Comprehensive assessment and sustainable use of treated sanitary sewage in irrigation

A case study, Egypt

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1. Introduction

Egypt is a country that lived for centuries on a fixed amount of fresh water, mainly from the River Nile. However, during the last 200 years the population has increased 40-fold; from 2.5 million in 1800 to almost 100 million at the present time. The obvious result of this has been a large deficit in the country's water budget that has had to be overcome through the successive recycling of water inside the closed basin system. The water multiplier in Egypt is estimated now at between 300 and 400%, meaning that every cubic meter of fresh water is recycled three to four times before it is disposed of into the Mediterranean.

Reuse of marginal water is not new to the Egyptian irrigation practitioners. It is believed that Al Gabal Al Asfar farm, located on the eastern side of Cairo, was established early in the 19th century to receive part of the treated sewage of the city (3000 Feddan). A large area of citrus on the farm is still irrigated with treated sewage. El Serw pumping station, on the north eastern part of the Nile Delta, was built in 1928 to lift drainage water from the perrenial irrigated land to the Domietta Branch, a distributary of the Nile.

Reuse of land drainage water was practiced on a large scale when all drains of Upper and Middle Egypt were designed to flow by gravity to the main course of the River Nile, following the construction of the High Aswan Dam in the 1960s.

The fast-growing population and the limited area of cultivable land, especially in Middle and Upper Egypt, forced large numbers of inhabitants of rural areas to migrate to urban areas. Consumption of potable water in urban areas grew progressively larger. This consumption was always deducted from the irrigation water simply because agriculture had the lowest return when compared with industry, tourism, or even fish farming. The situation as it now stands is that agriculture is getting almost 70% of the country's water budget while municipal and potable water is getting 15%, the remaining 15% is distributed between industry and all other activities.

Expectations now are that the population of Egypt is likely to reach 120 million by 2030 and almost 150 million by 2050. This rapidly increasing population will certainly be followed by a corresponding increase in the potable water supply at the expense of irrigation water.

Therefore, it is essential to recycle the vast quantities of municipal and domestic wastewater – currently about 7 billion[1] m^3/year. This quantity is a product of the almost 9–10 billion m^3 of potable water that are consumed by the majority (95–97%) of the Egyptian population country wide. Almost 50% of the sewage produced receives either primary or secondary treatment in the hundreds of plants scattered among the main cities, towns, and large villages. The other 50% of the sewage comes mainly from small villages that are not covered by treatment facilities yet.

Villagers can only dispose of their raw sewage through primitive septic tanks that need to have their surplus water emptied regularly. The other alternative is to connect to the nearest land drainage canal. Even in urban areas where there are sewage treatment plants, the ultimate connection for treated sewage is into these drains. This is a consequence of the closed basin status of the whole country in which water enters from one end (the High Aswan Dam Reservoir in the south) and leaves from the other end (the Mediterranean in the north).

There are only a few sites where treated sewage is used for the irrigation of timber trees. These are scattered mainly on the desert fringes of the Nile Valley and Delta.

Potable water and sewage treatment in Egypt are both subject to heavy government subsidies. The initial and running costs of both potable and sewage treatment plants is a huge burden on the country's budget, while if management of this marginal-quality water could be practiced on a sound scientific basis, it may lead to highly feasible conditions both economically and environmentally.

Treated sanitary sewage has a number of relative advantages over fresh water supply. These are:

- It relieves the land drainage canals of the extra quantity and the low quality of sewage which might cause negative environmental impacts
- It is highly nutritious and may contain useful elements for different crops
- It is produced continuously round the clock (does not follow the irrigation rotation system)

[1] 1 billion = 10^9

- It is produced locally in a large number of localities, which may reduce the conveyance and distribution costs
- It may be used for the production of high value, non-edible cash crops including industrial crops (cotton, flax, jute, etc.), cut flowers, ornamentals, timber trees, etc.

If treated, sewage can be subjected to further polishing through low cost techniques (e.g. engineered wetlands) so that it may become suitable for irrigating most edible and non-edible commodities.

In view of the ambiguous relationship between Egypt on the one hand and the Nile Basin countries on the other, there is very little chance of increasing the country's quota of Nile water, especially in the near future. The alternative would be either to desalinate sea and brackish groundwater or to pump from deep non-renewable groundwater reservoirs in the deserts, both of which are extremely expensive. This leaves treated wastewater as one of the low cost options that has to be seriously considered.

Most indicators show that climate change and the corresponding increase in temperature, reduction in rainfall (both inside Egypt and in the Nile Basin countries), and sea level rise might negatively affect groundwater storage in the northern part of the Nile Delta. They will certainly have severe impacts on the country's water balance (a reduced supply combined with an increased demand), hence, treated wastewater may prove to be one of the most important solutions.

2. Literature review

Reuse of wastewater provides a reliable alternative source for irrigation in arid and semi-arid regions. This water resource has been commonly used for agricultural activities because of the scarcity of freshwater resources (Carr et al., 2011; van der Hoek, 2004; Pescod, 1992). Irrigation with raw or diluted wastewater continues to increase in several regions in developing countries where wastewater treatment does not keep pace with urban growth and urban food demands (Qadir et al., 2010). Growing water stress, urbanization, urban wastewater generation, and agricultural activities are the key drivers that lead to the growing use of wastewater in agricultural activities in and around urban centers (Dreschel et al., 2010). The use of wastewater for irrigation helps in realizing societal and environmental goals, such as increasing production or profits and reducing wastewater discharges to the environment. However, it needs to be realized that wastewater is a source of harmful pathogenic diseases and it contaminates aquifers and water surfaces (Hamilton et al., 2007; Chen et al., 2005; Singh et al., 2004). Abou El Seoud and Matthews (2013) listed the main water management challenges facing the Arab region as:

- Water shortage and drought
- Environmental/ecological deterioration
- Weak economies and low investments in the water sector
- Inadequate water supply and sanitation facilities
- Poor water governance
- Political instability.

Given the pros and cons influencing the reuse of treated wastewater, El-Gohary (2006) emphasized that scientific planning and an integrated management approach, as well as raising wastewater-users' awareness of its properties and quality are required when irrigating different crops. They are essential for reducing the environmental risks and achieving the safe use for this resource. Huibers et al. (2010) suggested four precepts when establishing wastewater governance that accommodate agricultural use in the developing countries:

- The use of the (reverse) water-chain approach to design wastewater systems
- Decentralization of wastewater management services and systems

- Policy coherence and coordination for linking sectors, attributes, and costs
- Stakeholder involvement.

There is an urgent need for updated national data on wastewater generation, treatment, and use, which would also assist in regional and global wastewater assessments (Sato et al., 2013). Management practices for wastewater reuse in irrigation are critical for sustainable agricultural production. Mapping the potential quantities of wastewater available for reuse as well as the related costs and profits in different regions, could be helpful in improving water resource management. In order to set guideline limits for reclaimed wastewater reuse, more microbial and chemical risk assessments are required (Salgot et al., 2006). The World Health Organization (WHO) published guidelines for the safe use of wastewater (WHO, 2006), which are intended to be used as the basis for the development of international and national approaches to manage the health risks associated with wastewater use in agriculture. Additionally, public awareness campaigns are needed to address the legal, social, economic, and institutional considerations for treated wastewater (TWW) reuse (Mizyed, 2013). It might be beneficial to base the intention on a clear explanation of why reuse is a proposed solution (Hochstrat et al., 2008). Hamilton et al. (2007) identified the significant gaps in the science of sustainable wastewater irrigation:

- Long-term accumulation of bioavailable forms of heavy metals in soils
- An understanding of the balance of various factors affecting the environmental fate of organics in wastewater-irrigated soils
- The influence of reuse schemes on catchment hydrology, including transport of salt loads
- Risk models for helminth infections (mostly pertinent to developing nations)
- Application of public health microbial risk assessment models to wastewater contamination of aquifers and surface waters used by humans
- Transfer efficiencies of chemical contaminants to plants
- Effects of chronic exposure to chemical contaminants through consuming wastewater-irrigated food
- Detailed understanding of the psychology and sociology of wastewater irrigation, particularly in different cultures.

Definitions

WHO (2006) defined wastewater as the liquid waste discharged from homes, commercial premises, and similar sources to individual disposal systems or to municipal sewer pipes, and which contains mainly human excreta and used water. WHO called the water, which is produced by households and commercial activities, domestic or municipal wastewater or domestic sewage. According to the Egyptian code for the reuse of TWW for agricultural purposes (ECP 501, 2005), municipal wastewater is defined as the water that is produced by domestic and commercial establishments as well as the industrial effluent that was primarily treated to meet the sewer pipe network's criteria. Recently, Corcoran et al. (2010) defined wastewater as A combination of one or more of: domestic effluent consisting of black water (excreta, urine and fecal sludge) and greywater (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, storm water and other urban runoff; agricultural, horticultural and aquaculture effluent either dissolved or as suspended matter.

Marginal-quality waters refer to waters that are generated from the treatment of wastewater (municipal waste, urban rainfall runoff, and industrial waste). They can be called TWW or recycled water, gray water, treated or untreated brackish water, or treated or untreated agriculture drainage water. For the purpose of clarification, the following are definitions of the different components of marginal-quality waters.

TWW or recycled water is water that, as a result of the treatment of wastewater, is suitable for direct beneficial use or a controlled use that would not otherwise occur. (Adapted by the California Water Code Section 13050(n) available at http://www.leginfo.ca.gov/cgi-bin/displaycode?section=wat&group=13001-14000&file=13050-13051)

Graywater is untreated wastewater that has not come into contact with toilet waste. It includes water from clothes washing machines, showers, bathtubs, hand washing, lavatories, and sinks that are not used for the disposal of chemicals or chemical-biological ingredients. (Also spelled as gray water or greywater.)

Brackish water or ***briny water*** is water that has more salinity than fresh water, but less than seawater (about 35,000 mg/L). For the purpose of this study, brackish water is water containing from 2 to 10,000 mg/L dissolved salts or that has an electrical conductivity between 3.0 and 12.5 dS/m. It is sometimes referred to as slightly moderately saline water. Generally, this water is naturally developed water and is free of agriculture inputs, such fertilizers, pesticides, and herbicides.

Agriculture drainage water is the water that is naturally or artificially generated as a result of surface and/or sub-surface water flows from agriculture fields and it contains levels of agriculture inputs, such as fertilizers, pesticides, and herbicides.

The current and the potential use of wastewater for irrigation

Wastewater reuse is an essential alternative for sustainable water management. Wastewater is used for aquaculture and artificial groundwater recharge. However, agriculture is the largest water consumer and the reuse of wastewater is extensively practiced for the irrigation of cultivated soils. Agricultural irrigation is the oldest and most widespread reuse of treated or untreated wastewater for growing food, energy crops, or any other industrialized crop (Jiménez-Cisneros, 2014). The main risks of and constraints to wastewater use in agriculture could include the presence of pathogens, possible pollution of the soil and of the aquifer, salinity, toxicity, and acceptability in the market of the products grown using it (Bixio et al., 2008). Worldwide, 20 million ha of agricultural land are irrigated directly with untreated or TWW (Jiménez and Asano, 2008). According to a World Bank study, Mexico (4.493 million m^3/day), Egypt (1.918 million m^3/day), and China (1.239 million m^3/day) are the largest users of wastewater for irrigation (Dreschel et al., 2010). Sato et al. (2013) reported the volumes of wastewater generated, treated, and used based on country-specific data. The authors found that high-income countries, on average, treat 70% of their generated wastewater. They are followed by upper-middle-income countries (38%), lower-middle-income countries (28%), and low-income countries, where only 8% of the wastewater generated is treated. Therefore, it is possible to increase the amount of wastewater treated by from 30% to 92%.

In Europe, limited wastewater reuse can be observed because of the abundance of water resources in the northern countries. However, industry is generally encouraged to recycle water and use reclaimed wastewater. Whereas in the southern countries, with limited water resources, wastewater reuse provides an additional alternative for crop and golf course irrigation (Angelakis and Bontoux, 2001). The lack of comprehensive knowledge of the hazards associated with wastewater reuse, the difficulties in assessing the quality of reclaimed water, and poor management of the social aspects are the main reasons for the limited reuse of wastewater in these southern countries (Salgot, 2008). In France, the use of treated municipal wastewaters for the irrigation of crops and landscaped areas continues to cause serious thinking while its application remains very limited (Bontoux and Courtois, 1996). In the near future, the safe use of treated municipal wastewater is expected to become a systematic routine practice in both Greece and Spain (Pedrero et al., 2010). In Greece, the reuse of TWW is still experimental. The intent is to establish a scientifically sound and safe basis for reuse. In Spain 346 million m^3 of water per year are reused in Spanish agriculture. This amount of wastewater reuse could increase to1.1 billion m^3 (Pedrero et al., 2010). There is significant potential for the increased use of reclaimed wastewater in many European countries, specifically in the Mediterranean region (Hochstrat et al., 2006). The water sector in Europe is in a transitional phase with unique opportunities for water reuse to be implemented on a larger scale (Bixio et al., 2006).

In Asia, many countries considered wastewater as an alternative water resource for irrigation and as a way to reduce effluent discharges. For instance, China started using municipal wastewater to irrigate farmlands in the 1940s (Wei et al., 2006). For social, ecological, and economic reasons, China had not undertaken wastewater reclamation and reuse in an extensive way until quite recently (Chang et al., 2013). Yi et al. (2011) reported that 29% of the reclaimed wastewater – 1.66 billion m^3 – was used mainly for agricultural irrigation in 2008. The authors summarized the main issues limiting the use of reclaimed water in China as:

- Insufficient knowledge of water resources and incomplete regulations and supporting policies on the use of reclaimed water
- The pricing structure for marketing reclaimed water
- Lack of public awareness and acceptance
- Insufficient financial support
- Lack of a distribution network
- Lack of provision to ensure the reliability of the treatment facility
- Lack of systemic risk management.

In Vietnam, at least 9000 ha of land were found to be irrigated with wastewater (Raschid-Sally et al., 2004). Wastewater is commonly used in agriculture because it is a reliable source of water and nutrients (Raschid-Sally et al., 2001). In a recent study, Trinh et al. (2013) showed that wastewater effluent can be used to irrigate at least to 22,719 ha of paddy rice. That would eliminate part of the demand for synthetic fertilizers. The wastewater will provide a maximum of 22% of the nitrogen (N) and 14% of the phosphorus (P) requirement for the winter–spring crop. As an example of wastewater reuse, landscape irrigation with TWW is a well-established and successful practice in Saudi Arabia. Wastewater treatment has effectively reduced pollution of the environment and provided a valuable source of water supply for landscape irrigation (Al-A'ama and Nakhla, 1995). Hussain and A1-Saati (1999) conducted a comprehensive review that identified a potential for the recycling and reuse of wastewaters in agriculture following appropriate water treatment. The authors showed that wastewater for irrigation has a special significance because of the country's water scarcity as well as this water resource providing an appreciable amount of crop nutrients. Industrial and urban water reuse should be considered along with desalination as options for water supply in Saudi Arabia (Kajenthira et al., 2012).

The USA uses about 911 million m^3/day of wastewater for irrigation (Dreschel et al., 2010). In 1918, the State of California issued the first water reclamation and reuse standards in the US and addressed reuse for agricultural irrigation (Crook and Surampalli, 1996). In both Arizona and California, water reuse systems were developed to provide water for agricultural irrigation in the late 1920s (Asano and Levine, 1996). The recycling and reuse of TWW are likely to be considered as adaptation options in the future to cope with the water scarcity that could result from climate change (Mehta et al., 2013). In agreement with that, (Chen et al., 2013) analyzed the benefits and risks associated with reclaimed water irrigation in California. The authors found that reclaimed water can be a reliable and economical water resource and could ameliorate soil health conditions. They concluded that irrigation with reclaimed water is generally safe, and should be encouraged and promoted.

In Africa, the reuse of wastewater for irrigation is commonly practiced in Morocco, Tunisia, and Egypt, among others (Choukr-Allah 2005; Abu-Zeid, 1998; Bahri and Brissaud, 1996). For instance, wastewater reuse for agriculture is a well-established practice in Tunisia, where 118 million m^3/day is used for irrigation (Dreschel et al., 2010). Using untreated wastewater poses a real problem in such countries. In Morocco, Hajjami et al. (2013) evaluated the potential risks of reusing raw and TWWs for irrigation. They concluded that reuse of raw wastewater caused a parasitological contamination of irrigated crops and should be restricted. Crop choice and agricultural management are critical aspects in reducing the risks of using untreated wastewater for irrigation. Abdulai et al. (2011) examined the adoption of safer irrigation technologies for producing vegetables with untreated wastewater in Ghana. The authors concluded that understanding the adoption potential of new irrigation technologies and farmers' strategies in using untreated wastewater for irrigation are critical for improving current irrigation practices and also for recommending policies for food security and poverty alleviation in developing countries.

Wastewater reuse for irrigation in Egypt

Egypt has already exhausted its fixed share of the Nile waters and extracting groundwater requires expensive processes (E1-Kady and E1-Shibini, 2001). Thus, reuse of wastewater is a valuable alternative water resource for irrigation. According to the United States Environmental Protection Agency (USEPA, 2004a, b), about 42,000 ha of land had been irrigated with treated, undiluted, or diluted wastewater.

Numerous authors provide detailed studies on the effects of wastewater reuse in irrigation on Egyptian soils (Elbana et al., 2013; El Sayed et al., 2003; Elgala et al., 2003; Kandil et al., 2003; Rabie et al., 1996).

El Sayed et al. (2003) examined the TWWs from Al Gabal Al Asfar and Elberka wastewater treatment plants (WWTPs), which exhibited low concentrations (below the national limits set by Decree 44/2000) of all chemical constituents that are of agronomic and environmental concern for both short- and long-term reuse. In agreement with this, Elbana et al. (2013) found that the concentrations of lead, cadmium, copper, and nickel were less than the permissible levels for irrigation in all wastewaters used for irrigation at Al Gabal Al Asfar sewage farm (sandy soils). In addition, they assessed the effects of long-term irrigation with sewage effluents on the soil properties. The authors recommended that monitoring of heavy metal levels in the soil profile and remediation programs, as well as management strategies, are needed in the study area. In clay soils, Zinien area, El Giza Governorate, Kandil et al. (2003) evaluated soil and field crop pollution resulting from different irrigation water qualities (sewage waste water, secondary treated sewage water, water polluted with human activities and wastes, and canal water). They concluded that the prolonged effects of using low quality water for irrigation was reflected in an increase in heavy metal accumulation in the soil and plants. Therefore, the successful use of that water greatly depends on its being properly treated, adopting appropriate strategies aimed at maintaining soil productivity, and safeguarding public health and the environment. This is particularly the case where treatment plants operate below design capacity, which contributes to the discharge of untreated wastewater into irrigation canals. For example, wastewater constitutes 75% of the total flow of the Bahr El Baqar Drain that is used in the Eastern Delta, Egypt, for irrigation. Soil contamination with cadmium was observed in soil samples (FAO, 1993). In the rural areas, 95% of citizens have no access to sewer systems or wastewater treatment facilities; latrines and septic tanks were used for excreta and wastewater disposal (Abdel-Shafy and Aly, 2007).

The guidelines and laws regulating wastewater reuse

Several publications regarding the guidelines and measurement of standards for wastewater reuse have been published worldwide. WHO published a series of guidelines about the safe use of wastewater (WHO, 2006; WHO, 1989; WHO, 1973). The recent guideline – *Guidelines for the safe use of wastewater, excreta and greywater* – is intended to be used as the basis for the development of international and national approaches to assess and manage the risks associated with wastewater reuse in agriculture. Since the main environmental concern is public health, Shalaan (2003) recommended that standard quality wastewater should be conveyed away from the general public, or a clear indication of its quality should be provided. WHO (2006) suggested a combination of health protection measures to reduce the pathogen hazards. These included crop restriction, wastewater application techniques, pathogen die off between last irrigation and consumption, food preparation measures, human exposure controls, and wastewater treatments. The selection of these health protection measures depends on several factors, such as the availability of labor and funds. These measures require regular monitoring to ensure the functionality of the system. A variety of physical and chemical parameters should be monitored at regular intervals to verify the performance of wastewater treatment system (WHO, 2006). For instance, the threshold levels of trace elements in the irrigation water for crop production can be monitored to determine the potential risk to environmental resources. For this purpose, WHO (2006) reported the threshold levels of trace elements based on Pescod (1992) as shown in Table 1.

Table 1: The threshold levels of trace elements for crop production

Element	Recommended maximum concentration (mg/L)	Element	Recommended maximum concentration (mg/L)
Aluminum	5.00	Lithium	2.50
Arsenic	0.10	Manganese	0.20
Beryllium	0.10	Molybdenum	0.01
Cadmium	0.01	Nickel	0.20
Cobalt	0.05	Lead	5.00
Chromium	0.10	Selenium	0.02
Copper	0.20	Vanadium	0.10
Iron	5.00	Zinc	2.00

Source: Adapted from Pescod, 1992.

Table 2: Recommended water quality criteria for irrigation

Constituent	Maximum concentrations for irrigation (mg/L)	Remarks
Aluminum	5.0	Can cause non-productiveness in acid soils, but soils with pH between 5.5 and 8.0 will precipitate the ion and eliminate the toxicity
Arsenic	0.1	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice
Beryllium	0.1	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans
Boron	0.75	Essential for plant growth; sufficient quantities are present in reclaimed water to correct soil deficiencies. Optimum yields are obtained at a few tenths of a mg/L; toxic to sensitive plants (e.g. citrus) at 1 mg/L. Most grasses are tolerant at 2.0–10 mg/L
Cadmium	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L; conservative limits are recommended
Chromium	0.1	Not generally recognized as an essential element; given the lack of toxicity data, conservative limits are recommended
Cobalt	0.05	Toxic to tomatoes at 0.1 mg/L; tends to be inactivate in neutral and alkaline soils
Copper	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/L
Fluoride	1.0	Inactivate in neutral and alkaline soils
Iron	5.0	Not toxic in aerated soils, but can contribute to soil acidification and loss of phosphorus and molybdenum
Lead	5.0	Can inhibit plant cell growth at very high concentrations
Lithium	2.5	Tolerated by most crops up to 5 mg/L; mobile in the soil. Toxic to citrus at low doses – recommended limit is 0.075 mg/L
Manganese	0.2	Toxic to a number of crops at few tenths of a mg/L to a few mg/L in acidic soils
Molybdenum	0.01	Non-toxic to plants; can be toxic to livestock if forage is grown in soils with a high molybdenum concentration
Nickel	0.2	Toxic to a number of plants at concentrations of 0.5 to 1.0 mg/L; reduced toxicity under neutral or alkaline pH
Selenium	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium
Vanadium	0.1	Toxic to many plants at relatively low concentrations
Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils
Tin, Tungsten, and Titanium	–	Excluded by plants; specific tolerance levels unknown

Source: USEPA et al., 2012.

Recently, the USEPA collaborated with the United States Agency for International Development (USAID) to update the 2004 Guidelines for Water Reuse (USEPA, 2004a, b). As a collaborative effort between USEPA, the National Risk Management Research Laboratory, and USAID, the 2012 Guidelines for Water Reuse were intended to further develop water reuse by serving as an authoritative reference on water reuse practices (USEPA et al., 2012).

Similar to WHO (2006), the USEPA guidelines consider the water quality criteria for irrigation, emphasizing that fine-textured neutral and alkaline soils have high capacities to remove the different pollutant elements (see Table 2). In addition, USEPA et al. (2012) reported examples of global water quality standards for non-food crop irrigation. In Italy the total coliform count per 100 mL must be less than 23, while in Germany it must be less than 100. WHO (2006) recommended a fecal coliform or *E. coli* level of less than 10,000 per 100 mL for the safe use of wastewater for agriculture. The corresponding recommended value in the USEPA guidelines (USEPA et al., 2012) is less than 200 fecal coliform or E. coli per 100 mL.

The Egyptian code for the reuse of TWW for agricultural purposes prohibits the use of raw (untreated) municipal wastewater for agricultural use (ECP 501, 2005). Treated wastewater has been classified into three categories (A, B, or C) according to the treatment level (see Table 3). That in categories B and C can be used for agriculture purposes in desert areas, while category A TWW can be used for landscape irrigation in urban areas. Moreover, the Egyptian code reports the threshold levels of trace elements and the chemical properties of TWW based on Pescod (1992) as shown in Table 4.

Table 3: Criteria for treated wastewater for agricultural use

Criteria	Treatment level		
	A	B	C
Biological oxygen demand (BOD, mg/L)	< 20	< 60	< 400
Suspended solids (mg/L)	< 20	< 50	< 250
Fecal coliform or *E. coli* per 100 mL	< 1,000	< 5,000	Not defined
Intestinal nematodes (eggs/L or cells/L)	< 1	< 1	Not defined

Source: ECP 501, 2005.

Table 4: Chemical criteria for treated wastewater for long-term use in agricultural irrigation

Chemical	Recommended maximum concentration (mg/L)	Chemical	Recommended maximum concentration (mg/L)
Aluminum	5.00	Mercury	0.002
Arsenic	0.10	Vanadium	0.10
Beryllium	0.10	Cobalt	0.05
Copper	0.20	Boron	1.0
Fluorine	1.50	Molybdenum	0.01
Iron	5.00	Phenol	0.002
Lithium	2.50	Total (PO_4)	30
Manganese	0.20	Chlorine	400
Nickel	0.20	SO_4	500
Lead	5.00	HCO_3	400
Selenium	0.02	Sodium adsorption ratio	(6–9)
Cadmium	0.01	Sodium	230
Zinc in the Nile Delta	5.00	Magnesium	100
Chromium	0.10	Calcium	230

Source: Adapted from ECP 501, 2005.

3. Assessment of the current situation of infrastructure, production of wastewater, and its reuse

Wastewater treatment plants in the Nile Delta

It is important at this point to distinguish between the different geographic regions of the country with respect to sanitary sewage treatment and disposal.

The Nile Valley (both Upper and Middle Egypt)

All wastewater of this part of the system including land drainage, treated and raw sanitary sewage, and treated and untreated industrial effluent all are disposed of to the main course of the River Nile. Since the flow of fresh water in the river is very high compared with the return flow from the land, sewage, and industry, the impact of pollutants on the river flow can be considered insignificant.

The Nile Delta

The Nile Delta includes most of the country's industry, two-thirds of the country's population, and more than 5 million feddan[2] of fertile agricultural land. Most of the water residues from the city of Cairo go to the Delta (e.g. wastewater from the Al Gabal Al Asfar treatment plant ends up in the Bahr El Baqar Drain, which is carries it to Lake Manzala in the Eastern Delta. The Al Rahawy Drain carries part of the Giza sewage to the Rosetta Branch of the Nile River, etc.). Drains of the Nile Delta carrying land drainage, treated and raw sewage, and industrial effluent dispose of their loads either directly to the Mediterranean or indirectly through the coastal lakes (from east to west, these are: Manzala, Borollous, Edko, and Mariout). List of treatment plants in Nile Delta is provided in Table 5.

The Eastern Desert

The Red Sea Governorate includes the Eastern Desert and the oil cities of Safaga, Kosair, Herghada, and Marsa Alam. Far to the south, the cities of Halaib, Shalatin and Abu Ramad are located on the border with Sudan. This region is one of the least populated and has a limited area of agricultural land. Wastewater from the region, which depends mainly on costly desalinated water, is disposed of to the Red Sea.

Sinai Peninsula

The northern edge of Sinai runs parallel to the Mediterranean on the western part of the peninsula; Lake Bardaweel connects with the sea. Again Sinai is an area with a very low population density.

The Western Desert

The Western Desert runs parallel to the Mediterranean west of the city of Alexandria to the border city of Salloum. This strip is only over-populated during the two summer months of July and August. During, the second half of June and the first half of September it may be partially populated.

In conclusion, flows of fresh and wastewater to and from the Nile Delta form approximately 60–70% of the country's total, and, therefore, they should be given the same weight when undertaking a cost–benefit assessment for the whole country.

Table 5: Distribution of wastewater treatment plants in the Nile Delta from north to south (2015)

Wastewater Treatment Plant	Number of treatment plants	Design Capacity (1,000 m³/day)	Actual discharge (1,000 m³/day)
Cairo	13	4,565	3,504
Qalubia	15	288	135
Menoufia	19	355	220
Sharkia	31	384	260
Gharbia	33	570	442
Kafr El Sheikh	22	282	194
Behiera	25	474	212
Dakahlia	45	548	463
Alexandria	17	1,599	1,232
Domietta	27	319	260
Port Said	8	245	200
Total	255	9,629	7,122

[2] 1 feddan = 0.42 ha.

Wastewater reuse in the Nile Delta

Primary treated sanitary sewage has been in used for irrigation in Al Gabal Al Asfar farm, north east of Cairo, since 1911. However, the experience of large-scale reuse is still limited, simply because there was always an ample supply of fresh water, both from the Nile and from groundwater reservoirs. There was also a cultural reason behind the reluctance to reuse such water and that is the non-suitability of this water even for irrigation in some of the Islamic sharia.

It should be noted that the only applicable legislation at the present time is a Ministerial Decree issued in the 1990s that allowed the use of treated sewage only for the irrigation of timber trees. Therefore, the irrigation of any other trees or farm crops until now is banned under the prohibition of this Ministerial Decree.

In 2005, a code of practice for the reuse of treated sewage was issued trying to connect the water quality of the treated sewage and its suitability for irrigation. The code prohibited the use of secondary treated sewage for the irrigation of edible crops that are eaten raw. But it did allow use of this water for processed crops (like wheat) and the irrigation of trees the fruits of which have a non-edible skin (like citrus and bananas). The idea behind the code was to direct treated sewage to a nearby farm that produces commodities the sale of which can help defray part of the cost of operation and maintenance of the plant.

A good example is the South Helwan treatment plant in the south-eastern districts of Cairo, which was planned to irrigate an area of about 45,000 feddan in the Al Saff irrigation project. It was planned to mix treated sewage with fresh water for the irrigation of timber trees. However, being close to the consumer markets in Helwan and Maadi, the temptation to produce fresh edible crops could not be resisted and the whole country was devastated on a number of occasions when it became known that vegetables sold to the public were being produced by irrigating with sewage water. What made the public scandal even worse was that the plant was not able to treat the excessive incoming flow and the water quality was not that of either secondary or even primary treated sewage, but was sometimes completely raw sewage.

Because of this rather bad experience, a number of pilot farms were spread throughout the country in order to show the cost effectiveness of reusing of treated sewage. The remaining part of the treated and raw sewage is assumed to return back to the land drainage canals or to infiltrate to the groundwater.

The plan of the Holding Company for Water and Wastewater (HCWW) is to irrigate 80,000 feddan of marginal desert land distributed between 14 governorates and 2 districts and involving over 63 pilot locations. At present, just 12,000 feddan are cultivated. A summary of these locations is shown in Table 6.

The local governments in some parts of the country are voluntarily using treated sewage for irrigation in an area of about 5000 feddan. Details of this area are shown in Table 7.

It should be noted that one of the Giza main WWTPs, Abo Rawash, disposes of its treated water to the Al Rahawy Drain, which is connected to the Rosetta Branch. Table 8 presents the total discharge of sanitary drainage to the Nile Delta.

This is to say that almost 8.1 billion m^3 per day of treated sewage is actually drained to the Delta every day and this can be increased in the near future to reach 10.6 billion m^3/day.

The total amount of treated sewage in the country, according to the records of the Holding Company for Potable Water and Sanitary Sewage (2014), is 10,111,926 m^3/day as an actual quantity while the design discharge is 13,188,299 m^3/day. There are 375 WWTPs distributed throughout the country as shown in Table 9.

- Of this total only 10 WWTPs are equipped to receive industrial effluent
- The records of the HCWW indicate that 40 plants need to raise their efficiency
- Only two WWTPs produce tertiary treated water (May 15 City and October 6 City)
- Most of the WWTPs use the conventional activated sludge technique
- Most of the new communities (Ramadan 10, Shrouk, Badr, Sadat, etc.), which are constructed mainly on the desert fringes, have oxidation ponds, simply because desert lands can easily be made available
- When land availability become a constraint, gravel filters provide a solution for relatively large discharges and extended aeration for smaller

Table 6: Overview of the reuse locations

Governorate	No. of locations	Design discharge of WWTP 1,000m^3/day	Allocated land area (feddan)		
			Cultivated	Fallow	Total
Menoufia	1	36	1,200		1,200
10th of Ramadan	1			4,776	4,776
Beni Suef	3	74	300	1,821	2,121
El Minia	2	110		7,000	7,000
Faiyum	2	7	80	140	220
Assiout	9	472	400	12,507	12,907
Sohag	8	292	3,600	11,158	14,758
Luxor	3	56	700	1,506	2,206
Qena	11	325	900	16,340	17,240
Aswan	7	153	2,025	2,469	4,494
New Valley	5	79	650	4,283	4,933
Ismailia	1	20	500		500
Red Sea	4	94	200	4,609	4,809
Matrouh	1	50	950	1,105	2,055
North Sinai	2	65	250	2,350	2,600
South Sinai	3	67	500	67,708	79,763
Total	63	1,900	12,255	137,772	161,582

discharges. Gravel filters are used in most of the minor cities inside the Delta, where capital and major cities are generally using the conventional activated sludge technique

- Variations between treatment methods can be attributed to the assignment of a variety of consulting houses, which is normally done by funding organizations. Note that most of the sewage treatment facilities were constructed through grants or loans from these organizations
- The number of users, pressure lines, and gravity lines throughout the country is detailed in Table 10
- Almost 100% of the treated water is disposed of in the nearest drain. Good examples are the water from Al Birka, Al Gabal Al Asfar (stage 1), and Al Gabal Al Asfar (stage 2). A total of 2.26 million m^3/day is drained to Bellies Drain, which ends in Bahr El Baqar Drain. Bahr El Baqar Drain connects to Lake Manzala which is in direct connection with the Mediterranean
- In a number of the drains that receive treated sewage it is mixed with fresh water for some of the irrigation canals (see Table 11)
- About 11.5 billion m^3/year is the volume obtained if the amount of drainage water from Upper Egypt that is mixed with Nile water between Aswan and Cairo is added to the amount reused in the Delta. This figure forms part of the country's water budget that is used for different activities. The irrigation of agricultural fields accounts for about 70–75 % of this budget. The amount of water reused does not include the unknown quantity of drainage water reused by farmers when they face a shortage in the supply of fresh water.

It has to be concluded that drainage water is widely used in the Nile Delta either directly by individual farmers or indirectly by mixing drainage water with fresh water and using the mixture for irrigation.

Table 7: Details of areas voluntarily irrigated with treated sewage

Location	Governorate	Area (feddan)	Irrigation system	Crop irrigated
Alexandria	Alexandria	70	Drip	Eucalyptus, Casuarina, Salsify
Gamasa	Dakahlia	100	Drip	Serw, Eucalyptus, Turninalia
Sadat city	Menoufia	500	Drip	Serw, Eucalyptus, Pines, Casuarina, Palm
Abu Rawash	Giza	80	Surface	Eucalyptus, Casuarina, Zanzalaght
El Saff	Giza	120	Drip	Khaya, Serw
Arab El Madabegh	Assiout	45	Drip	Khaya
Awlad Azaz	Sohag	267	Surface	Khaya
Al Qola	Sohag	250	Drip	Jatropha
Luxor 1	Luxor	260	Surface	Jatropha, Mulberry
Luxor 2	Luxor	700	Drip	Eucalyptus, Khaya, Acacia
Qena	Qena	300	Surface	Khaya
Edfu	Aswan	300	Surface	Khaya
Ballana	Aswan	280	Drip	Khaya
Wadi El Alaqi	Aswan	60	Drip	Khaya
Nasr El Nouba	Aswan	100	Surface	Khaya
El Kharga	New Valley	300	Surface	Khaya, Neem, Casuarina, Temin
Baris	New Valley	60	Surface	Khaya
Mout	New Valley	160	Drip	Jatropha, Jojoba
El Rashda	New Valley	25	Surface	Eucalyptus, Terminalia
Serabium	Ismailia	500	Drip	Serw, Pines, Eucalyptus, Khaya, Mulberry
Hurghada	Red Sea	200	Drip	Khaya, Casuarina
Sharm El Sheikh	South Sinai	20	Drip	Eucalyptus, Casuarina
El Arish	North Sinai	80	Drip	Serw, Pines
El Tour	South Sinai	200	Surface	Serw, Eucalyptus, Casuarina, Oram Palm
Total	4,977			

Table 8: Total discharge of sanitary drainage to the Nile Delta

Total discharge	Design discharge (million m^3)	Actual discharge (million m^3)
Cairo and Delta Governorates	9,371.050	7,231.686
Abo Rawash	1,200	850
Total Delta	10,571.050	8,081.686

Table 9: Number of WWTPs in the country by governorate

Governorate	Number of WWTPs
Cairo	11
Giza	7
Qalubia	13
Menoufia	19
Sharkia	29
Gharbia	35
Total	114
Kafr El-Sheikh	22
Dakahlia	43
Behiera	24
Domiat	27
Alexandria	17
Matrouh	1
Sinai	12

Governorate	Number of WWTPs
Port Said	6
Ismailia	7
Suez	1
Beni Suef	15
Faiyum	25
Minya	11
Assiout	5
Sohag	6
Qena	5
Luxor	5
Aswan	14
New Valley	14
Red Sea	1
Total	375

Table 10. Number of users, pressure lines, and gravity lines by governorate

Governorates	No. of users	Pressure lines (km)	Gravity lines (km)
Cairo East	171,041	158.5	2,178.2
Giza	5,500,000	125.9	2,246
Qalubia	N/A	N/A	N/A
Sharkia	259,960	1,010	163,951
Gharbia	226,494	N/A	2,199.962
Kafr El-Sheikh (cities)	79,912	86.81	1,544
Kafr El-Sheikh (village)	N/A	N/A	N/A
Menoufia	311,013	10,108	1175.84
Behiera	178,447	142.059	1,206.614
Dakahlia	682,303	494.579	2,868.982
Domiat	79,600	153	610
Alexandria	3,355,305	N/A	N/A
Matrouh	27,311	31.887	200.941
Red Sea	30% of the population	36.50	113
Faiyum	126,365	117	750
Beni Suef	41,668	85	395.4
Minya	N/A	Total (832.648 km)	
Assiout	97,294	N/A	N/A
Sohag	1,571,492	38	414
Qena	15,491	41.1	271.5
Luxor	37,329	47	231
Aswan	102,089	94	619

Table 11: Regional discharges to irrigation canals and their average salinity and salt load

Delta region	Discharge (billion m^3/year)	Average salinity (gm/m^3)	Salt load (million tonne)
Eastern Delta	2.808	1,184	3.326
Middle Delta	3.402	1,223	4.161
Western Delta	0.769	851	0.625
Total	6.980	1,166	8.142

4. Wastewater reuse in agriculture in Egypt

Status of wastewater reuse in Egypt

Types of reuse

Treated wastewater can be used for the following different purposes:

- Agricultural reuse:
  - Irrigation of field crops (food crops or non-food crops such as fodder or fiber)
  - Afforestation plants: commercial (fruit, timber, fuel, and charcoal)
  - Irrigation of public parks, residential landscapes, and flowers
  - Fish culture: TWW could be used in fish farms to fill the fish ponds
  - Artificial recharge of groundwater aquifers to be used for irrigation.

- Other uses:
  - Urban reuse: the irrigation of school yards and highway medians, as well as for fire protection and toilet flushing in commercial and industrial buildings
  - Recreational impoundments: such as ponds and lakes
  - Environmental reuse: creating artificial wetlands, enhancing natural wetlands, and sustaining steam flows
  - Industrial reuse: process or makeup water and cooling tower water.

Agricultural reuse

The main purpose of this study was to focus on the reuse of TWW for agricultural purposes.

As stated previously, the total capacity of the sewage effluent treatment plants in Egypt is 8 billion m^3/year. From this 8 billion, 0.7 billion m^3/year is used directly for irrigation (0.26 billion m^3 for non-food crops and 0.44 billion m^3 for forests) and 2.95 billion m^3/year of TWW is pumped to the drains in Cairo and the Delta.

About 90,000 feddan (37,000 ha) are available for land reclamation using TWW either for onsite reuse (near the WWTP) or for off-site centralized reuse (Van Lier and Abdel Wahab, 2015).

Wastewater reuse in agriculture can be grouped into the following categories.

Mixing and dilution of wastewater with agriculture drainage water to irrigate field crops

The treated and non-treated effluent discharged into agricultural drains

All the drains of Upper Egypt discharge into the River Nile. This adds a further 2.4 billion m^3/year of treated sewage water that can be reused. The quality of the Nile water is still reasonable, because of the river's high flow volume and the relatively low discharge of drainage water. Table 12 presents the quality of the Nile water.

The reuse of drainage water for agriculture after mixing with irrigation water in the canals has been and will continue to be an important part of water consumption in the Nile Delta. The official quantities of reused drainage water are 6.8 billion m^3/year (DRI year book 2009) see Table 13. In addition to the official reuse, which is controlled by the Ministry of Water Resources and Irrigation (MWRI), there is the unofficial reuse by individual farmers receiving inadequate fresh water. They pump drain water without a permit. It is difficult to measure this quantity but is estimated at 2.8 billion m^3/ year (APRP, 2002).

Blending drainage water with irrigation canal (fresh) water dilutes the concentrations of most wastewater quality parameters. One of the wastewater management options is to mix marginal-quality water with fresh water in order to dilute the pollution concentration to a safe level (Van Lier and Abdel Wahab, 2015).

All crops, vegetables, and fruits are irrigated with mixed water in the reuse areas of the Delta with a relatively good productivity. Table 14 presents the outcomes of irrigating with fresh, blended, and drainage water on soil salinity and crop productivity for cotton, wheat, and maize in the Nile Delta.

The reused drainage water quality and the mixing ratio with fresh water is controlled by MWRI through an intensive monitoring program. This program is carried out regularly by the Desert Research Institute (DRI). What follows is an overview of the drainage water quality with the difference of each parameter from the standards of Law 48 for the year 1982.

Organic matter and oxygen

The main source of organic matter that reaches the drains is domestic and industrial waste (when industrial effluent is discharged to municipal treatment plants). The BOD values for the drainage water vary between 7 mg/L in small and slightly polluted drains to 54 mg/L in drains receiving large quantities of untreated organic waste, such as the Dilingat Extension Pump Station. The standard level as set by Law 48 is 10 mg/L. The chemical oxygen demand (COD) values vary between 10 mg/L and 64 mg/L, compared with the standard level, as set by Law 48, of 15 mg/L. All regions in the Delta show nearly the same pattern. It is not surprising that the COD concentrations in most drains are below the standard level. Typical average values lie between less than 1 and 9 mg/L, with a large variation.

Heavy metals

Heavy and trace metals mainly exist in drainage water industrial discharges or from impurities in fertilizers. The available data indicate low concentrations. Cadmium concentrations range between 0 and 0.003 mg/L in the Delta region. Iron concentrations are around 0.7 mg/L, copper around 0.02 mg/L, zinc 0.02 mg/L, lead around 0.003 mg/L, nickel 0.02 mg/L, and boron 0.07 mg/L.

Pathogens

Pathogens mainly originate from the disposal of domestic wastewater. The measured indicator is the total coliform count. Probable numbers are very variable in both distance and time. Most locations have average levels higher than 100,000 MPN/100 ml while the standard level for total coliform is 5000 MPN/100 ml.

Rural sanitation, prospective plans for wastewater reuse

About 90 million Egyptians are living in 220 cities, 4670 villages and 30,000 settlements. The Government of Egypt has prioritized the treatment of wastewater in the cities. No budget is available for the large number of villages in the rural areas. Rural sanitation coverage is less than 12%. According to the master plan to 2037, the estimated amount of funding required to fill this gap is about USD12 billion.

The Government of Egypt has ambitious plans for the economic development of all villages in Egypt. Other goals include controlling and minimizing pollution by providing integrated and sustainable sanitation services.

Table 12: Quality of the Nile water at four locations in the Delta Barrage

Physico-chemical parameters						
	Units					
Dissolved oxygen	mg/L	0.82	1.1	0.4	0.44	> 6
pH		8.38	8.31	3.50	8.07	6.5–8.5
Carbonate (CO_3)	mg/L	9	4		0	
Bicarbonate (HCO_3)	mg/L	180	185		176	
Total alkalinity	mg/L	189	189		176	
Electrical conductivity	mmho/cm	0.439	0.442	0.885	0.488	
Total dissolved solids	mg/L	280	282	568	213	< 500
Ammonia (NH_3)	mg/L	0.546	0.6148	1.229	1.98	< 0.5
Chemical oxygen demand	mg/L	72	42	23	29	10
Oil-grease	mg/L	0.0038	0.0018	0.0016	0.0019	< 0.1
Surfactant	mg/L	0.305	0.225	0.231	0.242	
Major cations						
Calcium (Ca)	mg/L	35.92	38.49	38.81	35.88	
Potassium (K)	mg/L	5.1	6.14	6.18	5.4	
Magnesium (Mg)	mg/L	15.55	11.08	11.46	12.44	
Sodium (Na)	mg/L	34	36	81.2	35.0	
Major anions						
Chloride (Cl)	mg/L	26.4	27.8	53	31.6	
Nitrite (NO_2)	mg/L	< 0.2	< 0.2	< 0.2	< 0.2	
Nitrate (NO_3)	mg/L	1.89	2.07	1.20	1.80	
Phosphate (PO_4)	mg/L	< 0.2	< 0.2	< 0.2	< 0.2	
Sulfate (SO_4)	mg/L	30.9	31.2	379	35.0	< 300
Trace metals						
Aluminum (Al)	mg/L	0.119	0.172	0.48	1.044	
Antimony (Sb)	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	
Arsenic (As)	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.01
Barium (Ba)	mg/L	0.012	0.01	0.023	0.008	
Cadmium (Cd)	mg/L	0.001	< 0.001	< 0.001	0.004	< 0.001
Chromium (Cr)	mg/L	< 0.001	< 0.001	0.001	< 0.001	< 0.05
Cobalt (Co)	mg/L	< 0.005	< 0.005	< 0.005	< 0.005	
Copper (Cu)	mg/L	0.042	0.039	0.1	0.033	< 0.01
Iron (Fe)	mg/L	0.042	0.034	0.185	0.069	
Lead (Pb)	mg/L	< 0.001	0.005	0.037	0.006	< 0.01
Manganese (Mn)	mg/L	0.031	0.014	0.063	0.012	< 0.3
Nickel (Ni)	mg/L	0.006	< 0.001	< 0.001	< 0.001	< 0.02
Selenium (Se)	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.01
Tin (Sn)	mg/L	< 0.005	< 0.005	< 0.005	< 0.005	
Vanadium (V)	mg/L	< 0.005	< 0.005	< 0.005	< 0.005	
Zinc (Zn)	mg/L	< 0.001	< 0.001	0.079	< 0.001	< 0.01
Microbiological parameters						
Total coliform	CFU/100 ml	1,900	3,200	0	0	
Fecal coliform	CFU/100 ml	410	1,090	0	0	

Source: Central Laboratory, National Water Research Center, 2015

Table 13: Salinity classification of reused drainage water in the Nile Delta during 2007/2008

Salinity class	Eastern Delta (billion m^3/year)	Middle Delta (billion m^3/year)	Western Delta (billion m^3/year)	Total Delta (billion m^3/year)
< 750	0.466	0.000	0.499	0.964
750–1000	0.976	0.642	0.053	1.674
1000–1500	1.101	2.346	2.271	4.017
1500–2000	0.000	0.204	0.000	0.204
2000–3000	0.000	0.000	0.001	0.001
Total	2.845	3.192	0.823	6.860

Table 14: Average irrigation water salinity, soil salinity, and yields of selected crops in the Nile Delta, 1997

	Eastern Delta	Middle Delta	Western Delta
Irrigation water salinity (dS/m)			
Fresh water	0.75	0.71	0.65
Blended water	1.70	1.75	0.97
Drainage water	2.87	2.07	2.89
Soil salinity (dS/m)			
Fresh water	2.03	2.63	2.15
Blended water	2.70	4.06	2.27
Drainage water	4.16	3.96	3.68
Cotton yield (t/ha)			
Fresh water	1.73	1.82	2.40
Blended water	1.51	1.68	2.30
Drainage water	1.06	1.56	2.09
Wheat yield (t/ha)			
Fresh water	9.36	5.76	5.52
Blended water	8.40	4.32	5.28
Drainage water	5.52	4.56	4.80
Maize yield (t/ha)			
Fresh water	5.52	5.04	3.60
Blended water	3.84	6.24	3.36
Drainage water	3.60	6.96	2.40

Source: Adapted from Drainage Research Institute, Louis Berger International, Inc., and Pacer consultants, 1997.

The HCWW considers that the solution is the reuse of wastewater following collection and low cost technology treatment. Direct reuse could be undertaken in the villages on the fringes of the Nile Valley (Upper Egypt) and the fringes of the Delta. In this regard, through an Egyptian–Dutch cooperation program, a feasibility study has been formulated to develop a low cost technology for wastewater treatment in one village in Menya Governorate, Upper Egypt. The program will also test a strategy for the reuse of treated water for agriculture. It is assumed that implementation of the developed proposal will take the form of a pilot project, and this pilot project will be used as a model to be repeated in all the villages in Upper Egypt (See Annex 1).

For the villages located in the Nile Delta (old lands), where there are no lands available for treatment, and in the command areas where the drains are contaminated, the wastewater will be treated and clean effluents discharged to the drains.

The government will give first priority to those villages feeding into the branches feeding into the El-Salam Canal and the Rosetta Branch.

The El-Salam Canal is the main source of water in the Sinai area and, therefore, is the key determinant for agricultural and agro-business development. Preservation of the water quality in the command areas of the El-Salam Canal is urgently required to ensure successful cultivation of the lands previously reclaimed by the government.

The El-Salam Canal relies on a mix of drainage water with water from the River Nile the (Damietta Branch).

Sewage from 509 villages contaminates the drainage water and consequently the El-Salam Canal water. These villages have a population of around 3.68 million. To implement these projects, approximately 54.2 MW of electrical power is needed.

The Rosetta Branch (Rashid Branch) contains a mix of water from three agricultural drains as well as water from the River Nile.

In total, 260 villages and two cities contaminate the Rosetta Branch (Rashid Branch). The planned sanitation projects would serve 3.33 million persons and would require 34.7 MW of electrical power.

Irrigation of residential landscapes

Many residential areas now have their own wastewater treatment plant. The treated water is used to irrigate, landscapes, gardens, and trees.

A good example of a community using treated water in this way is Madinati. Madinati is a modern and multiple-activity residential area, constructed on 8000 feddan in the Eastern Desert on the extension of the Cairo Swais Road. The planning of this area (El Said, 1994) includes the establishment of a modern sophisticated tertiary wastewater treatment plant with the treated water being used to irrigate the green areas. It was planned to construct this plant in four phases. The first one will be completed in 2015. The green area constitutes 40% of the whole, some 3160 feddan. Table 15 lists the green areas and the required wastewater to be delivered at each phase.

The cultivated area in the first phase requires between 13.44 and 14.6 million m^3 (of treated water). The remaining volume will be sold to neighboring compounds at a price of EGP per m^3.

The plant includes restrictions to apply regular monitoring and evaluation of the impact of the reuse water on the environment and to apply all the Egyptian laws and regulations.

Reuse of wastewater effluent for forest plantations

In the mid-1990s, the Egyptian Government launched the National Programme for the Safe Use of Treated Wastewater for Afforestation. Afforestation is the commercial planting of trees for fruit, timber, fuel, and charcoal. Afforestation in arid regions is multi-functional, as the newly established plantations can be of considerable economic, ecological, and social benefits.

The wastewater-irrigated forest plantations were started in 1995 in Luxor on 100 feddan of sandy desert soil, right behind the main sewage station of Luxor City. Initially, 40 feddan of the land were planted with: Eucalyptus, Casuarina, Acacia, Mulberry (*Morus Japonica* and *Morus Alba*), Khaya, and Cypress. The area was irrigated with treated sewage water from the nearby treatment station using the flood irrigation system.

Table 15: Madinati green areas and their wastewater requirements at each phase

	First phase	Second phase	Third phase	Fourth phase
Treated wastewater (million m^3)	14.6	29.2	43.8	58.4
Water requirements for green areas (m^3/feddan)	4,606.14	4,606.14	4,606.14	4,606.14
Green area (feddan)	3,160	6,339	9,509	12,679

Table 16: Net short-term and long-term profits from trees grown in timber plantations

Item	Cost for 12 years (EGP/feddan)	Revenue for 12 years (EGP/feddan)	Net profit for 12 years (EGP/feddan)
Long term for Cypress only	29,150	160,000	130,850
Short and long term for Cypress with Poinciana	56,450	208,000	151,550
Short and long term for Cypress with Perishauria	54,350	240,000	185,650

Eighteen months later, the pioneer experiment was evaluated. Some tree varieties were growing fast, specifically Eucalyptus, Acacia, and Khaya trees. This led to an extension for other pilot projects initiated in other governorates (5,000 feddan) as listed in Table 7.

On-site reuse – Luxor WWTP

Results of research and experiments on pilot sites confirm the following conclusions:

- Wastewater effluent is free-of-charge and always available for use. The WWTP provides a sustainable irrigation source for forest plantations
- The lands used in forest plantation have sandy desert soils. Such lands can be sold or leased by the government at low prices
- The tree varieties selected for the pilot sites have excellent economic value in timber production. For example, Cypress starts wood production 10–12 years after planting and African Mahogany starts timber production after 15–25 years
- Inter-cropping other crops with trees has been shown to be fully possible. This helps obtain faster economic returns. Such crops include ornamental plants, cut flowers, and mulberry shurps (for rearing silk-worms and enhancing sericulture products)
- In Egypt, there is great potential for forest plantations to have satisfactory economic returns both in the short term and the long term. Table 16 presents the costs and profits for different plantation scenarios.

Moreover, Egypt offers a great opportunity for large-scale afforestation because of the availability of sufficient sewage water and a huge area of unused desert lands. This gives an opportunity to store millions of tonnes of carbon dioxide annually in the new plantation forests (El Kateb and Mosandl, 2012). Large-scale afforestation may stimulate cloud formation and may result in rainfall that the country urgently needs to expand its agricultural production areas (El Kateb and Mosandl, 2012).

Figure 1: Forest plantations in Egypt

Use of wastewater in fish farms

Fish is the cheapest source of animal protein in Egypt and it is important for the country's food security. In the past two decades the aquaculture sector of Egypt has grown rapidly. With a production approaching 1 million tonne in 2013, Egypt is by far Africa's largest producer of farmed fish.

The Government of Egypt is very concerned about the limited amount of fresh water available to the nation. Currently, the fish farms are using water from the drainage canals. Most of the Egyptian fish farms are located in the northern and eastern parts of the Nile Delta (near Lake Borullus, Lake Mariut, Lake Edko, and Lake Manzala).

The majority of these farms rely on drainage canals as the source of water to fill ponds and to refresh pond water. This reliance carries the risk of raising fish in water that is contaminated with agro-chemicals and/or heavy metals or organic pollutants.

Egyptian fish farmers would like to grow a product that is free from contaminants, safe for all consumers, and which can also be exported. As long as Egyptian laws prohibit the use of irrigation (Nile) water for the grow-out of freshwater fish, most farmers will in the years to come continue to rely on water from the drainage canals.

In 2011, the Fish Producers and Exporters Association, an organization of approximately 30 Egyptian fish farmers, suggested investigating and testing if constructed (engineered) wetlands are effective as filters that could remove hazardous chemicals and biological contaminants from the drainage canal water before the water is used to fill the fish ponds.

A collaborative project between the Centre for Development Innovation (Wageningen University), and a private fish farm in Egypt set out to test the effectiveness of a constructed wetland (CW) in reducing the levels of pesticides and heavy metals in drainage canal water (Van der Heiden et al., 2014).

A pilot wetland was constructed on a private fish farm in Kafr El Sheikh Governorate, Egypt. The levels of pesticides and heavy metals in fish grown in drainage canal water treated by the pilot CW were compared with those in fish grown in untreated drainage canal water.

The absence of pesticides and the very low levels of only some heavy metals in the untreated drainage canal water at the moment of sampling and the low levels or absence of such contaminants in the fish made it impossible to draw conclusions about the effectiveness of the pilot wetland (see Tables 17 and 18). Further and better controlled studies are needed.

Figure 2: Fish pond harvest

Artificial recharge of groundwater

Treated wastewater can be used partially for the artificial recharge (AR) of the aquifer system. Where soil and groundwater conditions are favorable, a high degree of upgrading can be achieved by allowing sewage effluent to infiltrate into the soil and move down to the groundwater. The unsaturated zone then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses, and other microorganisms. Significant reductions in nitrogen, phosphorus, and heavy metals concentrations can also be achieved. This gives an advantage to AR with wastewater over direct application methods. This process is known as soil-aquifer treatment (SAT).

Another advantage of AR over the direct application of wastewater is that water recovered from an AR system is not only clear and odor-free, but also comes from a well drain or through natural drainage to a stream or low area, rather than from a sewer or sewage treatment plant. Thus, the water in the public's eye is coming out of the ground rather than from sewage effluent. This can be an important factor in the public acceptance of the reuse scheme.

Table 17: Results of analysis of fish (flesh and liver), water and fish feed samples

	Pesticide (mg/kg)				Heavy metals (mg/kg), water samples (mg/L)							
	Diazonon	Malathion	Ethoxyquin	Chlorpyrifos	Hg	Mn	Pb	Cur	Co	Cr	Cd	As
Water inlet CW	No pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Water outlet CW	No pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tilapia pond A2, flesh	No pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tilapia pond A2, liver	No pesticide residues detected				n.d.	< LOQ	n.d.	28.2	n.d.	n.d.	< LOQ	n.d.
Tilapia pond A6, flesh	No pesticide residues detected				n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tilapia pond A6, liver	No pesticide residues detected				n.d.	< LOQ	n.d.	33.3	n.d.	n.d.	< LOQ	n.d.
Fish feed	0.01	0.03	0.02	0.03	n.d.	37.9	1.03	24.5	n.d.	31.5	0.08	n.d.

n.d. – not detected, LOQ – level of quantification
Sampled: December 2013. Analyzed: 21 and 22 December 2013

Table 18: Results of analysis of fish (flesh and liver), water and fish feed samples

	Pesticide (mg/kg)					Heavy metals (mg/kg), water samples (mg/L)							
	Diazonon	Malathion	Ethoxyquin	Sulfur	Chlorpyrifos	Hg	Mn	Pb	Cur	Co	Cr	Cd	As
Water inlet CW	No pesticide residues detected					n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.	0.34	n.d.
Water outlet CW	No pesticide residues detected					n.d.	0.13	< LOQ	n.d.	n.d.	n.d.	0.00037	0.001
Tilapia pond A2, flesh	No pesticide residues detected					< LOQ	< LOQ	n.d.	LOQ	n.d.	n.d.	n.d.	n.d.
Tilapia pond A2, liver	No pesticide residues detected					< LOQ	< LOQ	n.d.	19.2	n.d.	n.d.	< LOQ	n.d.
Tilapia pond A6, flesh	n.d.	n.d.	< LOQ	n.d.	n.d.	< LOQ	< LOQ	n.d.	< LOQ	n.d.	n.d.	n.d.	n.d.
Tilapia pond A6, liver	n.d.	n.d.	0.04	n.d.	n.d.	< LOQ	< LOQ	n.d.	29.4	n.d.	n.d.	< LOQ	n.d.
Fish feed	0.03	< LOQ	0.13	0.12	0.31	n.d.	55.4	n.d.	11.2	n.d.	n.d.	0.024	n.d.

n.d. – no data, LOQ – level of quantification
Sampled: 29 October 2014. Analyzed: 24 and 26 November 2014.

Many schemes use SAT as a method for the tertiary treatment of wastewater. Highly efficient removal of bacteria and viruses was identified by Van Puffelen (1982) in the recharge of heavily polluted river water in the coastal sand dunes of the Netherlands.

Soil-aquifer treatment schemes have the added advantage of providing a temporary storage for water between irrigation seasons.

In Egypt, steps, in form of experimental-scale basins and wells, have been taken to use AR for storing fresh water during low demand periods (Fadlelmawla et al., 1999). This is described in a report prepared by the Research Institute for Groundwater (RIGW) and IWACO (1999). The report includes a description of the preparatory efforts to introduce the technology of AR using wastewater into Egypt in an official and organized manner, which would ensure the most beneficial and safe application. These efforts were directed in two parallel channels – desk studies to formulate a framework (i.e. suitable locations, methods, available wastewater, etc.) for the application of AR using wastewater, and laboratory experiments to study the main factors and processes controlling the efficiency of applying the technology.

Artificial recharge using wastewater has a wide range of applications and objectives. However, at this stage for health and environmental safely reasons, the proposed application of this technology is confined only to providing water for irrigation purposes at reclaimed areas.

A number of methods for the AR are being practiced worldwide. However, only surface infiltration methods (i.e. mainly basin recharge, CWs, etc.) are suitable for Egypt for the time being. Unless significant volumes can be injected into the aquifer, groundwater recharge may not be economically feasible. Figure 3 shows areas selected for AR with TWW.

Wastewater is unique in its composition. The physical, chemical, and biological constitutes of this water must be taken into consideration. The acceptability of TWW for use as a non-conventional water source very much depends on whether the possible health risks during reuse are within acceptable levels.

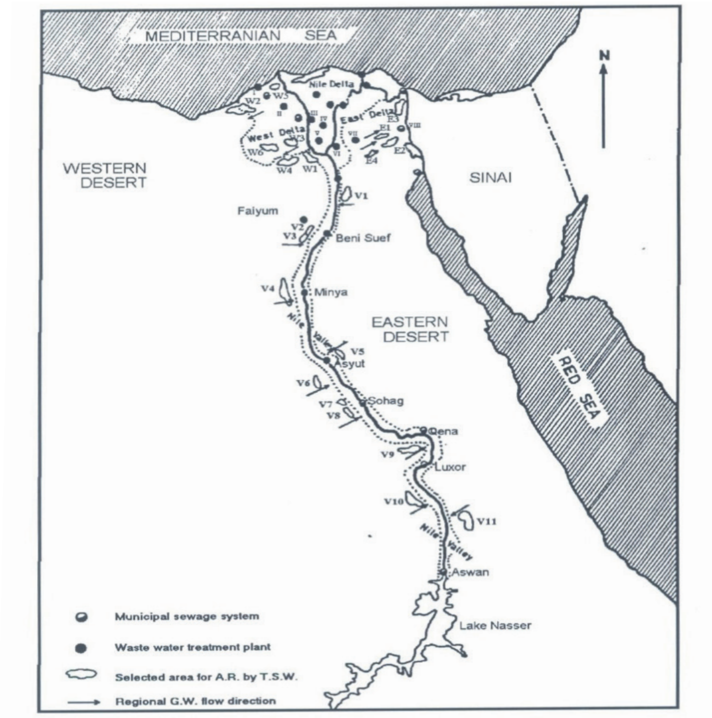

Figure 3: Selected areas for recharging aquifers with treated water (Attia et al. 2009)

Egyptian code for the reuse of treated wastewater in agriculture (2001/2005)

The Ministry of Housing, Utilities, and New Communities, supported by seven technical committees, issued the *Code for the reuse of treated wastewater in agriculture* (the Code). The Code stipulates the precise requirements in the planning and approval procedures, responsibilities, permitted use according to effluent quality, and monitoring. The Code regulates only the direct use of wastewater, not the wastewater discharged into drains.

According to the Code, the reuse of TWW – irrespective of the treatment level – is prohibited for the production of vegetables, whether eaten raw or cooked; export-oriented crops (i.e. cotton, rice, onions, potatoes, and medicinal and aromatic plants); as well as citrus fruit trees and the irrigation of school gardens.

Restrictions are in place for the type of crops, irrigation methods, and health precautions. The existing reuse schemes are operated by public institutions, mainly ministries, such as the Ministry of Housing, Utilities, and New Communities, the Ministry of Agriculture and Land

Reclamation, and the Ministry of State for Environmental Affairs.

Plants and crops irrigated with TWW are classified into three agricultural crop groups that correspond to three different levels of wastewater treatment. Biological and chemical standards for these three levels of treatment are set out as well. The Code further stipulates conditions for the irrigation methods and health protection measures for farm workers, consumers, and those living on neighboring farms.

The Code classifies wastewater into three grades (A, B, and C) depending on the level of treatment it has received and specifies the maximum concentrations of specific contaminants consistent with each grade. The Code also stipulates those crops that can be, and importantly those that cannot, be irrigated with each grade of TWW (Tables 19 and 20).

Grade A is advanced, or tertiary treatment that can be attained by upgrading the secondary treatment

Table 19: Limit values for treated wastewater reused in agriculture (mg/L)

Treatment grade requirements		A	B	C
Effluent limit for BOD	BOD_5	< 20	< 60	< 400
Suspended solids (SS)	SS	< 20	< 50	< 250
Effluent limit value for fecal coliform and nematode cells or eggs (per liter)	Fecal coliform count 2 in 100 m^2	< 1,000	<5,000	Unspecified

Excerpt from Egyptian code for the use of treated wastewater in agriculture. February 2005

Table 20: Plants and crops for which irrigation with treated wastewater is permitted

Code	Agriculture group	Plant and crops
A	G 1-1: Plants and trees grown for greenery at tourist villages and hotels	Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees, and shade trees
	G 1-2: Plants and trees grown for greenery inside residential areas at the new cities	Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees, and shade trees
B	G 2-1: Fodder/feed crops	Sorghum sp.
	G 2-2: Trees producing fruits with an epicarp	Such as lemon, mango, date palm, and almonds on condition that they are used for processed purposes
	G 2-3: Trees used for green belts around cities and afforestation of highways or roads	Casuarina, camphor, Tamarix aphylla (salt tree), oleander, fruit-producing trees, date palm, and olive trees
	G 2-4: Nursery plants	Nursery plants including wood trees, ornamental plants, and fruit trees
	G 2-5: Roses and cut flowers	Local rose, eagle rose, onions (e.g. gladiolus)
	G 2-6: Fiber crops	Flax, jute, hibiscus, sisal
	G 2-7: Mulberry for the production of silk	Japanese mulberry
C	G 3-1: Industrial oil crops	Jojoba and Jatropha
	G 3-2: Wood trees	Khaya, camphor, and other wood trees

Excerpt from: Egyptian code for the use of treated wastewater in agriculture, February 2005 plants (i.e. Grade B plants) to include sand filtration, disinfection, and other processes.

Grade B represents secondary treatment at most facilities serving Egyptian cities, township, and villages. It is undertaken using any of the following techniques: activated sludge, oxidation ditches, trickling filters, and stabilization ponds.

Grade C is primary treatment that is limited to sand and oil removal basins and the use of sedimentation basins.

According to the Code, the following irrigation methods are permitted when using TWW:

- Flood irrigation (furrow irrigation), wetting almost all the soil surface
- Basin irrigation, using irrigation pipes to deliver water to the basins
- Strip irrigation, where water covers only part of the soil surface
- Drip irrigation, which ensures the least amount of the treated municipal wastewater contacting the irrigated plants and the agricultural laborers
- Sub-surface irrigation, which minimizes contact with the treated municipal wastewater used in irrigation
- Pressurized irrigation, which is controlled by valves regulating the flow of treated municipal wastewater
- Pop-up sprinklers, characterized by low pressure and high discharge.

The Code describes health and safety measures to reduce public hazards related to water reuse in agriculture and recognizes five target groups:

- Farm workers
- Harvesters and processors (workers)
- Consumers
- Public and other users of open spaces and gardens
- Passers-by and residents who live near the reuse sites.

The code has defined mandatory safety measures for farm workers and harvesters.

Table 12 shows the composition of wastewater in several cities (or villages) and the quality of waste water after treatment. Comparing this with the Egyptian Code, the quality is B.

5. Conclusions

- The total production of potable water treatment plants in Egypt is, at the present time, 25 million m^3/day
- The expected amount of sanitary sewage would be of the order of 20 million m^3/day
- The total production of the WWTPs in the country is almost 10 million m^3/day
- This means that almost half of the amount of sanitary sewage remains untreated before it is disposed of to the drainage network
- More than 7 million m^3/day of sanitary sewage is treated in the Delta region
- Almost all treated sewage in the Delta is directed to land drains
- The final conclusion of the above argument is that both treated and raw sanitary sewage ends up in the drainage system at the present time
- The idea of using treated sewage for the irrigation of timber trees resulted in the cultivation of just 12,000 feddan distributed across 63 sites all over the country and the consumption of only 1.9 million m^3/day
- The above area is part of the HCWW activity. Another 5000 feddan at 24 sites in 14 governorates are irrigated voluntarily
- The modest, but rather poor, experience of using treated sewage by governmental organizations indicates that their preference was to get rid of the water to the nearest drain and avoid any possible resulting side effects (causing health problems) or overspending in infrastructure or operation and maintenance
- The amount of wastewater produced in Cairo is almost 4 million m^3/day, in Alexandria 1.15 million m^3/day, and in Giza 1.54 million m^3/day. Most of this water is transported for long distances before it is disposed of in the coastal lakes or directly to the Mediterranean. Local use of this water will reduce the risk of health hazards and reduce the cost of transportation in the meantime
- If the Cairo water (4 million m^3/day) and Abu Rawash WWTP (0.85 million m^3/day) outputs are added to that of Alexandria (1.15 million m^3/day) the total would be 6 million m^3/day. The remaining 4 million m^3/day is divided between Upper Egypt (about 2 million m^3/day), which is disposed of into

the main course of the Nile, and 2 million m^3/day in the Nile Delta
- The major part of the treated sanitary sewage is available only in urban areas. The amount of treated sewage in rural areas is quite minor.

6. Recommendations

- Since most of the treated sanitary sewage produced comes from urban areas, the principle use of this water should be in the irrigation of landscaping. Most of the new communities, which are located on the outskirts of Greater Cairo City, Giza, Alexandria, and other capital cities, are in the form of compounds with well-defined boundaries. This makes recycling of TWW easier. With minor polishing of the primary or secondary treated sewage, the water could be used for the irrigation of green areas
- Public parks, golf courses, sport clubs, stadiums, front and back gardens, street islands, street shade trees, and any green areas inside the cities can be irrigated with treated sanitary sewage provided that the quality standard of the water is improved and it does not pose a health risk to members of the population who come into contact with it
- The Middle Delta, with a deep cap of clay soil, is the optimum site for AR activities, given that precautionary health measures are observed
- The desert fringes of the Nile Valley and Delta are the best locations for green belts and the raising of timber trees. If the water is further treated to the permissible standards it could be used for the irrigation of edible and non-edible crops. According to the new code of practice (still to be published) allowance should be made for the use of water according to its constituent elements. This code provides opportunities to investors to improve the water quality to the level that provides the best economic return for the water used.

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