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Water resources management to satisfy high water demand in the arid Sharm El Sheikh, the Red Sea, Egypt

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ABSTRACT

Sharm El Sheikh (Sharm) in South Sinai, Egypt, is situated in an area of extreme aridity (annual rainfall between 20–50 mm/y). It has been undergoing rapid development and attracts about one million tourists annually which results in an ever-increasing demand for water. The main source of water is desalinated seawater produced by two government-owned reverse osmosis (RO) plants, two centralised privately-owned RO plants and by about 50 decentralised small RO plants in hotels. The government-owned RO plants sell water to the local residents at a very low subsidized price while the two centralised private RO plants (owned by two different companies) charge commercial rates and raise prices considerably in the summer periods of high water demand. For all the plants, there are concerns over high energy consumption and the impact of brine discharge on the environment. Other sources of water in Sharm include tankers and pipes delivering groundwater from Al Tor (100 km distance) and treated domestic wastewater for landscape irrigation. The Egyptian Environmental Affairs Agency (EEAA) is not regulating and monitoring water management sufficiently. Increasing water shortages and price rises as well as environmental degradation would impact the tourism industry. This paper describes the current water resources management practices in Sharm, and outlines simple strategies which could be undertaken to improve the situation.

Keywords: Desalination; Wastewater reuse; Integrated water resources management; Tourism; Water demand; Reverse osmosis

1. Introduction

Egypt has to cope with increased water demand due to population growth, rising standards of living, expansion of tourism, industrial output and agricultural activities. The South Sinai region in particular experiences water shortages. This area is important for Egypt's economic growth due to rapidly expanding tourism. A major tourist city in the arid environment of South Sinai is Sharm El Sheikh (Sharm), a popular Red Sea resort.

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The purpose of this paper is to describe how Sharm's water demand is met and to highlight existing shortcomings of a hap hazardous approach to water resources management. Sharm can be seen as a typical example of a touristic city in an arid environment, with a water resources management. Sharm is situated on the southern tip of the Sinai Peninsula with the Red Sea on one side and the mountains of Mount Sinai on the other. Sharm, "the jewel of Sinai", has year-round sunshine and popular beaches.

About one million tourists from Egypt and abroad visit Sharm each year. The current permanent population of Sharm was estimated to be 25,000 in 2006 but may be much higher due to non-registered temporary labourers. The annual growth rate for the local population is about 3.8% per annum. In May 2006 there were 65 hotels, mostly 3–5 star category, and 63 more hotels under construction within the city limits. Future construction will be outside the city limits [1].

Little attempt has been made to minimize the water consumption of hotels even though the city is located in a region of extreme aridity (annual rainfall between 20–50 mm/y) [2], and has no groundwater resources. To meet rising demand, privately-owned seawater reverse osmosis (RO) plants are being built.

It is estimated that approximately 91% of the current average water demand in Sharm is from the tourism industry (hotels, restaurants, bars, shops, staff housing and landscape irrigation). The remaining 9% of the water demand is from the local population [1]. The per capita water consumption of the permanent residents is about 100–150 l/cap/d. However, the actual consumption is much higher reaching 250 l/cap/d, mainly due to wastage, absence of water meters, cheap subsidized water for residents and leakage from the distribution system which can reach up to 40% [3].

The average tourist uses huge amounts of water ranging from 300 to 850 l/d depending on hotel facilities and services, occupancy rates, ambient temperature, staff housing and irrigation area [4].

Most of the data shown in this paper was obtained from the Sinai Development Authority (government) which is responsible for all development activities in South Sinai including water supply, wastewater, road building, etc. Data was also obtained from interviews with the Chief Engineers of several government-owned and private RO desalination and wastewater treatment plants in Sharm, and with hotel managers from eight 5-star hotels.

2. Water supply methods used in Sharm

There is a mixture of water supply methods used in Sharm (Fig. 1). The city depends mostly on RO desalination (86% of the water supply) with the remainder being supplied by groundwater transported by tankers or long-distance pipelines.

2.1. Pipelines and tankers

In the 1970's, Sharm depended on a 100 km long water pipeline (diameter of 250 mm) transporting groundwater from the Al Tor 100 m thick fresh water aquifer [5]. Due to developments in Sharm requiring more water, tankers were added. With a further increase in local population and tourism, tankers were no longer a practical solution.

There are two other pipelines which bring treated Nile water to Sinai. At first these were intended to bring water also to Sharm, but all the water is now delivered to other locations and does not reach Sharm.

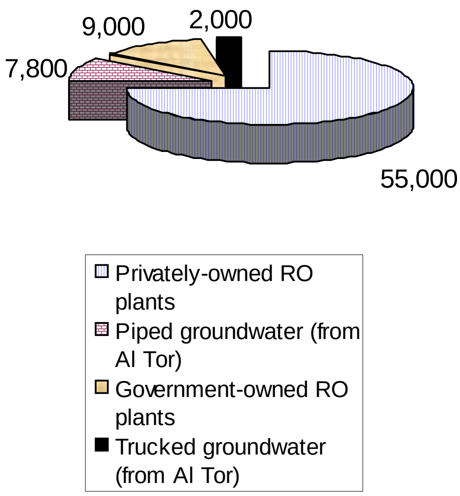

Fig. 1. Average potable water production in Sharm for 2008 from different resources (in m^3/d). Total amount is 73,800 m^3/d [1]. Treated wastewater reuse is not included.

The groundwater abstraction rates in Al Tor are now unsustainably high (in total 9,800 m^3/d of groundwater is pumped/trucked from Al Tor to Sharm). Wells are drying up due to the groundwater table going down as recharge is low in this region.

2.2. Reverse osmosis seawater desalination plants

RO desalination is organized by three types of plants (Table 1):

- Two government-owned RO plants;
- Two centralised private RO plants; and
- About 50 private RO plants in individual hotels.

The government-owned RO plants provide water to the local population and public buildings, but do not meet the demand. Each residential district receives water for 2–4 h a day.

These plants have direct surface intakes for seawater. Their source water is of a lower quality than intake water from beach wells since beach wells can act as natural filters for seawater. This increases production cost due to extra pre-treatment needed.

The two centralised private RO plants provide water to those hotels which do not have their own desalination plants, or where the water demand exceeds the capacity of their own RO plants.

Many hotels (about 50) have their *own private desalination plants* to achieve autonomy. These decentralised RO plants are not monitored and regulated. Intake water is sourced from beach wells (30 m depth) which in many cases are not very far apart (less than 50 m) from

Table 1
RO desalination plants in Sharm

Type of plant	Capacity (m^3/d)	Customers	Unit production cost (US$/$m^3$)	Selling price (US$/$m^3$)	Comments (intake source)
2 government-owned RO plants		Local residents and public buildings	1.2[a]	0.05–1.21 (see Table 4)	Production is not enough to satisfy local population, therefore does not sell to hotels (surface intake)
Al Ta'meer	6,000				
Al Shabab	3,000				
2 private centralised RO plants		Hotels	0.9[b]	1.6–2.5 (the higher value is charged during peak summer months)	Licensed to produce and sell water to others (beach wells)
South Sinai Water Co.	17,000				
Ridgewood	7,000				
50 private decentralised RO plants	31,000 (typical value about 600 m^3/d per plant)	Hotels	1.2–2.9[c] (based on 14 plants)	N/A	Located within individual hotels for own usage (varied)
Total 54	64,000				

[a] [3]
[b] [10]
[c] [11]

brine disposal wells (60 m depth) regardless of the suitability of the local geological formation, thus raising the salinity of the intake water (from 45,000 to 52,000 ppm). Increased salinity of intake water results in increased energy requirements of the RO plant [6].

Apart from well disposal, brine is disposed into the sea which is likely to have adverse impact on sensitive marine life. Brine contains chemicals concentrated during the pre-treatment, and brine disposal was shown to cause damage and reef degradation in the area of Ras Mohamed National Park in Sharm [7]. Similar impact on fauna and flora has been observed in the vicinity of the brine outlet at an RO plant in Ashkelon, Israel [8]. In 1994 the Egyptian Ministry of State for Environmental Affairs (EEAA) has set up Law 4 [9] forbidding brine disposal into the sea but this law is not well enforced.

2.3. Treated effluent reuse

Domestic wastewater is treated with the following two aims:

- to produce water of suitable quality for hotel landscape irrigation (apart from treated effluent, RO product water is also being used for landscape irrigation in many hotels because of low quality of treated effluent or insufficient amount of treated effluent); and/or
- to allow discharge to the environment according to the Egyptian regulations.

Domestic wastewater is treated in wastewater treatment plants (WWTPs) in Sharm (Table 2).

- One government-owned wastewater treatment plant;
- One private centralised wastewater treatment plant;
- Fifty private decentralised wastewater treatment plants in individual hotels.

The interviewed hotel managers claim that the effluent quality from their WWTPs complies with Category 1 of the Egyptian Decree No. 44 of the year 2000 (which is an amendment to Law 4), which regulates wastewater reuse for irrigation (hotels do their own effluent quality monitoring, and the EEAA is supposed to perform regular checks on the wastewater treatment plants of the hotels but is failing to do so). The hotel managers were not willing or able to disclose effluent quality data from their wastewater treatment plant during the interview process.

Agriculture activities are classified into three categories (Table 3): Category 1: landscape irrigation; Category 2: animal feed plantation, dried seeds, flowers, fruits with skin (commercially processed) e.g. lemon, dates; Category 3: woods. The Decree forbids the usage of treated wastewater for irrigation of edible vegetables (whether eaten raw or cooked), as well as fruits eaten raw without a skin, e.g. grapes. According to the Decree, Category 1 requires the highest level of treatment: secondary treatment, sand filtration and disinfection (tertiary treatment). Category 2 requires only secondary treatment, e.g. activated sludge, oxidation ditches, trickling filters and stabilization ponds. Category 3 requires only primary treatment.

Table 2
Wastewater treatment plants in Sharm

Type of plant	Capacity (m^3/d)	Type of plant	Use of treated effluent
1 government-owned WWTP	15,000	Waste stabilization ponds	Half the flow is treated and used to irrigate 40 ha of government-owned forest plantation (average raw sewage inflow in 2006: 8,500 m^3/d). Rest of flow is diverted to the private centralised WWTP
1 private centralised WWTP (South Sinai Water Co.)	6000	Aerobic/anaerobic treatment	Treated effluent used to treat a golf course (100 ha) owned by South Sinai Water Co.
50 private decentralised WWTPs [a]	400 per plant	Aerobic/anaerobic treatment	Treated effluent used to irrigate hotel landscape
Total	41,000		

[a] 80% of total hotels in Sharm have their own WWTP; hence there are about 50 small WWTPs

Table 3
Egyptian standards for the three categories of agriculture activities along with suggested guidelines from USEPA for open and restricted access landscape irrigation and a sample from treated effluent from the government-owned WWTP in Sharm

Parameter	Egyptian Standards			USEPA Guidelines [a]		Effluent quality from government-owned WWTP (One sample)
	Category 1	Category 2	Category 3	Open landscape irrigation	Restricted access landscape irrigation	
pH	—	—	6–10	6–9	6–9	—
BOD (mg/l)	≤20	≤60	≤400	≤10	≤30	105
E. coli (no./100 ml)	1000	5000	—	none	200	—
TSS (mg/l)	20	50	250	—	30	26
Residual chlorine (mg/l)	—	—	—	≥1	≥1	340
COD (mg/l)	40	80	≤700	—	—	222
Oil and grease (mg/l)	≤5	≤10	≤100	—	—	2.2
TDS (mg/l)	2000	2000	2500	—	—	138
Temperature (°C)	—	—	≤40	—	—	—

[a] [12]

USEPA guidelines for open landscape irrigation are equivalent to Category 1 in the Egyptian standards, while USEPA guidelines for restricted landscape irrigation are equivalent to Category 2. The Egyptian standards for treated effluent for reuse in landscape irrigation (Category 1) are less stringent than suggested guidelines from USEPA (open access) for *E. coli*. While USEPA requires no *E. coli* in treated wastewater, the Egyptian standards allow up to 1000/100 ml. The BOD limit in the Egyptian standards (Category 1) is also higher than the USEPA guidelines (open access).

The treated effluent sample from the government-owned WWTP (used for woods irrigation) adhered to Egyptian regulations (Category 3) but not to USEPA guidelines (either open or restricted access) in case of BOD. There was no test performed for *E. coli*.

Law 4 for year 1994 mandates that excess sludge from WWTPs is disposed in sanitary landfills. The centralised government-owned WWTP is relatively new (built in 2002) and is currently operating at only half its capacity. Desludging of the ponds will only be required in several years. In the case of small decentralised WWTPs, excess sludge is commonly disposed of in the backyards of hotels causing health and environmental hazards. This is against the EEAA's environmental regulations but these regulations are not sufficiently enforced in Sharm. The monitoring is easier for the centralised government-owned WWTP than for the many small WWTPs.

3. Water supply costs in Sharm

3.1. Potable water from pipelines, tankers and RO desalination plants

In this extremely arid region, pumping water from the Nile is using up precious Nile water on one hand. On the other hand, the pipes' capital and O&M costs are substantial compared to RO desalination costs. The unit production cost of long-distance piped water for a distance of 368 km (distance from nearest Nile water source) and a capacity of 15,000 m^3/d, for instance, is about 1.9 US$/m^3 compared to an international standard trend of less than 1US$/m^3 for RO desalinated water [11]. The price of tankered groundwater is approximately 2.6 US$/m^3 which is higher than RO product water [3,13].

The government-owned RO desalination plants sell water at a much lower rate than the actual cost (see Table 1). Table 4 shows the government's tariff system for RO product water for different clients. The actual unit production cost of product water for these RO plants is approximately 1.2 US$/m^3 whereas the selling price is as low as 0.05 US$/m^3.

In the Canary Islands in Spain, for instance, the government also offers state support to desalination plants to obtain water prices equal to that of water used by households in all of Spain. This subvention has lead to a higher level of water production with fewer interruptions for the users. However, the subvention is inversely proportional to the energy consumption of the plant, and proportional to the efficiency of the water supply network in order to encourage optimised plant performance [14]. A similar system could be devised as a subsidy scheme for the government-owned RO plants in Sharm.

The unit production cost of the government-owned RO plants is high (though lower than those of the private decentralised RO plants) due to excessive use of chemicals and additional pre-treatment stemming from the surface intake as opposed to the beach wells; also their capacities are smaller than the private centralised RO plants.

The selling price of RO product water from the private centralised plants is relatively high (1.6–2.5 US$/m^3 as per Table 1; the higher value is charged during the peak summer months) and hotels are forced to buy to satisfy their demand unless they have enough water from their own RO plants. The lowest unit production cost is achieved by the private centralised RO plants due to their more continuous and optimal operation. These plants take their intake water from beach wells therefore reducing pre-treatment cost.

The current unit production costs of the private decentralised RO desalination plants in Sharm are high compared to international trends (up to 2.9 US$/m^3 in Sharm vs. less than 1 US$/m^3 worldwide) [11]. Reasons for elevated costs of RO desalinated water in Egypt are: (a) old plants; (b) technical problems due to lack of experience and poor maintenance, (c) small-capacity desalination plants (no economies of scale) and (d) large variations in operating time. Especially the latter appears to be a significant factor as water production cost is inversely proportional to operating time [15].

Due to variations in hotel occupancy rates in Sharm, water demand varies throughout the year. As a result, the small decentralised RO plants only operate at full capacity during relatively short periods of time, and are frequently ramped down. This interrupted service affects the quality of water and the lifetime of membranes and accordingly increases their costs. This problem is faced by tourism-dominated arid regions around the world.

Table 4
Tariff system for RO product water from government-owned RO plants

Usage	Consumption (m^3/month)	Prices (US$/m^3)
Domestic (public)	1–30	0.05
Domestic (public)	30–50	0.06
Domestic (public)	50 and above	0.19
Construction	No limit	0.19
Airport	No limit	0.19
Hotels/domestic (private)	No limit	1.21

3.2. Non-potable water from WWTP's

The government charges the local population for the wastewater collection and treatment by charging an additional 33% of the potable water bill. If the government was selling potable water to hotels, it would have charged them a wastewater discharge fee of 0.4 US$/m^3 of potable water used. However, as the government-owned RO plants do not provide potable water to hotels, the government does not charge them for wastewater collection and treatment although nearly all hotels are in fact connected to the public sewer network (though not all of them discharge to the network).

Table 5 shows unit capital costs for five wastewater treatment plants (all waste stabilization ponds) in South Sinai. The O&M cost is about 0.2 US$/m^3 including maintenance and spare parts, labour and chemicals (chlorine). The unit production cost of treated wastewater (for the government-owned WWTP in Sharm) is calculated to be about 0.25 US$/m^3 based on 30 years lifetime and 8% interest rate.

Since this cost is much lower than the unit cost of RO product water, it of course makes economic sense for the hotels to use treated wastewater for landscape irrigation instead of RO product water.

Table 5
Capacity and capital costs of waste stabilization ponds in South Sinai, Egypt-all owned by the Sinai Development Authority (costs are adjusted for year 2008[a])

No.	Year built	Location	Capacity (m^3/d)	Capital cost (million US$)	Unit capital cost (US$/$m^3$/d)
1	2002	Sharm El Sheikh	15,000	2.69	179
2	2001	Ras Sudr	5,000	1.52	303
3	2001	Abou Zeinema	5,000	1.29	258
4	2001	Abu Rudeis	5,000	1.26	252
5	2001	Saint Catherine	1,000	0.54	542

[a] Calculated based on the US Consumer Price Index

4. Options for improved integrated water resources management

As shown above, the current water resources management in the city of Sharm is facing significant challenges with respect to institutional, economic, technical and environmental aspects. These challenges, and possible solutions, are summarised in Table 6. Optimised management of water resources in the area would lead to better services and possibly lower prices (for RO product water sold to hotels), positively impacting the tourism sector (lower hotel running costs), as well as the communities that directly depend on this industry.

A decision support system (DSS) is currently being developed to aid decision makers, including public and private investors, in the design and assessment (both economically and environmentally) of future water supply infrastructure projects for arid coastal regions [11]. For example, the DSS could predict the optimal capacity and required expansion of RO plants based on input values provided by the user, such as time-variant water demand and hotel characteristics.

5. Conclusions

The city of Sharm is a typical example of a tourist city located in an extremely arid environment with a hap hazardous approach to water resources management. Water supply to Sharm is mainly from RO desalination complemented by groundwater transported from Al Tor by tankers or long-distance pipelines and by treated domestic wastewater (for landscape irrigation).

Desalinated water is provided by two government-owned RO plants, two centralised privately-owned RO plants and by about 50 decentralised small RO plants. The government-owned RO plants sell water at a very low subsidized price to the local residents while the two centralised private RO plants (owned by two different companies) could control the market and raise prices considerably especially in periods of high water demand (selling price ranges from 1.6 to 2.5 US$/$m^3$). All of these RO plants cause environmental problems due to high energy consumption per m^3 of water produced and the impact of uncontrolled brine disposal on the environment.

The EEAA does not regulate and monitor water management in Sharm sufficiently. In the longer term, this situation is likely to lead to further water shortages and price rises as well as environmental degradation which would impact the tourism industry.

Measures including stronger enforcement of related laws; evaluating the impact of erection of (semi-) centralised desalination and wastewater treatment plants; and considering alternative management methods for brine and sludge can help in achieving a more sustainable water resources management. A decision support system (DSS) is currently being developed to aid decision makers, including public and private investors, in the design and assessment (both economically and environmentally) of future water supply infrastructure projects for arid coastal regions.

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Table 6
Summary of challenges and suggested actions related to existing water resources management in Sharm

Category	Problems	Suggested actions for improvements (in bold: most important problems and actions)
Institutional	• Brine disposal at private decentralised desalination plants is not effectively regulated and monitored • Lack of effective monitoring for sludge disposal in private decentralised wastewater treatment plants • Local regulations are less stringent than international guidelines (USEPA) for wastewater treatment (e.g. *E. coli*) for Categories 1 and 2 • Egyptian law does not allow irrigation of edible vegetables (and skinless fruits) with treated wastewater	• Stronger enforcement of law 4 for year 1994 by the EEAA and introducing of fines for violation of the law • Review of Egyptian standards for reuse of treated wastewater to further improve quality of treated effluent to minimize health and environmental risks
Economic	• Cheap subsidized water for local residents • Hotels are not charged for being connected to the public sewers • Insufficient cost recovery from government-owned plants (desalination and wastewater treatment) • High unit production costs for private decentralised RO desalination plants • The two private water supply companies may dominate the market	• Adjust subsidy system for local residents to provide incentives to stop wasting water; install water meters • Better billing system for wastewater discharge to public sewers (by hotels) • Evaluate if erection of more (semi-) centralised plants (desalination and wastewater treatment) to replace the small decentralised plants would reduce production and treatment costs due to economies of scale (using newly developed DSS) and allowing for better monitoring and enforcement of regulations
Technical	• Interrupted water supply services for local residents • Water consumption by residents is high and not metered • High leakage in public distribution network • Increased salinity of desalination plants beach wells due to close proximity to brine disposal wells • Aquifer underlying Al Tor is being exhausted (groundwater table is going down) • Hotels are irrigating with RO product water when own treated effluent has low quality or insufficient amount	• Put a leakage detection programme in place, repair leaks in water supply network • Construction of deep brine disposal wells to avoid mixing with source water from shallow intake wells (and proper investigation of subsoil formation to avoid interference between supply and reject water) • Roll out a programme of water demand management for hotels, for example low water use appliances; low-flush toilets; use drought-resistant desert plants for landscaping to reduce on irrigation water use
Environment	• High energy requirements per cubic metre of water produced • Effluent quality from decentralised wastewater treatment plants is not monitored sufficiently • Negative impact on seawater quality from brine disposal in the Red Sea is likely • Negative environmental impact due to open disposal of sludge in hotel backyards is likely	• Evaluate alternative methods for brine and sludge management to reduce environmental impacts (using newly developed DSS)

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