SAFE REUSE OF TREATED WASTEWATER FOR AGRICULTURE IN EGYPT

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Abstract

Water scarcity in Egypt is one of the most serious problems that could limit the economic development. Limited water resources in Egypt are the main factor driving the exploration of unconventional sources that can fulfil the water demand of the increasing population. Egypt's water resources are limited and population growth increases the gap between the demand and the available resources. Reuse of treated wastewater TWW and of drainage water DW in agriculture is considered one of the most sustainable alternatives to cope with water scarcity in Egypt. Reuse of treated wastewater and of drainage water in agriculture could be an effective method to reduce the gap between water demand and supply, to save freshwater in addition to enhance the physiochemical properties of light-textured soil. However, the bioaccumulation of pathogens and toxic chemicals are the main problems of TWW reuse in agriculture. This study aims to discuss Egypt's current situation of water supply and uses, to analyze the quantities of generated wastewater and TWW, to highlight the main problems related to the use of wastewater in Egypt, furthermore, the safe reuse of TWW for agriculture and related laws and regulations, and approaches to control pollution in agricultural drains. Finally, opportunities and challenges of using TWW & DW in agriculture in Egypt are presented.

1 Introduction

In water-scarce urban and peri-urban areas, where competition for water is high, unconventional water resources are being used for balancing water demand and supply. Egypt is one of the developing countries that necessitate the use of unconventional water sources in order to combat water scarcity [1]. The Nile River is the major water source in Egypt, and the agricultural sector is the largest water consumer [2]. The use of unconventional water sources, such as treated wastewater (TWW) and recycled water, especially recycled agricultural drainage water (DW) could be important sources to combat water scarcity in Egypt [1].

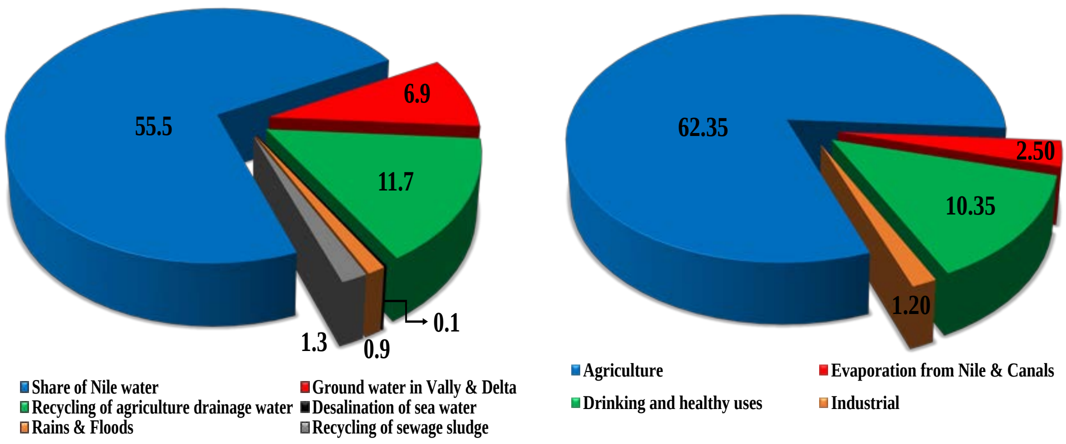
A significant volume of drain water is often pumped and used for irrigating crops, especially during the summer season when water in the irrigation canals is scarce [2]. On the other hand, TWW provides a promising, unconventional water source for irrigation in Egypt [3]. One of the main goals of Egypt's water policy is to increase the reuse of TWW to $2.0\text{x}10^9$ m^3 by the end of 2017 [4]. In 2014, the Ministry of Water Resources and Irrigation confirmed that recycling wastewater and drainage water in Egypt is necessary to reduce the gap between current water demand and supply [5].

The agricultural drains in Egypt were initially planned to comprise the irrigation drainage. However, the increase in population, and the random growth and the leakage of sewerage facilities have enforced people to discharge all their types of wastes into these drains. The discharge of different wastewater and residues of human and natural activities into drains has several impacts. It may cause a decrease and even depletion of the dissolved oxygen content and become dangerous on the natural balance of the stream's aquatic life. Also, the ability of self-purification of the water body in order to permit the re-establishment of the community balance decreases. The final result is that the direct use of the water from polluted drains for irrigation has become risky and has severe impacts on human and environmental health [6]. This requires further efforts by both the government and research centers to improve the quality of this water before reuse.

The main objectives of this paper are to present an overview on the current water supply situation and uses in Egypt, and the quantities of wastewater generated and treated, and to discuss the major problems and issues related to the current use of treated wastewater in Egypt, further, the applicability of TWW in agriculture and the related laws and regulations, and finally, to present the opportunities and challenges of using TWW in agricultural sector in Egypt.

2 Water resources and uses in Egypt

Egypt covers a total area of almost one million km^2. It has hot and dry weather in summer and a warm winter with an average rainfall of 50 mm/yr. The inhabited part of Egypt is the 1,000 km valley from Aswan to Alexandria, flanked by desert [7]. Egypt has an estimated population of about 94 million in 2017 [8]. About 95% of the population lives in around 5% of the country's land along the banks of the Nile valley and Nile delta. Figure 1 shows the quantities of different water resources and uses in Egypt during 2014–2015, where the Nile River is the major water source in Egypt; it provides 55.5×10^9 m^3 freshwater annually, moreover, the total water resources of the country including non-conventional water were 76.4×10^9 m^3 in 2015 [8]. The data illustrate that during 2014–2015 the shallow groundwater in the Nile delta and valley provided 6.9×10^9 m^3, while wastewater recycling provided 1.3×10^9 m^3. Egypt's agricultural sector is the largest water consumer, using more than 80% of the total. The agricultural sector exhausted 62.35×10^9 m^3, while the drinking and healthy uses consumed 10.35×10^9 m^3. Total water resources in Egypt increases with increasing agricultural drainage water recycling [8]. Otherwise, the increase in the Egyptian population and the changes in lifestyle during the last decades are the main reasons for the rise in the consumption of water for drinking and healthy uses [2].



a) Egyptian water resources (10^9 m^3) b) Egyptian water consumption (10^9 m^3)

Figure 1: Egyptian water resources and consumptions during 2014–2015 [8]

3 Reuse of treated wastewater and drainage water in Egypt

3.1 Treated waste water reuse in Egypt

The competition for limited water resources is a key driver for reusing TWW, especially with an increasing population that provides a continuous substantial supply of TWW [9]. However, water scarcity derived the implementation of reusing treated or untreated wastewater for several activities such as landscaping, groundwater recharge, greenbelts, cooling systems, and agricultural production [2]. Unfortunately, the farmers irrigate with wastewater because of the limited availability of freshwater, availability of nutrients, affordable costs compared with pumping deep groundwater, and being adjacent to urban market areas. Moreover, there is no well control through the government. So, the quantities of wastewater generation and treatment are required for improving the treatment, management, and distribution of wastewater [10]. The total collected wastewater in 2014–2015 was 5.05×10^9 m^3, and the total TWW represented 74.4% of the collected wastewater. The primary, secondary, and tertiary-treated wastewater represented 16.8%, 81.4%, and 1.8% of the total treated wastewater, respectively [8].

Wastewater reuse for irrigation has been practiced historically in Egypt. One of the main uses of TWW in Egypt is wood production via forest plantation [2]. Thus, Ministries of State for Environmental Affairs, Agriculture and Land Reclamation, and of Housing, Utilities, and Urban Communities have conducted national programs of using 2.4×10^9 m^3 of TWW for afforestation and greenbelts [2]. Furthermore, the Ministry of State for Environmental Affairs, in cooperation with the United States Agency for International Development, evaluated the safe reuse of TWW to irrigate different crops (e.g., jatropha, jojoba, sorghum, flax, flowers) in Luxor governorate [2]. This evaluation endorsed using drip irrigation techniques and implementing natural resource monitoring in the project area as well as conducting risk reduction measures for protecting the workers involved [11]. Jatropha is a bio-oil crop cultivated in Egypt since the late 1990s using TWW and, recently, its cultivated area has spread to over 855 hectar; it is planted mainly in Upper Egypt governorates and has promising economic potential [12].

On the other hand, untreated and partially treated wastewater has been used for irrigation at Elgabal Elasfar farm, in the Eastern Desert 25 km North East Cairo, since 1911 [2]. This farm was initially established for wood production, and it has been converted to citrus and field crop production. Although the quality of the irrigation water currently applied meets acceptable levels, sustainable management strategies recommend monitoring the levels of heavy metals in the soil and performing appropriate remediation programs due to the historical use of untreated wastewater at this farm [13].Thus, TWW would be mainly used for greenbelt and non-food agricultural production based on several factors such as the balance of supply and demand, treatment type and level, availability of cultivation area, irrigation method, cropping pattern, environmental impacts, and costs as stated by Ministry of Water Resources and Irrigation [14]. Moreover, utilizing TWW for irrigation can be recommended in case of improving wastewater treatment and continuous monitoring in order to prevent the accumulation of toxic elements and to maintain microbiological loads within permissible levels in soil and plants [15].

3.2 Drainage water reuse in Egypt

The environmental conditions controlling agriculture in Egypt, e.g., clay soil, arid climate, and intensive agriculture, needing an intensive efficient drainage system has resulted in huge amounts of agricultural drainage water [16]. Network for monitoring drainage water quantity and quality was established since 1976 (Figure 2) in order to provide real time information for drainage water disposal and reuse management on safe and sustainable basis [17]. The reuse of agricultural drainage water is a common practice in Egypt due to water scarcity, although some of these agricultural drains turn into major carriers of untreated wastewater, which are subsequently utilized for irrigation [18]. Moreover, the absence of sanitation systems in the rural Nile delta drives farmers to discharge wastewater into agricultural drains; this is a common, but unofficial practice [19]. So, drainage water is loaded with different sorts of pollutants from agricultural, industrial, or domestic sources, where salts, nutrients, and pesticides run-off from irrigated fields and are carried by drainage water. Also, untreated industrial effluents discharged into the drains contain heavy metals and organic compounds; similarly, untreated domestic wastewater containing organic compounds, bacteria, and pathogens is disposed of into drains [16].

Therefore, the strategies for drainage water reuse were adopted by Egyptian National Committee on Irrigation and Drainage [20] in order to include the following objectives: implementing several projects to expand the reuse capacity at different areas for increasing the reuse of drainage water, improving the quality of drainage water especially in the main drains, separating sewage and industrial wastewater collection systems from the drainage system, draining 50% of the total generated drainage water in the delta into the sea for preventing seawater intrusion, and to maintain the salt balance of the system, implementing an integrated information system for water quality monitoring in drains using the existing data collection network after updating and upgrading, continuous monitoring and evaluation of the environmental impacts due to the implementation of drainage water reuse policy especially on soil characteristics, cultivated crops, and health conditions, limiting the use of treated wastewater to cultivated non-food crops such as cotton, flax, and trees, separating industrial wastewater from domestic sewage, so that it would be easier to treat domestic sewage with minor costs and to avoid the partly intensive chemical treatment needed for industrial wastewater.

Figure 2: Drainage network in Egypt [17]

In order to divert considerable amounts of drainage water to newly reclaimed areas, several projects have been undertaken by the Ministry of Water Resources and Irrigation [21]. For example, constructed engineered wetland in El-Manzala was implemented to treat $25x10^3$ m^3 per day of water from Bahr El-Baqar drain. After treatment, the major portion of water is used for irrigation, while some are diverted into basins designed for fish farming [22]. Moreover, in El-Salam, Canal project treats $2x10^9$ m^3 of drainage water from Bahr Hadous, and Lower Serw drains are mixed with $2x10^9$ m^3 freshwater from the Nile River (Damietta branch) to irrigate $92.5x10^3$ hectares in the Eastern Nile Delta and $168x10^3$ hectares in Sinai. Additionally, Umoum project reuses $1x10^9$ m^3 of drainage water to irrigate 84874 hectare in El-Nubaria after mixing with freshwater. On the other hand, the drainage water near Banjar El-Sokar, Borg El-Arab City, Alexandria, was examined by [22] and found that the drain does not meet the standards for direct reuse in irrigation, and vegetables irrigated with such drainage water are not safe for human and animal consumption. Therefore, remediation of drainage water using physical, chemical and/or biological methods was recommended in order to meet the standards for drain water before it can be discharged into agricultural irrigation. Moreover, recently there are different investigations has been carried out for enhancement of self-purification capacity of agricultural drains to reduce its organic contaminants for reuse the drainage water directly or even for reducing the quantity of freshwater that is used for dilution of drains water before used in irrigation [6, 23, 24].

4 Impact of reusing TWW and DW

Numerous benefits can be gained with the safe use of TWW in agriculture. Reusing TWW can conserve freshwater resources, recycle the nitrogen, phosphorus, and potassium required for plant growth [25]. Additionally, using TWW to irrigate sandy soils elevates the content of soil organic matter and enhances its cation exchange capacity [13]. However, pathogens and bioaccumulation of toxic chemicals are the main risks of wastewater reuse in agriculture that can threaten farmers' health in cases of direct contact with raw wastewater [26]. Additionally, the accumulation of heavy metals, pesticides, and pharmaceutical chemicals in cultivated plants irrigated with wastewater is a threat to consumers [27]. Moreover, improper use of low-quality wastewater could lead to soil pollution as well as to contamination of surface water and groundwater with chemicals and microorganisms [25].

The major problems and issues related to the current use of TWW in Egypt are the following: (1) not enough infrastructure (treatment plants) to treat the amounts of wastewater produced, (2) only about 50% and 3% of the urban and rural populations, respectively, are connected to sewerage systems, (3) a significant volume of wastewater enters directly into water bodies without any treatment, (4) many wastewater treatment facilities are overloaded and/or not operating properly, (5) some industries still discharge their wastewater with limited or no treatment into natural water bodies, (6) domestic and industrial solid wastes are mainly deposited at uncontrolled sites and/or dumped into water bodies (especially outside Greater Cairo), (7) the quality of treated wastewater differs from one treatment station to another, depending on inflow quality, treatment level, plant operation efficiency, and other factors, and (8) negative impacts of the above problems on both health and environment [28].

5 Safe reuse of TWW for irrigation in Egypt

5.1 Regulations and relevant laws of reusing TWW in Egypt

Egypt does not have a single general law on integrated water resource management, however, it has several sectorial laws and decrees, such as laws on water and environment: Law 93/1962, Law 48/1982, Law 4/1994, Law 9/2009, and laws and regulation for wastewater reuse: Law 93/1962, Law 44/2000, Decree 603/2002, Decree 171/2005, Decree 1038/2009 and Egyptian Code 501/2005 [22-29] and the latest Egyptian Code 501/2015. The Law 93/1962 controls the reuse of wastewater in agriculture as described in the following rules: (1) it is prohibited to harvest yields, which were irrigated with a treated wastewater until two weeks after stopping irrigation; (2) it is prohibited to use treated wastewater, primary or secondary treatment, to irrigate cattle pasture; (3) it is acceptable to reuse treated wastewater for agricultural purposes, only if it would be in accordance with the conditions and criteria mentioned in Law 93 /1962 [30]. Moreover, Law 48/1982 and Decree 8/1993 protect the River Nile and waterways from pollution. Furthermore, specific laws for irrigation, Law 12/1984 and Law 213/1994, define the use and management of public and private sector irrigation and drainage systems [31].

5.2 Selection of crops to be irrigated with TWW

Selecting crops suitable to be irrigated with TWW is a key for achieving the successful use of TWW [2]. For example, oil crops such as canola and sunflower are suitable for TWW irrigation [9]. Additionally, cultivating jatropha with TWW is recommended because of the availability of marginal desert soil and the socio-economic benefits associated with biofuel production [12]. So, the Ministry of Housing, Utilities, and Urban Communities published two versions of the Egyptian Code for reusing TWW (ECP 501, 2015 and 2005). The 2005 version (ECP 501, 2005) classified TWW into three categories (A, B, and C), while (ECP 501, 2015) classifies TWW into four grades (A, B, C, and D) depending on the level of treatment (Table 1). The Egyptian Code prohibits the reuse of TWW for any raw vegetables, such as cucumber or tomatoes. Moreover, the Code specifies the allowable crops for each TWW category [32] (Table 2).

Table 1: Criteria for different levels of wastewater treatment [32]

Criteria	**Treatment level**			
	A	B	C	D
Total Suspended solids (TSS, mg/L)	< 10	< 30	< 50	< 300
Turbidity (NTU)	< 5	N.D.	N.D.	N.D.
Biological Oxygen Demand (BOD)	< 15	< 30	< 80	< 350
Fecal coliform of *E. coli* per 100 mL	< 20	< 100	< 1,000	N.D.
Intestinal nematodes (cells/L)	< 1	< 1	< 1	N.D.

N.D: Not defined

Table 2.Allowable crops for each TWW category [32]

Grade of Treatment	**Agricultural Group**		**Description**
A	A-1	Green landscapes in educa-tional establishments, public and private parks	All types of grass and fence plants and all kinds of flowers
B	B-1	Dry grains crops, cooked & processed vegetables	All kinds of vegetables (manufactured) and dry crops of all types such as wheat-corn-barley-rice-beans-lentils-sesame
	B-2	Fruit crops	Fruit trees with sustained and deciduous leaves such as: citrus fruits - olive -palm -mango-pecan-pomegranate for the pur-pose of drying
	B-3	Medicinal Plants	Anise-hibiscus-Cummins-Marjoram-Ammi-Fenugreek-moat-fennel-Chamomile -sage herb
C	C-1	Dry grain crops, fruits, medi-cinal plants contained group (B)	Same species in addition to sunflower plant providing that spray irrigation is not used.
	C-2	Non-food seeds	All seeds of propagation for major food crops such as wheat, corn and all kinds

			of vegetables' seeds
	C-3	All types of seedlings, which are then transplanted in permanent fields	Seedlings of Olive - pomegranate - citrus - bananas - palm - figs - mango - apples – pears
	C-4	Roses and cut flowers	Roses farm yard – *Rosa Canina* - bulbs such as algeladiols, bird of paradise and all kinds of ornamental plants.
	C-5	Trees suitable for planting in highway sand green belts	Alcazurina – camphor – oleander – tamarisk - types of ornamental palms.
	C-6	All types of fiber crops	Such as cotton – linen – Jute - kenaf.
	C-7	Grassy forage crops and leguminous crops	Sorghum types and kinds of shamrock
	C-8	Mulberry to produce silkworm silk	All kinds of berries
	C-9	All plants and ornamental trees nurseries	Like *Ficus décor – F. natda – Ambassndr – Acacia*
D	D-1	Solid biomass crops	All crops for the production of bio-diesel fuel and energy oils such as: soybean – rapeseed - Jojoba and Jatropha - Castor.
	D-2	Crops to produce cellulose	All non-food crops for the production of glucose and its derivatives like ethanol and acetic acid-ethanol–generation
	D-3	Timber trees	All trees for timber production such as Alcaaa – camphor and mahogany

6 Control of pollution in agricultural drains in Egypt

Approaches to control sources of water pollution can be grouped into a systematic 3-steps strategic approach [33] as follows:

1st step: Prevention or reduction of waste production: Reduction of quantity of waste pollutants generated by an activity is obviously the most desirable approach to pollution control [34-35]. Since it conserves resources that would be wasted and eliminates the cost of removing pollutant after they are produced

2nd step: Treatment and recovery of waste components: Wastewater treatment systems are needed to reduce pollutant loads (before discharged into water streams) to acceptable levels. The amount of treatment required depends largely on the water quality objectives of the receiving water and also the dilution capacity available.

3rd step: In-situ reduction or elimination of pollution: Waste minimization and treatment help to prevent pollution from occurring and should be the principal approaches to water quality maintenance. Occasionally, however, when a water body is already adversely affected, efforts should be made to increase the waste assimilative capacity of the receiving water-body [34]. Methods to facilitate this are collectively grouped under in-situ control techniques.

[35] stated, when discharging waste into a river, controlling of water quality can be achieved by controlling the initial concentration at the outfall zone by two methods: (1) Reducing the concentration of pollutants in wastewater by diluting it with freshwater at the discharging point from upstream reservoir storage or from diversions from nearby bodies of water. This solution does not always lead to better water quality [37], (2) Increasing the biodegradation rate at the influent point by several methods, one of them is using fixed film systems [38] or in-situ submerged biofilters (SB). Installation of SB in the stream accelerates the growth of microorganisms, and hence the biodegradation rate. This will lead to the decrease of the received organic load in the stream at the influent zone, where the fixed-filter is installed.

The use of SB usually made of gravel or plastic media, for enhancement of self-purification polluted water streams were recommended by several investigators [6, 23, 36, 38-43] used self-Rotating Biological Contactors (Self-RBC) in order to increase the self-purification efficiency of polluted water streams.

During 2006 and 2007, a field experimental study has been carried out by a team of researchers (Dept. of Environmental Engineering, Faculty of Engineering, Zagazig University) as a part of funded project for enhancement of self-purification process of open drains in Egypt. The study aimed to investigate the effects of SB and self-RBC on improving the water quality of the drain, and to study the factors that affect the performance of these bioreactors. During the experimental work, a field experimental model (seven stream pilots of 40 m length, 0.38 m width, and 0.75 m wall height) was used. This model was constructed on the berm of Bilbeas main drain; at El-Sahafa bridge (KP 35.0) as shown in Figure 3 and 4, consisting of seven stream pilots; four of them were used to study the use of SB, whereas the later three pilots were used to study the effect of self-RBC. The four stream pilots, three of them were equipped with three different types of media (gravel, plastic star shape media and pall rings media) working as SB, while the fourth stream remained without any media in order to provide a corresponding reference for the natural stream self-purification. [6] stated that using submerged biofilters in polluted drains increases the COD removal efficiency from 1.4–18.4% in the reference stream (without any media) to 14.0–58.0% in streams packed with the media with a ratio of increase ranged between 1.2 and 14.5 times versus the natural removal (as shown in Figure 5).

Figure 3: a) The field experimental stream pilots installed at Bilbeas drain;
b) Plastic media (Pall rings and Star shape), c) Self-RBC

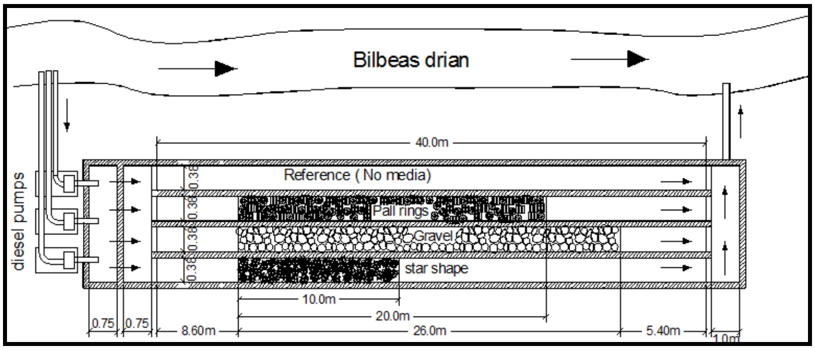


Figure 4: Schematic diagram for the stream pilot installed at Bilbeas drain

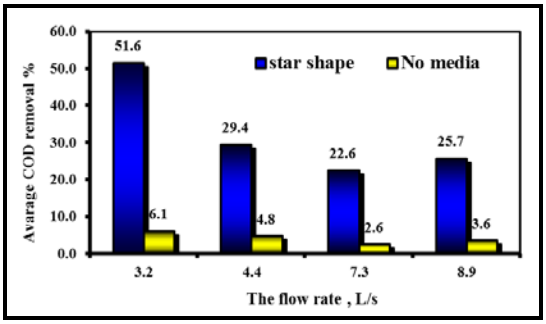


Figure 5: Effect of using SB (star shape) on COD removal comparing to natural self-purification

Daif [43] developed a new form of the Rotating Biological Contactors in order to rotate with free energy depending upon the hydraulic discharge of the drain water (see Figure 3). He studied the performance of Self-RBC under varying conditions (flow rates, number of stages used and spacing between stages). The results of this study showed that using self-RBC in the drain water increases the COD removal efficiency for about 34.1- 65.32% compared with 3.8-16.5% for the reference channel. Also, the dissolved oxygen concentration increased from 0.8–2.0 mg/L to 1.95–3.79 mg/L, compared with 0.86–2.25 mg/L for the reference channel. The effect of using Self-RBC on COD removal ratio at two sites A and B are shown in Figure 6.

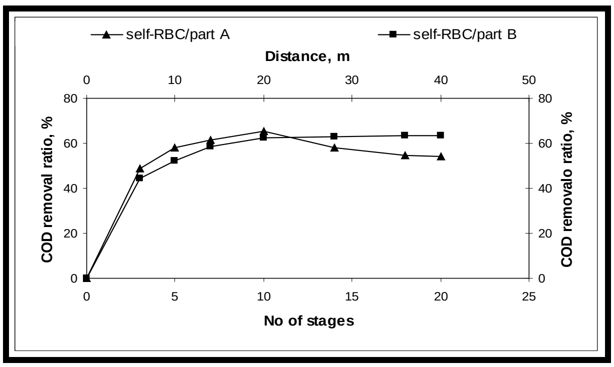


Figure 6: Effect of using Self-RBC on COD removal ratio

7 Opportunities and challenges of reusing TWW and DW

Due to water scarcity, Egypt's farmers endure using TWW as a source for irrigation water. A significant portion of treated wastewater is pumped and used for irrigating crops, particularly when water in the irrigation canals is scarce. Thus, the key challenge of reusing TWW and the significant opportunities to maximize the benefits of TWW reuse in Egypt could be achieved by the following [2, 44, 45]:

- Farmers must comply with the specific regulations for TWW reuse, especially those related to irrigation methods and cultivation only of permissible crops,
- Public awareness of health and safety practices for safe use of this resource is a prerequisite for large-scale implementation of TWW reuses, specifically protection of workers from direct contact with TWW by promoting the use of long boots and gloves,
- Developing positive perceptions about TWW reuse is a key for public acceptance, so informing consumers about the level of treatment would ensure public acceptance,
- Applicable executive programs for implementing the TWW-reuse policies are needed,
- Public awareness of health risks and environmental pollution are required if successful TWW reuse in agriculture is to be achieved,
- Improving the infrastructure of the treatment plants by recent developments in wastewater treatment technology, and Combining biophysical aspects with social, economic, and policy aspects is very much essential in order to reduce health risks associated with wastewater reuse.

8 Conclusions

Reuse of TWW and DW in agriculture under proper agronomic and management practices has many economic benefits, which include alleviating freshwater scarcity, providing a drought resistant source of water and nutrients, which reduce the fertilizer costs, increase water productivity by cultivation of multiple crops through the year, and confers environmental benefits. However, variability in composition of wastewater causes risks to soil, ecosystems, plants, animals and human beings. Monitoring of wastewater quality regularly and coming up with maximized benefits while minimizing impacts of the negatives make WW irrigation sustainable. This paper discussed the safe reuse of TWW and DW in agriculture as an alternative water resource in Egypt. Different aspects were considered in this study including the quantities of collected WW and generated TWW, and their quality for agriculture use based on different parameters such as their characteristics, level of treatment, and type of crops that suite for each level of treatment, irrigation type, health and environmental impacts, and effects on economy and national income. Furthermore, the impacts of reusing TWW and DW on soil, groundwater, crops, health, safety and economy are discussed. The control of pollution in agricultural drains could be achieved just after the discharge points using in-situ submerged biofilters and self-RBC, which accelerate the biodegradation rate of organic contaminant resulting in improvement of stream self-purification capacity and enhance the water quality for safe reuse.

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10 References

[1] Rassoul E.M.A.: Prospects of water reuse in Egypt. In: 10th international water technology conference, IWTC10, Alexandria, Egypt, 2006, pp 561–567

[2] Elbana, T.A., Bakr, N., Elbana, M.: Reuse of Treated Wastewater in Egypt: Challenges and Opportunities, Unconventional Water Resources and Agriculture in Egypt, HdbEnvChem, Springer International Publishing AG, 2017

[3] Elbana, T.A., Bakr, N., Karajeh, F., El Quosy, D.: Treated wastewater utilization for agricultural irrigation in Egypt. In: The national conference on water quality: challenges and solutions, National Research Centre, Cairo, Egypt, 2014, pp 35–46

[4] Ministry of Water Resources and Irrigation (MWRI): Water for future-national water plan for Egypt-2017. NWRP project. Planning Sector, Egypt, 2005

[5] Ministry of Water Resources and Irrigation: Water scarcity in Egypt: the urgent need for regional cooperation among the Nile Basin countries. Technical report, 2014

[6] El-Gohary, E.H.: Enhancement of Streams Water Quality Using In-situ Filters", MSc. in environmental engineering, Faculty of Engineering, Zagazig University, Egypt, 2007.

[7] Bushra, M.: Regional study on policies and institutional assessment of solid waste management in Egypt. Blue Plan. Regional Activity Centre, Sophia Antipolis, 2000

[8] Central Agency for Public Mobilization and Statistics (CAPMS): Water resource and its rationalization use in Egypt. Cairo, 2015; http://www.capmas.gov.eg.

[9] Zidan M.S., Dawoud, M.A.: Agriculture use of marginal water in Egypt: opportunities and challenges. In: Shahid SA, Abdelfattah MA, Taha FK (eds) Developments in soil salinity assessment and reclamation: innovative thinking and use of marginal soil and water resources in irrigated agriculture. Springer, Dordrecht, 2013, pp. 661–679.

[10] Sato, T., Qadir, M., Yamamoto, S., Endo, T., Zahoor, A.: Global, regional, and country level need for data on wastewater generation, treatment, and use. Agric. Water Manag. 2013, 130, 1-13.

[11] International Resources Group (IRG) Task 6: improved waste water reuse practices environmental evaluation of using treated wastewater in agriculture: Luxor demonstration site. Report No. 45. US Agency for International Development, 2008

[12] Soliman, W.M., He X.: The potentials of jatropha plantations in Egypt: a review. Mod. Econ. 2015, 6(2), 190–200.

[13] Elbana, T.A., Ramadan, M.A., Gaber, H.M., Bahnassy, M., H., Kishk, F.M., Selim, H.M.: Heavy

metals accumulation and spatial distribution in long term wastewater irrigated soils. J. Environ. Chem. 2012, 1(4), 925–933

[14] Ministry of Water Resources and Irrigation (MWRI): Integrated water resources management plan. Technical report 34180 00.81, Arab Republic of Egypt, 2005

[15] Pedrero, F., Kalavrouziotis, I., Alarco`n, J.J., Koukoulakis, P., Asano, T.: Use of treated municipal wastewater in irrigated agriculture: review of some practices in Spain and Greece. Agric. Water Manag. 2010, 97(9), 1233–1241.

[16] Loutfy, N.M.: Reuse of Wastewater in Mediterranean Region, Egyptian Experience, Waste Water Treatment and Reuse in the Mediterranean Region, Hdb Env Chem, Springer-Verlag Berlin Heidelberg, 2010

[17] Abdel-Dayem, S.: Drainage Water Reuse: Conservation, Environmental and Land Reclamation Challenges. IXth World Water Congress of IWRA, A special session on Water Management Under Scarcity Conditions: The Egyptian Experience, Montreal, Canada, 1997

[18] El Gamal, F., Mostafa, H., Shalby, A.: Reuse of low quality water in Egypt. In: Hamdy A, El Gamal F, Lamaddalena N, Bogliotti C, Guelloubi R (eds) Non-conventional water use: WASAMED project. CIHEAM/EU DG Research, Bari, 2005, pp. 93–103

[19] El-Agha, D.E., Molden, D.J., Ghanem, A.M.: Performance assessment of irrigation water management in old lands of the Nile delta of Egypt. Irrig. Drain Syst. 2011, 25(4), 215–236.

[20] ENCID (Egyptian National Committee on Irrigation and Drainage): Adopted measures to face major challenges in the Egyptian water sector. From the HAGUF 2 ND world water forum 2000 to the Kyoto 3 RD world water forum, 2003

[21] Ateia, M., Nasr, M., Yoshimura, C., Fujii, M.: Effect of salinity on organic matter removal from polluted agriculture drainage water by moving bed biofilm reactor. In: 9th IWA International Symposium on Waste Management Problems in Agro-Industries; Kochi, Japan, 2014

[22] Nasr, M., Zahran, H.F.: Assessment of agricultural drainage water quality for safe reuse in irrigation applications-a case study in Borg El-Arab, Alexandria, J. Coastal Life Med. 2015, 3(3), 241-244

[23] El Monayeri, D.S., Atta, N.N., El Mokadem, S., EL-Gohary, E.H.: Enhancement of Bilbeas Drain Water Quailty Using Submerged Biofilters (SBs)", Eleventh International Water Technology Conference, IWTC11 2007 Sharm El-Sheikh, Egypt, 2007a

[24] El Monayeri D.S., El Karamany, H. , Nacer, A., Aboul-Fotoh, A., El Gohary, E,: Enhancement Of Drain Water Quality Using Biofilters", Al-Azhar University 10th International Conference, Cairo, Egypt, 2008

[25] Mok, H., Dassanayake, K.B., Hepworth, G., Hamilton, A.J.: Field comparison and crop production modeling of sweet corn and silage maize (Zea mays L.) with treated urban wastewater and freshwater. Irrig. Sci, 2014, 32(5), 351–368.

[26] Ikehate, K.: Hazardous agents in wastewater: public health impacts and treatment options for safe disposal and reuse. In: Sharma SK, Sanghi R (eds) Wastewater reuse and management. Springer, Dordrecht, 2013

[27] Christou, A., Karaolia, P., Hapeshi, E., Michael, C., Fatta-Kassinos, D.: Long-term wastewater irrigation of vegetables in real agricultural systems: concentration of pharmaceuticals in soil, uptake and bioaccumulation in tomato fruits and human health risk assessment. Water Res. 2017, 109, 24–34

[28] Shaalan, N. S.: Egypt country paper on wastewater reuse. Joint FAO/WHO Consultation for launching the Regional Network on Wastewater Reuse. Amman, Jordan, 2011

[29] ENFP, Egyptian National Focal Point. Egypt, MWRI, 2008, http://www.emwis-eg.org/

[30] Khassaf, S.I., Kizar, F.M.: Reuse of treated sanitary sewage in Najaf city for agricultural purposes. Al-Qadisiya J. Eng. Sci. 2011, 4(1), 558-578.

[31] El Sayed, A.: Strategy for wastewater reuse and action plan in Egypt, Proceedings of International Symposium on Environmental Pollution Control and Waste Management; Tunis. 2002.

[32] ECP 501: Egyptian code of practice for the reuse of treated wastewater for agricultural purposes. The Ministry of Housing Utilities and Urban Communities ECP 501 (2015) Egyptian code of practice for the use of treated municipal wastewater for agricultural purposes. The Ministry of Housing Utilities and Urban Communities, 2005

[33] Innocent, N., Huub J.G.: A 3-step strategic approach to sustainable wastewater management", Water SA, 2005, 31(1), 133-140.

[34] Waite, T.D.: Principles of water quality, Academic Press, Inc. Orlando, Florida, 1984

[35] Thomann, R.V., Mueller, J.A.: Principles of Surface Water Quality Modeling and Control", Harber& Row, New York, USA 1987

[36] Abd El-Rahman, W.H.: Discharge of Domestic Wastewater into Rivers, PhD Thesis, Faculty of Engineering, Helwan University, Matarya Branch, Egypt, 2002

[37] Rinaldi, S., Soncini-Sessa, R., Stehfest, H., Tamura, H.: Modeling and Control of River Quality, McGraw-Hill, London, UK, 1979.

[38] Hino, M.: Water Quality and Its Control, A. A. Balkema/Rotterdam/Brookfield, 1994

[39] Moussa, M.S., Salem, S., El Gammal, H., Atta, M.A., Abdel Khalek, M.A.: Enhancement of the self-purification in the West Bank Drains, Egypt, 2nd International Conference Environmental Sciences and Technology, September 4-6, Egypt, 2006

[40] El Monayeri, D.S., Atta, N.N., El Mokadem, S., Aboul-fotoh, A.M.: Effect of Organic Loading Rate and Temperature on The Performance of Horizontal Biofilters", 11th International Water Technology Conference, IWTC11 2007, Sharm El-Sheikh, Egypt 2007b

[41] El Monayeri, D.S., Atta, N.N., El Mokadem, S., Aboul-fotoh, A.M.: Biological Treatment of Drain's Water Using Submerged Bioreactors, Second Ain Shams University International Conference on Environmental Engineering, Egypt, 2007c

[42] Aboul-fotoh, A.M.: Biological Treatment of Drain's Water Using Submerged Bioreactors, MSc Thesis, Faculty of Engineering, Zagazig University, Egypt, 2007

[43] Daif, S.A., El Monayeri, D.S, Atta, N.N., El Baz, A.: Organic and Ammonia removal of polluted streams using self-Rotating Biological Contactor, Al-Azhar University, 10th International Conference, Cairo, Egypt, 2008

[44] Hanjra, M.A., Blackwell, J., Carr, G., Zhang, F., Jackson, T.M.: Wastewater irrigation and environmental health: implications for water governance and public policy. Int. J. Hyg. Environ. Health 2012, 215(3), 255–269

[45] Dolnicar, S., Hurlimann, A., Bettina, G.: What affects public acceptance of recycled and desalinated water, Water Res. 2011, 45(2), 933–943