Sustainable Drinking Water Solutions for Egypt's Remote Areas

by Martina Jaskolski, Philipp Otter

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Introduction

About 80% of the approximately 1 billion people without access to safe water sources live in rural areas. Past experience has proven that in remote areas the technologies commonly and successfully applied in urban regions cannot simply be replicated, due to technical and operational difficulties (UNICEF and WHO, 2012). Local conditions and capacities do not permit the constant availability of technically capable personnel to run such systems, there is often a lack of supply of required chemicals to ensure water safety (such as chlorine), and there may not be sufficient energy supply to run a water treatment process. Therefore, for the remote areas of the planet, new and innovative technological approaches are desperately needed.

Egypt's challenges of managing its limited fresh water resources in sustainable ways and providing sufficient amounts of water to its population that is fit for human consumption pose real problems to the daily lives of people in rural Egypt. Some of Egypt's remote rural areas still lack a reliable, safe drinking water source. Although some drinking water quality studies found a compliance with national and WHO standards in urban areas (El-Harouny et al., 2009; Mohamed and Osman, 1998; Saleh et al., 2001), other authors (El Bahnasy et al., 2014; Mandour, 2012) have identified problems with drinking water contamination in rural areas due to heavy metal pollution, high levels of ammonia, iron and manganese, as well as chemical and biological contamination that exceed Egyptian standards. One of the reasons for the unreliability of health standards is a lack of disinfectants, such as chlorine, as well as issues with correct dosing and automatic monitoring of exact concentrations in the water. Another reason for water standards not being up to scratch is a lack of maintenance – for example the exchange of filters and membranes at the prescribed intervals.

In some drinking water stations in remote Egypt, chlorine has not been added at the local water filtration stations for the last 15 years, leaving residents without sufficient protection from disease. In Egypt's Western Desert, high iron content in the water of up to 13 mg/L turns the water orange and unpalatable, a problem that no local technical solution has been able to fully resolve. Residents of the oases located in this remote desert try to filter their water through clay pots – a procedure that removes some of the iron but does not remove pathogens, which build up as water is stored in jerry cans and containers for days.

The Challenge of Providing Rural Areas with Safe, Clean Drinking Water

The major challenge in water supply of rural developing regions is ensuring that water is free of pathogens. Thus, as a first priority, any treatment process must be able to assure the complete removal/deactivation of pathogens (WHO, 2008). Only after such safe disinfection is guaranteed should further contaminants such as iron, arsenic, fluoride and emerging contaminants be dealt with. Even where disinfection technologies such as UV or UF-membranes promise the complete deactivation/removal of pathogens and render water safe for drinking directly after the treatment process, this water is not necessarily safe at the time of consumption, which is often after a period of storage. Especially in rural areas, people transport the water over long distances in inappropriate and contaminated containers and store these for several days at elevated temperatures. Under these conditions, bacteria and pathogens have a chance to grow, thus compromising safe water consumption.

In order to guarantee a longer-term safety of drinking water residual disinfection has to be applied. Most of these disinfectants are chlorine-based compounds, which remain in the water for some time and ensure that the water quality is safe enough for drinking, even under the aforementioned conditions in remote areas.

The supply and dosage of those chemicals are standard procedures in central water treatment systems. In rural developing regions, however, the supply, handling and dosage are very challenging. Several studies conducted in India indicate that treating water with chlorine tablets has no effect in reducing the prevalence of diarrhea (Boisson et al., 2013). The main reasons are poor compliance by users and a lack of supply of chemicals, putting such community-based approaches at risk of failing.

The problem of pathogenic contamination in the water is one that also applies to Egypt's rural areas. The Research Institute for a Sustainable Environment (RISE) of The American University in Cairo (AUC) conducted studies in remote areas of Egypt's Western and Eastern deserts which showed that most conventional systems of water purification require the manual addition of chlorine, the exchange of filters and/or membranes, as well as manual checks on water quality. In remote areas, most conventional drinking water filtration technologies fail because these three requirements cannot be met. Due to the distance from urban areas and supply shops, which in many cases exceeds several hundred kilometers, operators are not able to receive the required materials, such as chlorine or exchange filters and membranes, on time. As there is no automatic monitoring of water quality in these common systems, the stations continue to operate even though the water may be unsafe to drink. Moreover, as technical problems emerge in the station, there is often a lack of capacity among the residents of remote villages to fix the station's technology. For this reason, RISE has witnessed that the majority of smaller drinking water filtration stations installed in Egypt's Western Desert fail within their first six months of operation.

Observations and field assessments in Egypt have revealed that manually adding the right dose of oxidants for drinking water disinfection and changing filters and membranes on time is challenging even for public bodies in rural areas. In some public water filtration stations in Western Desert oases, chlorine has not been added to the system for 15 years, and water consumption continues. This problem may be well known, but little is done to improve the situation, mainly due to the lack of technological alternatives.

A second problem is the high energy requirement of conventional drinking water systems. A drinking water system that contains filters, chlorination units, pumps and UV technologies easily requires 3,000 kW to operate. However, many of Egypt's remote communities are not connected to the electricity grid and solely rely on energy provided by local generators. Electricity is often not available for more than five hours per day. In communities that have access to additional solar power, the local systems are not large enough to power a functional drinking water station.

In partnership with the German startup AUTARCON, RISE of The American University in Cairo (AUC) has developed tailor-made drinking water solutions for two remote areas in Egypt – the oases of the Western Desert and the valleys of the Eastern Desert along Egypt's far southern Red Sea Coast. Pilot studies and community feedback have shown that such sustainable, small-scale systems can be more successful at providing drinking water solutions to communities in remote areas than many of the conventional, larger-scale systems.

Drinking Water Provision in Egypt

The Egyptian Government has made significant progress over the past two decades in improving the population's access to clean drinking water. A report released by Egypt's Environment Affairs Agency (EEAA) in 2008 claims that between 1990 and 2006, the access to piped water increased from 89% to 99% in urban areas, and from 39% to 82% in rural areas (El Bahnasy et al., 2014). Statistics published by the World Bank, based on assessments performed by the WHO and UNICEF, state that Egypt's rural population has almost universal access to an improved water source. However, this includes both household connections as well as the use of public taps, stations or boreholes (The World Bank, 2016).

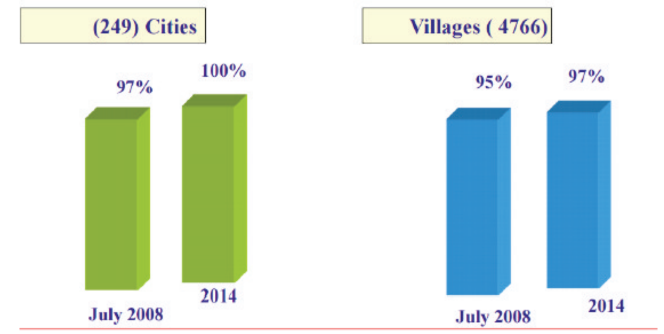

Figure 1: Water coverage in Egypt as presented by the HWCC in 2014 (Raslan and Abdel Wahaab, 2014).

Despite the progress made in water delivery to households in Egypt, drinking water problems remain, particularly in rural areas. As UNICEF stated in the early 2000s, "Unfortunately, there are many villages in rural Egypt that continue to rely on water delivery and waste disposal systems that are outdated, unhygienic, and therefore unsafe. As a result, the situation with regard to safe drinking water, household sanitation, and the immediate environment within these communities is far from satisfactory" (UNICEF, 2016). El Zanfaly (2015) shows that the problem is not always that of access, but also of the quality of infrastructure and drinking water. A paper published by El Bahnasy et al. in 2014, based on research carried out between 2011 and 2013, revealed that in Menoufia Governorate 1% of the total urban population and 15% of the rural population did not have access to safe drinking water (with a stress on the word safe). The authors concluded that this was due to improperly kept infrastructure and irregular amounts of chlorine added to the water. As a result of this, the authors contend, the majority of the governorate's population was forced to use filtered, bottled or vended water for drinking, or drinking water from privately operated filtration stations run by non-governmental organizations (El Bahnasy et al., 2014). This evaluation clearly represents a lack of trust in the quality of potable tap water provided by the Egyptian Government. Research conducted by RISE in the northeastern Delta in 2015 and 2016 has shown that many villages relatively close to urban centers are not connected to a potable water grid. While some of these houses at least receive a delivery of 1 cubic meter of water per family per week free of charge from the Egyptian Government, others must purchase the water required for their households from private vendors.

Two Remote Desert Locations: The Western and Eastern Deserts of Egypt

The oases of Egypt's Western Desert rely solely on the water of the Nubian Sandstone Aquifer. The water extracted from the depths of the aquifer, a finite reservoir of fossil water stored in the porous layers of sandstone rock (Burmil, 2003), has an extremely high iron and manganese content. Some areas additionally suffer from high levels of lead in the water (Soltan, 1999). Not all oasis communities in the Western Desert have access to purified tap water. Some communities receive unfiltered water that is extracted from a groundwater well and directly fed into public pipes. In the untreated source water of wells located in Western Desert oases, the research team measured up to 13 mg of iron per liter in the water directly extracted from the aquifer, while water treated by the local government stations in various locations still contained between 0.4 and 2.0 mg of iron per liter. The WHO (2004) and the US Water Research Center (2014) recommend a maximum

Figure 2: Western Desert oasis

Figure 4: Pictures of a rain-fed well in the desert wadis of the Wadi El Gamal National Park (top two pictures) and images of collection points that nomads would travel to in order to collect water for their families (bottom two pictures).

content of 0.3 mg of iron per liter of water. Iron remains more of a problem related to taste, color and turbidity. The real danger is that both treated and untreated water in the Western Desert do not contain enough chlorine to prevent the contamination with pathogens during water transport and storage. In the case of existing government treatment stations, local operators often do not add the required amount of chlorine to the water. Local residents traditionally filter their drinking water through unglazed clay pots called zirs in Arabic. This applies to both treated and untreated tap water. While the zirs are able to remove most of the iron from the water, they cannot ensure that water is pathogen free, especially when it is kept in containers for days before consumption (Figure 4).

Given that the oases of Egypt's Western Desert are located between 360 km and 650 km away from Cairo and do not have access to many of the components sold in urban centers across Egypt, any system that requires extensive exchange of spare parts is ultimately unsustainable. Several conventional small-scale drinking water stations working with greensand filters and chlorination units have failed in the oases. Usually the problems are technical

Figure 3: The traditional *zirs* – burnt but unglazed clay pots that are permeable and let water drip through drop by drop, filtering it in the process.

failures that cannot be solved, a lack of maintenance, or the inability to manage the stations properly.

In coastal settlements located directly 80 km south of Marsa Alam in the Wadi El Gamal National Park, residents also receive desalinated water for their daily use. While some village have been part of a social housing development project that built domed brick homes, others consist of make-shift, informal huts that are set up with ply wood, metal sheets, blankets and pieces of plastic.

The residents of these settlements are from the Ababda tribe that originated in Ethiopia and Sudan. Former nomads from the wadis of the Eastern Desert, many of the coastal residents have strong family ties with nomads in the valleys. The desalinated water is delivered to large tanks in the settlements, and then to smaller tanks placed on the roofs of the simple homes. The desalinated water is used for the bathroom and for washing and cooking, but residents do not like to drink the water due to a still present salty taste. Most families purchase additional drinking water from trucks that bring it from the Nile Valley and sell it by the cubic meter or by the jerry can. The purchase of additional drinking water places a financial burden on the households. Moreover, the transportation of water from the Nile Valley to the southern Red Sea coast by truck causes substantial pollution and carbon dioxide emissions.

For the nomads living in the remote valleys of the Eastern Desert, Wadi El Gamal National Park organizes a truck to transport desalinated water from a large community water tank to seven collection points located 5-10 km into the wadis.

At these collection points, several large plastic tanks (5-10 cubic meters each) store water for nomads to collect in their own pickup trucks. There are a few natural wells inside the valleys of Wadi El Gamal National Park, but these wells are replenished by rain water only and notoriously run dry over the summer months. The nomads in the valleys have been suffering from drought and lack of water in the wells, particularly in recent years, which force them to travel further and further up the wadi in search of rain and shrubs to feed to their herds of goats and sheep (Figure 5).

In both the Eastern and Western deserts, communities do not drink the provided water directly. In the case of the Western Desert, it is the high iron content that makes consumers re-filter the water. In the Eastern Desert and along the Red Sea coast line, it is the salty taste of desalinated water that leads locals to purchasing drinking water. In the Western Desert, many conventional technologies of small-scale drinking water purification have failed.

New Technologies for Sustainable Drinking Water Purification

The main feature of AUTARCON's technology is the solar-driven electrolytic conversion of the naturally dissolved chloride to chlo-

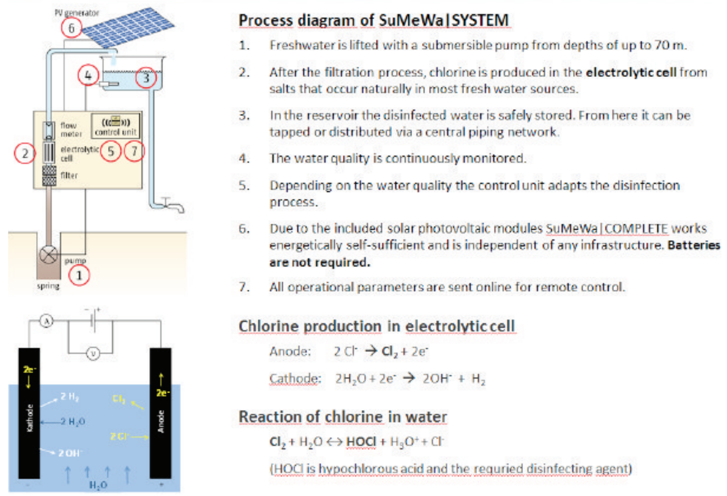

Figure 5: Working principle of SuMeWa|SYSTEM

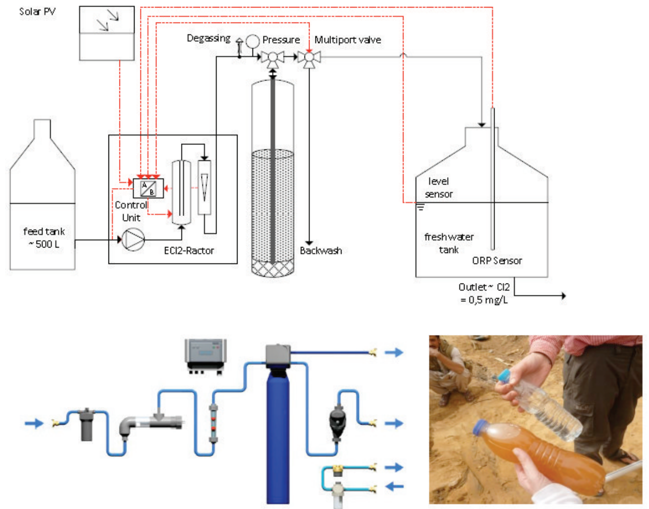

Figure 6: Setting of solar driven iron removal and disinfection system and water before and after treatment.

rine. Inline electrolytic chlorine production (electro-chlorination ECl2) allows the production of chlorine and other oxidizing substances directly from the water itself. As nearly all natural waters (except rain water) contain sufficient chlorides, no chemicals are required to run this process. In order to produce sufficient oxidants from such low concentrations, specially doped, mixed-oxide electrons and profound knowledge on how to control this process is required. Although a long-known solution, inline electrolytic chlorination is still not widely recognized as a water treatment technology, even though it has several advantages compared to the addition of oxidants, especially for remote regions. When producing sufficient quantities of chlorine from the natural Cl- content of the polluted water it can substitute handling and dosing of chlorine and thus serves multiple water treatment objectives.

With the supply of this oxidant, dissolved iron is oxidized, precipitates and becomes filterable. No chemicals ever have to be added to run this system. The water is safely disinfected and water quality is automatically monitored. This process – including pumping, filtration, and water quality monitoring – requires extremely low amounts of electricity and can run on a small solar energy system, which means water treatment stations can operate completely independently of external energy and chemical supply. Installation, operation and maintenance can be easily conducted by local residents.

AUTARCON has integrated such electro-chlorination systems into a comprehensive small-scale drinking water treatment setting that can be installed anywhere in the world independent from energy and chemical supply. The solution features pumping, filtration, disinfection and water quality monitoring systems. All systems contain a small robust ORP[1] sensor setting which continuously controls the water quality and indicates safe water. This allows for a continuous, fully automated adaption of the chlorine production process to the ever-changing local source water conditions and ensures that chlorine levels are always at the optimum required level. All operational parameters are also transferred online for remote system performance control by user, responsible water agencies and AUTARCON. Depending on source water quality, each system can safely disinfect up to 20,000 liters per day. The systems aim to supply the water with 0.5 mg/L of free chlorine as residual disinfectant after the water treatment, following WHO guidelines. The operational principle of the technology is schematically explained in Figure 6.

As the chlorine production process is energetically very efficient, the system can be run without external electricity supply if it is connected to solar PV technology. AUTARCON has mastered the challenge of running the disinfection units without the need for batteries. Pumping rates and chlorine production are adapted online to available solar radiation. At night, the system turns off. Residual disinfectant ensures safe water conditions until the next day. The system generally requires < 100 W of electricity. Solar PV modules between 200 – 400 Wp (including pumping) are generally sufficient to run the units during the day throughout the year. With market prices of around 0.5 USD per Wp, the systems can be supplied with energy at very low costs. Because of this innovative combination of solar and water technologies the system is called SuMeWa|SYSTEM – an acronym of the words Sun Meets Water. Most implemented solar stations produce surplus energy which allows local residents to charge mobile phones or run other small electric appliances. Each SuMeWa|SYSTEM produces enough drinking water for up to 2,000 people (up to 20,000 L/d) from wells or other fresh water bodies. Maintenance is conducted by local residents themselves, as only a toothbrush and some lime juice or vinegar is necessary. The setting was proven reliably remove iron and manganese in the laboratory as well as in field tests in the Western Desert. The filter is automatically backwashed in order to remove the filtrated iron flocks so that it is kept in a regenerated stage all the time. In the oases of the

Figure 7: Left-hand side: Water after backwash (left) and after AUTARCON filtration (right), right-hand side: the new system brings down iron levels to less than 0.03 mg/L (water on far left), which is well below the 0.42 mg/L level the water contains after filtration by the government station (middle) and the 4.46 mg/L level detected in the water before filtration (right).

1 ORP - oxidation reduction potential as an indirect indicator for chlorine concentration

Western Desert, the AUTARCON technology has also proven an extremely suitable solution due to its ability to run on solar energy, its extremely low maintenance requirements, and the fact that chlorination is managed automatically, ensuring that consumers can rely on having an appropriate amount of chlorine in their water at all times (Figures 7 and 8).

Since the first trials were performed in 2014, RISE has installed a total of 12 of these stations in the Western Desert. For the very first time, these communities have access to clean and healthy drinking water that tastes like bottled water. In order to generate sufficient income for maintaining the units, they have been equipped with a pre-paid public water tap. Locals pay a very marginal fee to tap the water, using a card system. Small water delivery services have emerged, creating new business opportunities for residents. The stations attract farm and factory owners who collect drinking water for their workers from as far as 50 km away, thus benefiting the entire region (Figure 9).

On the Red Sea Coast water does not contain high amounts of iron. RISE and AUTARCON installed a SuMeWa|SAFE system. This system does not require any filters, but ensures that chlorine levels are kept stable and the water is safe to drink. In the RISE pilot project, the system treats already desalinated water and is connected to the large water tank that stores the water for coastal residents and nomads in the wadi (Figure 10).

Conclusion

The partnership between RISE and AUTARCON is an example of German, Egyptian and American researchers working jointly on sustainable water management solutions for Egypt. The case of the water stations presented here, all of which were funded through corporate social responsibility funding, shows that often small-scale systems that make use of environmentally-friendly technology can work more efficiently and successfully than larger conventional approaches to water purification. Finding appropriate solutions for different locations is an absolute necessity in sustainable community development. The two AUTARCON solutions presented here were tailored exactly to the specific drinking water problems of people living in these remote areas of Egypt. The partnership also proves that technology transfer can be successful as long as it is kept simple, easy to handle, and manageable by local operators. Currently AUC and RISE are conducting thorough water quality analysis and community surveys to access the social, health-based and economic impacts of these stations.

Figure 8: Drinking water stations installed across the Western Desert.

Figure 9: AUTARCONs SuMeWa|SAFE station installed in a coastal village on the far southern Red Sea coast. In the top pictures the large storage tank for the village and the nomads in the wadis is visible.

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Potential of River Bank Filtration in Egypt

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Motivation

Drinking water supply in Egypt is based on surface water abstraction (91.4%), groundwater (8.3%) and desalination (0.24%). Surface water pollution, increasing treatment costs and the potential for the formation of disinfection byproducts justify the assessment of other sources. For example, more than 100 years ago, direct river water abstraction in Germany was widely replaced by river bank filtration (RBF) as a reaction to increased surface water pollution. Today, public water supply in Germany still depends to about 17% on bank filtration and artificial groundwater recharge. In Egypt, RBF use is less than 0.1% but could be developed on a wider scale. Based on the experiences from Germany, RBF can confront the problems that conventional treatment techniques in Egypt are currently facing. These problems include increasing contaminant loads, closure of plants during shock loads from flash floods, accidents and contaminant spills, seasonal algae blooms and their toxins and disposal of treatment plants backwash wastes.

Principle of River Bank Filtration

By definition, river bank filtration means induced recharge of river water, often as a result of pumping from wells installed along the banks of rivers or canals. However, water extraction on one side of a river could cause groundwater flow from the other side beneath the river bed toward the wells (Figure 1). The subsurface passage of surface water through the riverbed and aquifer material provides several natural treatment processes including filtration, biodegradation, adsorption and redox reactions. Bank filtration is a highly effective method for removing turbidity, organic contaminants, algae and microorganisms.

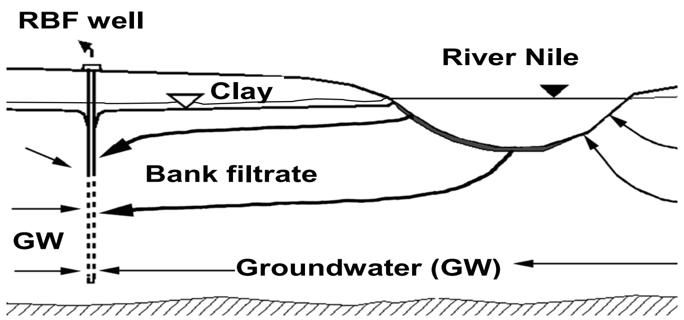

Figure 1: Schematic of river bank filtration

RBF in Egypt

Within a German-Egyptian research project, Ghodeif et al. (2016) investigated RBF test sites in Egypt that have been previously constructed and designed by local water companies along the Nile River and its main canal banks (Figure 2). Fortunately, a number of RBF schemes have been successfully constructed along the Nile in Upper Egypt that receive a substantial amount of bank filtrate share and produce water that complies with the Egyptian drinking water standards for organic, inorganic and microbial parameters (Shamrukh & Wahaab 2008; Abdalla & Shamrukh 2011; Abdel-Lah 2013). A few sites have either failed to deliver a substantial amount of bank filtrate or failed after short-term operation at very high abstraction rates due to canal bed clogging.

Hydrogeological Aspects

A good hydraulic connection between the river and the aquifer is a prerequisite for bank filtration. The Nile riverbed must cut into the aquifer or be lower than the bottom edge of the top layer. The average water depth of the Nile varies from 2.3 m to 6.2 m. The clay layer in the middle Nile Delta is too thick for the river to cut through and the shallow surface sandy top layer has an insufficient thickness for the abstraction of water. These conditions prevent the hydrologic connection and thus are unfavorable for RBF. In the