularly narrow width can make an island's groundwater resources more vulnerable. Economic factors such as those which limit the ability of communities to build good sanitation facilities or which make solid waste difficult to dispose of can also result in the degradation in quality of an island's groundwater.

Government has tried to address the problems on the most severely affected islands. On R. Kadholhudhoo, Lh. Hinnavaru, K. Male', B. Thulhaadhoo, Sh Komandoo and K. Gulhi, the five most densely populated islands and the ninth most densely populated (see the above table), sewerage systems have been built to try and protect the groundwater resources from pollution, while rainwater storage tanks have been provided free for community use and on a cost recovery basis to households. On the most crowded islands, there is insufficient space even for adequate rainwater storage tanks, and on R. Kadholhudhoo and K. Male', the difficulty experienced in getting safe water for drinking and cooking has become so pronounced that desalination plants have been provided. Plans are now proceeding to provide Lh. Hinnavaru and Lh. Naifaru with the same. The following section of the report describes how desalination has been introduced to Maldives.

Desalination in Maldives

Where the water quality has been degraded (by high salinity and/or polluted water) and where there is insufficient space available for rainwater collection and storage, desalination has become the only alternative means of providing a safe water supply. This is the case in the capital Male' and in the most densely populated island, R. Kandholhudhoo. Desalination plants have been used in Maldives' tourist resorts since the late 1970's.

Desalination in Male'

The first desalination plant in Male' was installed in 1988 with a capacity of 200 m^3/day. In line with increases in population and water consumption, the capacity has been increased steadily and now stands at 5,800 m^3/day. Because it is very expensive, desalinated water is not used for all purposes. Most households use desalinated water for drinking and cooking, bathing and some other domestic purposes. Groundwater is mainly used for toilet flushing. Those who can often prefer to collect rainwater for drinking in order to save money. Many households are still using groundwater for bathing. Those who cannot afford to have house connections can collect limited quantities of water for free from tap bays located in 15 places around the island.

Water tariff and charges

The cost of water varies according to whether it is used for domestic or commercial purposes. The domestic tariff is stepped so as to provide a minimum quantity of water per day at an affordable rate. Table 5 gives the details.

Consumer Group	Rate of subsidy/Tax	Price to consumer, per m3
Domestic household	Up to 90L/day	MRf 25.32 (band A) (US$1.99)
"	90 – 270L	MRf 75.95 (band B) (US$5.96)
"	270L and above	MRf 101.26 (band C) (US$7.94)
Institutions	Metered flat rate	MRf 75.95 (US$5.96)
Commercial	Metered flat rate	MRf 101.26 (US$7.94)

Note: Fixed Line charge MRf 30 per month (US$2.35)

Table 5. Water Tariffs in Male'

At the current consumption levels, under the stepped tariff, the average price of water for domestic customers is Mrf 71.36 *(*US$5.60) per m^3. This price covers the cost of water and sewerage services, that is, sewerage costs are taken from the water revenue.

Since the initial desalination plant was installed in 1995, energy consumption for water production has been reduced from 10 kW/m^3 to 3 kW/m^3 in 2002. This has largely been as a result of advances in energy recovery of the desalination systems. Due to these advances in energy recovery the cost of production has decreased. Using the combination of desalination systems currently installed in Male', costs are US $3.65 per m^3 which includes production, operation, maintenance and administrative costs. Of the two technologies which have been used, multi-effect evaporation (ME) desalination and reverse osmosis (RO), the latter has emerged as the most suitable technology due to the compact size of the systems and the lower cost of operation and maintenance.

Demand and capacity for production of desalinated water

The capacity for producing desalinated water has increased steadily since 1988, as Table 6 shows. Plants donated by various countries have since been complimented by plants installed since the formation of MWSC in 1995.

Year	Total desalination capacity (m3/d)	Remarks
1988	200	200 m^3 plant donated by Danida
1990	400	200 m^3 plant donated by France
1990	1000	600 m^3 ME plant donated by Danida
1991	1500	500 m^3 plant financed by Government
1995	2000	500 m^3 RO1 installed
1996	2800	1300 m^3 RO2, RO3, RO4 installed (Danida ME taken out of service)
1998	3300	500 m^3 RO5 installed
2000	4300	1000 m^3 RO6 installed
2002	5800	RO5 increased by 1500

Table 6. Development of desalination capacity in Male' (m3/d)

The quantity of water consumed has steadily increased since 1996, as Table 7 shows. The total volume of water distributed in 1996 (323,300 m^3) was equivalent to 886m^3 per day (32% of capacity). In 2001, the equivalent figure stood at 3,307m^3 per day (77% of capacity).

Month	1996	1997	1998	1999	2000	2001
Total	**323.3**	**571.9**	**728.6**	**905.0**	**1098.0**	**1206.9**
January	23.4	39.8	49.9	60.0	77.2	97.8
February	26.7	43.7	52.4	67.3	85.8	93.1
March	34.1	56.9	66.0	82.9	97.2	106.7
April	26.4	53.2	65.3	77.9	93.0	104.7
May	29.8	45.5	60.4	76.2	99.0	101.8
June	22.5	45.4	58.5	68.8	86.6	101.5
July	20.7	50.0	56.2	76.2	92.8	100.4
August	18.6	51.3	69.1	76.9	95.3	107.7
September	22.3	39.4	60.1	78.2	90.3	96.0
October	29.9	48.4	66.2	77.4	97.5	99.0
November	33.7	56.1	63.5	85.3	90.9	103.0
December	35.2	41.8	61.0	77.7	92.3	95.2

Table 7. Water Distribution by months, 1996 – 2001 (in '000 m^3)
Source : MWSC

The cost of desalination in Malé'

Male's desalinated water is expensive. The average household spends between US$40 and $60 per month on water. The average household in Male' earns something like US$ 668 dollars per month (MPND/UNDP, 1998) so people can be spending about 6 to 9% of their income on their water bill. Wastewater charges are also included in the water charge.

The advantage of the present arrangement is the public have the choice of whether to use groundwater, rainwater or desalinated water according to the customer's need and affordability. The application of charges has made the public aware and willing to conserve and use water judiciously.

Desalination outside Male'

Outside of Male', desalination is most widely used in the tourist resorts. Each resort island has its own desalination plant. The water produced is generally used for bathing only, as guests are encouraged to buy bottled water for drinking. These plants are usually operated and maintained by a technician appointed for that purpose. The associated costs are covered by the resorts revenue, of which they are a relatively small percentage.

Besides the resorts, only one other island at present has a desalination plant. This is R. Kadholhudhoo, the most densely populated island in the country. The island is only 4.40 hectares in area, yet is home to 2,650 people. The installed plant has a production capacity of 50m^3/day, and is a reverse osmosis plant. The total cost of purchase, transport and installation was MRf 1.3M (US$102,000). Because the island is so small, it was considered adequate to provide three taps in a single tap bay from which people could collect water. People are charged MRf 0.1 per litre at the time they collect the water, so filling a 20L container costs MRf2 (US$0.16). The cost per m^3 is therefore US$7.84. This tariff covers the cost of operation and routine maintenance, but does not provide any additional funds to cover the cost of replacing the filter membranes or other spare parts, which can be expensive and difficult to obtain. The capital cost of the plant was met by Government. There is no attempt being made to recover this cost through the tariff being collected.

The responsibility for operation and maintenance of the plant on Kadholhudhoo is held by the Island Office, equivalent to a local government office. One person has been appointed to run the plant and to collect the tariff from people at the taps. Because he is also responsible for running the island's diesel powered electricity generator, he has to share his time between the two and so the water is only available for two periods of three hours every day. This causes long delays. On a recent visit, people reported having to queue for two hours.

The feasibility of providing desalination plants to two more of the most densely populated islands, Lh. Hinnavaru and Lh. Naifaru, is currently being considered by the Ministry of Health. All of the above issues are being taken into account.

Other sources of water

Besides rainwater, groundwater and desalinated water, the only other source of water available is bottled water. Although some of this bottled water is mineral water imported from neighbouring countries, a significant percentage is actually desalinated water produced on the island of Thulusdhoo near Male' by the Coca-Cola Company. Bottled water is not commonly used by local people because of its high cost (a 1.5 litre bottle retails in local markets for around US$0.63 so the equivalent price is therefore US$418/$m^3$). However, all of Maldives' tourist resorts sell bottled water to their guests as drinking water, at a cost of around US$2 for a 1.5 litre bottle (that is, at a cost of over US$1,333/$m^3$). MWSC are keen to expand their operations into the bottling of desalinated water so as to compete for this market. It is hoped that any resultant profits made by government (as the major shareholder in MWSC) can contribute to the provision of water and sanitation infrastructure for the rural islands.

Knowledge gaps in relation to water resources

There are significant knowledge gaps in relation to water resources in Maldives. Examples of areas where there is a lack of adequate data include (but are not limited to) rainfall, vegetation cover, porosity and permeability of soils, tidal movements, groundwater abstractions. Difficulties have been experienced in assessing available groundwater resources and estimating sustainable yield due to a lack of data, equipment and trained personnel.

A lack of knowledge of the collection, analysis and interpretation of water quality data has meant that there are no national groundwater quality guidelines or standards set up that are appropriate for Maldives. International guidelines such as the WHO Guidelines for Drinking Water Quality are used when appropriate.

There has been little access to information and data collected by other concerned departments both in Maldives and other small island states, and accordingly there is also limited knowledge of different technologies used in other small islands for water resource management and protection that could be replicated in Maldives.

Sustainable development of water resources

Policies for the sustainable development of water resources are set out in the context of the Health Master Plan 1996 – 2005 and the Second National Environmental Action Plan 1999. The policies are set out in brief below:

?? One policy is to increase household collection and storage of rainwater. This will include the sizing of rainwater tanks at the household level to have sufficient capacity to store rainwater to last the whole year through.
?? A second policy is to improve community collection and storage by increasing the storage capacity, renovating existing tanks, increasing catchment areas and conducting information, education and communication (IEC) activities to ensure rainwater is collected safely. This will include the building of underground rainwater tanks during construction of community buildings, and will encourage directing rainwater into household wells where rainwater tanks are not available.
?? Maldives is keen to pilot new schemes such as community groundwater systems (infiltration galleries) in areas of low salinity with a low risk of pollution, as a means of supplementing rainwater supplies where necessary.
?? In order to protect groundwater resources from becoming saline, we would like to discourage the use of electric pumps.

Surface and groundwater catchment management

In the absence of any surface water resources other than a few freshwater ponds (*kulhis)*, catchment management in Maldives is concerned with groundwater resources. This will require improved land use planning, assessment of groundwater conditions prior to development, and the designation of groundwater protection zones. The latter is something we would like to instigate in newly developed or rapidly developing islands.

The need is recognized for groundwater quality protection through improved sewage treatment and disposal of wastewater. Work will shortly begin to trial the use of gravel bed hydroponics (GBH) or constructed wetlands for sewage treatment so as to protect the groundwater from pollution.

The *kulhis* could possibly be developed as a water resource, though studies have yet to be undertaken to explore the feasibility of this.

Capacity building and training needs

In accordance with the knowledge gaps identified previously, training is required on the following topics:
?? Water quality monitoring and groundwater assessment, processing and interpretation of data and selection and use of equipment
?? Developing geographical information systems (GIS) and groundwater modeling techniques, hydrology, hydrogeology and surveying.
?? Water balance studies to assess groundwater recharge and sustainable yield using climate and other data.
?? Design of appropriate groundwater pumping systems including infiltration galleries.
?? Appropriate methods and techniques for determining marine water quality.

Summary & Conclusions

The geography of Maldives means it has very few surface water resources. Until the beginning of the 20th Century, groundwater was used for all purposes including drinking and cooking. However, the country's groundwater resources are highly vulnerable. They are found at very shallow depths and can therefore be easily polluted. The major source of pollution is poor sanitation facilities. In most islands, the freshwater lens is also quite thin, and can therefore become saline quite rapidly if abstractions exceed the sustainable yield. For these reasons, rainwater has become the main source of drinking water for the vast majority of islands.

Populations have increased rapidly during the last few decades. The capital Male', in particular, has grown from a city of 15,000 in 1972 to one of over 70,000 now. This has put great pressure on the island's groundwater resources, to the point where they are now badly polluted, very saline and of little use. The density of population makes it impossible to collect sufficient rainwater to serve the whole population, and so desalination has become the only means of providing safe water for all.

Male's first desalination plant was installed in 1988. Several more plants have since been installed to increase the total capacity of production from $200m^3$/day to over $5,000m^3$/day. The use of desalination as a means of providing safe water has been a success story in Male'. Though the cost of the water produced is relatively high, the supply of water is reliable, safe and, because the revenue is sufficient to cover the costs of operation and maintenance in the long term, sustainable.

There are a number of densely populated islands which are experiencing similar problems to those which have made desalination necessary in Male'. Only in R. Kadholhudhoo, however, has a desalination plant so far been installed. Although the plant has been reasonably successful, there are a number of issues relating to operation and maintenance, the availability of spare parts and in particular, cost recovery, which need to be considered if the use of desalination in the more densely populated islands is to be expanded.

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