SUSTAINABLE MANAGEMENT OF TREATED WASTEWATER – CASE STUDY: NEW EL-MAHSAMA WASTEWATER TREATEMENT PLANT IN SINAI

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Abstract

Eventually in arid and high urban-populated countries like Egypt, treated wastewater can serve as an important water resource to augment the increasing irrigation water requirements, as far as strict safeguards for human health and environment protection are met. The available fresh water resources in Egypt from the River Nile, few coastal precipitations and small non-renewable deep groundwater are extremely less than the food demand of the increasing population of Egypt, resulting in a deficit of more than 54 billion m^3 per year. Reusing the agricultural drainage water several times fills about 20 billion m^3 per year of that deficit gap. Importing virtual water (key crops are wheat, meat and oils) closes the remaining deficit of about 34 billion m^3 per year. As part of the national water resources strategy 2030 of Egypt, safe usage of treated wastewater should be expanded in new agricultural lands. In 2020, a first mega-waste water treatment plant (El-Mahsama WWTP) was constructed in the east of Suez Canal in Sinai Peninsula to treat 1.0 million m^3 per day of the agricultural El-Mahsama Drain and other small drains mainly for relevant agricultural purposes in Sinai. However, treated wastewater utilization unwisely may incur several risks to human health, agricultural crop yields, livelihood, social and economic conditions and the environmental sustainability, attributed to the possible existence of chemical, biological or salts in such treated wastewater. This research paper aimed at analyzing the best sustainable uses of that treated wastewater of El-Mahsama WWTP in agriculture without causing risks to the human and environmental health. Using a qualitative evaluation approach, it was proved that the "favorable alternative sustainable management" includes cropping pattern for the 1st scheme (70,000 feddans) as wheat, barley, beans, and maize, then cropping pattern for the 2nd scheme (about 52,000 feddans) as cotton, flax, kenaf, oil crops as jojoba, jatropha, canola and sunflower. The socio-economic benefits associated with its application is high. The disposal of agricultural drainage water from the agricultural schemes shall be diverted to irrigate wooden forest trees "mahogany". The risk of shortage of water in El-Mahsama Drain (or temporarily stopping the WWTP) could be compensated by developing a number of groundwater wells to be readily standby for such unlikely water shortage for the agricultural schemes. The compost produced can be safely used after appropriate processing and special treatment of the effluent sludge as animal fodder. Furthermore, the sludge can be used after anaerobic digestive processes to produce biofuel energy for the nearby communities' daily life activities. Any remaining harmful effluent sludge waste of the WWTP should be damped into secured and impervious evaporation ponds. Finally, WWT shall reduce the carbon emission and the climate change risks shall be minimal due to the high resilience of the selected crops against climate change. Such expansion in non-conventional water use shall give wastewater a second life in Egypt with target to reduce water scarcity, reduce environmental deterioration, increase resilience to climate change and improve people's livelihoods.

Keywords: *treated wastewater of a blend of marginal waters, sustainable water management, human health, environmental quality, less carbon emission, sustainable development, qualitative evaluation approach, El-Mahsama Drain, Sinai development, El-Mahsama wastewater treatment plant.*

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1. Introduction

1.1 Wastewater reclamation and use

Wastewater may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts (Podapoulous, 1995). The indiscriminate use of wastewater for irrigation as a result of freshwater shortage could impair soil functions and cause environmental pollution (Abegunrin, *et al.,* 2016). Consequently, mismanagement of wastewater irrigation would create environmental and health problems to the environment and human beings (Mohammad M. J. and M. Ayadi, 2005.) when waste water is used continuously as the sole source of irrigation water for field crops in arid regions. Excessive amounts of nutrients and toxic chemical constituents could simultaneously be applied to the soil plant system. That would cause unfavourable effects on productivity and quality parameters of crops and the soil (Vazquez-Montiel *et al.,* 1996). Although treated wastewater irrigation reduces the pressure on freshwater usage, it could lead to accumulation of heavy metals residuals in soils. The indicators commonly used for risks of utilizing such water with marginal quality in agriculture include concentration of heavy metals residuals in crops and salts concentration, nutrients, phosphorus, metals and chloride in soils (Cao *et al.,* 2018). FAO (1985), Oron *et al.* (2002), Cetin and Kirda (2003) and Schoups *et al.* (2005) suggested that degradation of soils using alkali water constitutes a major threat to irrigate agriculture especially for the cultivation of sodicity sensitive crops long-term sodic water irrigation increased sodium adsorption ratio (SAR).

Organic materials present in the wastewater are detergents, pesticides, fats, oil, grease, solvents and phenols. The modern WWTPs are equipped by sludge drying, separation and utilization facilities. The solid sludge disposed from the WWTPs is rich in nutrients and good for the production of compost for agricultural purposes, a material with good physical and chemical properties that allows for increase in crop growth and yields. Biofuel could be a by-product after effluent sludge through anaerobic digestive extraction processes. Also, usage of the produced compost from that treatment in agriculture systems holds sustainable advantages and benefits. It could reduce environmental degradation and soil erosion in clayey soils, in addition, its continued application could improve the soil quality as physical and chemical properties (Galal, Y. G. M., 2012). Such technologies enable full safe utilization of all by-products (compost and biofuel).

1.2 Water resources status in Egypt

Water scarcity is a serious and growing concern in Egypt. According to the Ministry of Water Resources and Irrigation (MWRI), Egypt requires 114 billion m^3 of water per year to cover the country's increasing demands in the drinking, agricultural and industrial sectors. The River Nile, few costal precipitations, small non-renewable groundwater generates about 60 billion m^3/year (MWRI's Strategy 2030, 2018). This results in water shortage (deficit) estimated at 54 billion m^3/year. The agricultural sector consumes most of the country's available water resources, accounting for nearly 80% of the nation's total water withdrawals (Noureldin, 2016). About 55% of the population of Egypt are dependent on the agricultural sector for their livelihood, a sector that accounts for about 15% of a Gross Domestic Product (GDP) of US$232 billion, and close to one-third of total employment force in Egypt (FAO, 2019).

As fat no toxic constituents exist, agricultural drainage water with sufficiently good quality can be used directly for safe irrigating crops. Otherwise, agricultural drainage water could be reused after mixing with freshwater resources to reduce the concentrations of the existing chemicals and salts.

Alternatively, drainage water can be used cyclically with freshwater separately during the crop life time. In Egypt, reuse of agricultural drainage water is widely practiced (several times) since decades to close the gap between the available freshwater resources and water demands for all sectors by about 20 billion m^3/year (NWRP, 2018).

1.3 Development projects in Sinai

Egypt embarked in constructing large land development project in north, middle and south Sinai (CEDARE, 1992). Then, the National Water Resources Strategy of Egypt focused more on the effective sustainable development of the Sinai Peninsula (MWRI's Strategy 2030, 2018). That strategy includes the establishment of several agricultural projects in the desert areas and create attractive communities' settlements in Sinai. Agriculture development projects in north Sinai depends on mixing the Nile water with agricultural drainage water making more than 5 billion cubic meters per year, which shall be mainly pumped from Bahr El-Baqar wastewater treatment plant into the agricultural schemes in north Sinai (Egypt Today, 2019). Additionally, in middle Sinai, treated water of El-Mahsama Drain shall be pumped into Sinai adding about 265 million m^3/yr to irrigate other agricultural schemes.

1.4 Wastewater treatment facilities in Egypt

El-Gabal El-Asfar project was the first direct domestic wastewater treatment plant in Egypt in 1990. It was expanded on several phases to increase its capacity in order to cope up with the increasing wastewater amounts of the growing population of Greater Cairo as mega city, thereby contributing to improving the human health and the environment (AfDb, 2009). El-Gabal El-Asfar WWTP is considered the largest in the Middle East and Africa, with a total capacity of 1,800,000 m^3 per day (Hassan Allam, 2019). Its treated wastewater is being used under supervision of the HCWW to mainly irrigate wood forests in the fringes of Cairo. Eventually, there is about 7.6 billion m^3 of domestic wastewater is produced, out of which about 3.8 billion m^3 of wastewater is treated each year in Egypt (Rewater, 2019). Currently, a fraction of that treated wastewater is diverted to irrigate forest trees, with a target to contribute to empowering the national wood industry in Egypt, thus reducing the national financial burden allocated to cover the costs of wood importing in large amounts. The national water resources policy urges and gives incentives to the private sector firms and large investors to implement investment and development projects using treated wastewater.

1.5 Water quality monitoring in Egypt and water quality status in El-Mahsama Drain

In early 1980's, the Drainage Research Institute (DRI) of the National Water Research Center of Egypt established a water quality monitoring network covering the whole irrigation and drainage systems and lakes in the Nile Delta of Egypt. Then in 1997, DRI developed a denser and wider monitoring network that covers more strategic sites as well as more water quality parameters (Alaa F. Abukila, 2015). El-Mahsama Drain is mainly agricultural drain but also carries some domestic wastes from various villages and cities along its course. It includes significant amounts of salts, nutrients and biological pollutants. Figure (1) shows the location of El-Mahsama Drain among the DRI's water quality monitoring network in Nile Delta of Egypt. Because El-Mahsama Drain used to mix its polluted water into El-Ismailia Canal and after the expanded urbanization in that region and due to the local governments and communities' pressure of health risks, the government stopped the mixing to El-Ismailia Canal (Bazaraa, 2002).

Since that time and up to the beginning of 2020, the full discharge of El-Mahsama Drain was disposed into El-Temsah Lake (through Gabal Miriam pump station) causing significant environmental pollution to the Lake's ecosystem (S.G. Abd El Samie *et al.,* 2008). DRI used to collect water samples and analyze the following water quality parameters: in-situ measurements of Oxygen content, pH, temperature, turbidity, electrical conductivity and total suspended solids. DRI also collects water samples for laboratory analysis including (Oxygen budget: BOD, COD and DO), (salts: EC, TDS, SAR, Adj SAR, and RSC), (plants nutrients both major/minors: NO_3, NH_4, Total Nitrogen TN and Total Phosphorus TP), (metals: Cu, Fe, Mn, Zn, Pb and Ni), (Bacteria: Fecal and Total Coliform), Boron (B) and chloride (CL). According to the results of water quality analysis done by DRI and mentioned in its latest publication, the Year Book (2015-2016), Table (1) shows the typical annual average water quality parameters at El-Mahsama Drain outfall before the construction of El-Mahsama WWT Plant. It is noted that Coliform bacteria number does not meet the FAO Standards (FAO, 1985) nor the Egyptian Code (ECP 501, 2015) along El-Mahsama Drain, as it is described below.

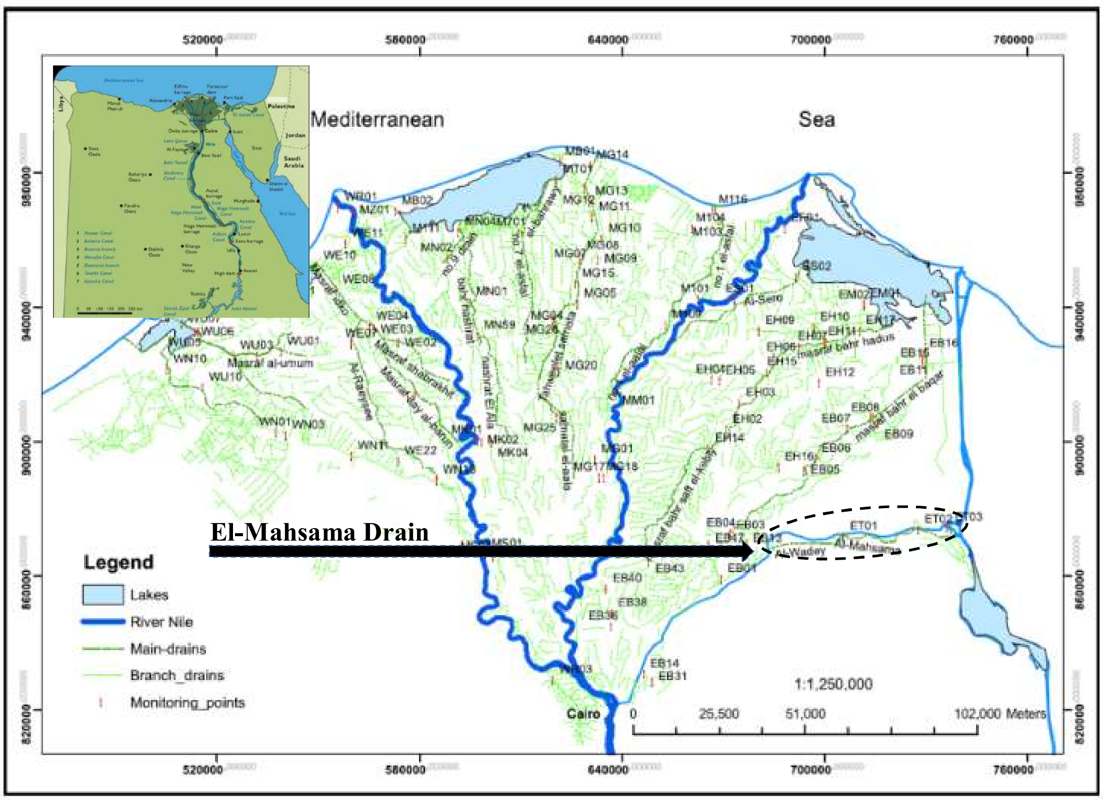

Figure (1): Location of El-Mahsama Drain among the water quality monitoring network in the Nile Delta (source: DRI database)

1.6 National wastewater treatment policy and legislations in Egypt

Specific laws (law 93 in 1962, law 12 in 1984, law 4 and law 213 in 1994) defined the use and management of marginal water for irrigating agricultural crops. Then, the Holding Company for Water and Wastewater (HCWW) of the Ministry of Housing, Utilities and Urban Communities of Egypt issued the Egyptian Code for using treated wastewater in agriculture (ECP 501, 2015). That new code permits using the treated water in irrigating industrial crops, some non-edible raw agricultural crops, fiber crops, grass and oil trees taking into consideration the required health safety measures, following the approach recommended by the World Health Organization (WHO) in 2006. The new code is more flexible than the old laws, yet the health safeguards of the humans and environment are still strictly met. In addition, during environmental and human health impacts assessment, the new Egyptian Code abides by law 4 in 1994 modified by law 9 in 2009 with its bylaws. Table (2) presents the maximum thresholds of major water quality parameters after treatment (as stated in ECP 501, 2015).

Table (1): Typical annual average water quality parameters at El-Mahsama Drain outfall

pH	7.33	-
DO	3.7	mg/l
EC	2.09	dS/m
TDS	1124	PPM
TSS	35	mg/l
COD	55	mg/l
BOD	40	mg/l
NH_4	1.59	mg/l
Coliform Bacteria	20968	MPN/100ml
Fecal Bacteria	5523	MPN/100ml
Fe	1.12	mg/l
Zn	1.9	mg/l
Pb	2.0	mg/l
Ni	1.0	mg/l
Co	1.9	mg/l
Cr	1.9	mg/l
Cd	1.2	mg/l

Source: DRI's database and technical reports - DRI Year Book (2015-2016)

Table (2): Permissible limits of major water quality parameters after wastewater treatment processes, according to (ECP 501, 2015)

Parameter	limit	unit	Parameter	limit	unit	Parameter	limit	unit
Al	5	mg/l	Cd	0.01	mg/l	SO_4	500	mg/l
As	0.1	mg/l	Zn	5	mg/l	HCO_3	400	mg/l
Be	0.1	mg/l	Cr	0.1	mg/l	SAR	9	mg/l
Cu	0.2	mg/l	Hg	0.002	mg/l	Na	230	mg/l
F	1.5	mg/l	V	0.1	mg/l	Mg	100	mg/l
Fe	5	mg/l	Co	0.05	mg/l	Ca	230	mg/l
Li	2.5	mg/l	B	1	mg/l	TSS	15	mg/l
Mn	0.2	mg/l	Mo	0.01	mg/l	Turbidity	5	NTU
Ni	0.2	mg/l	Phenol	0.002	mg/l	BOD_5	15	mg/l
Pb	5	mg/l	TDS	2000	mg/l	E. Coli	20	count/100 ml
Se	0.02	mg/l	PO_4	30	mg/l	Nematoda worms	1	count/100 ml

(source: HCWW, Egyptian code for treated wastewater use in agriculture, ECP 501, 2015)

The key factor for achieving safe and sustainable use of treated wastewater is selecting suitable crops to be irrigated with such treated wastewater (Elbana T. A. *et al.,* 2017). For example, oil crops such as canola and sunflower can safely be irrigated with treated wastewater (Zidan M. S. and Daoud M. A., 2013). Furthermore, irrigating jatropha with treated wastewater is favorable because of the socio-economic benefits associated with its high compost and biofuel by-products. The old Egyptian code for using treated wastewater issued in 2005 classified treated wastewater into three categories (A, B, and C), while ECP 501 (2015) classifies treated wastewater into four grades (A, B, C, and D) depending on the level of treatment (Table 3). It prohibits the use of treated wastewater for any raw vegetables such as cucumber or tomatoes. Moreover, the ECP 501 (2015) specifies the allowable crops for each treated wastewater category.

Table (3): Criteria for different grades of wastewater treatment (ECP 501, 2015)

Criteria	**Treatment level**			
	A	B	C	D
Total Suspended Solids (TSS, mg/l)	< 15	< 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	1000	N.D.
Intestinal Nematodes (cells/l)	< 1	N.D.	N.D.	N.D.

N.D. means "not defined"

The Government of Egypt puts strict operation safeguards for wastewater secondary treatment processes of El-Mahsama WWT Plant to follow the ECP 501 (2015). The effluent is classified as "Grade A", which is good for irrigating all types of agricultural crops (except raw vegetables) as well as grass and trees. The design threshold values of water quality generated by El-Mahsama WWTP are as shown in Table (4).

Table (4): The design thresholds values of El-Mahsama WWTP

WQ Parameters	Unit	Max value (Out)
COD	mg/l	15
BOD	mg/l	10
TSS	mg/l	10
Turbidity	NTU	5
E. coli	count/100 ml	20
Nematoda worms	count/100 ml	1

(Source: Masr Consultants, 2019)

The goal of this research paper is to quantify, analyze and determine the safe and sustainable uses of the treated wastewater of El-Mahsama WWTP, which originally included a blend of agricultural drainage water and municipal wastewater, mainly for agriculture purposes. Using a qualitative evaluation approach, "favorable alternative sustainable management" was developed in this research paper for using WWT, reducing risks to human health and environmental quality and furthermore, reducing the carbon emission to the atmosphere.

2. Materials and methods

2.1 The case study - El-Mahsama wastewater treatment plant

Year 2020 witnessed the completion of the first drainage wastewater treatment plant in Egypt for safe use of treated wastewater in irrigating new agricultural schemes, as one of the most promising non-conventional solutions for overcoming water scarcity challenges in Egypt. El-Mahsama WWTP is a mega drainage wastewater secondary treatment facility in Sinai Peninsula east of Suez Canal (area of 42,000 m^2, cost of 100 million US dollars), as shown in Figure (2). El-Mahsama WWTP was recognized internationally in 2019 and 2020 as the best engineering infrastructure project and best world water recycling project. It aims at treating the whole El-Mahsama Drain water rather than letting it run into Lake El-Temsah causing significant negative environmental impacts in the lake ecosystem. That plant is planned to treat a blend of domestic waste and agricultural drainage water from El-Mahsama Drain and other small agricultural drains. El-Mahsama WWTP is equipped by sludge anaerobic digestive, drying and utilization processing facilities. Water of El-Mahsama Drain (west of Suez Canal) is being transferred to El-Mahsama Plant (east of Suez Canal) through eight pumps and two major tunnel siphons crossing underneath the old and new Suez Canal system at new Sarapium site. The depth of the tunnels is 60 m with 20 m diameter each with shafts at the ends. Each tunnel has a length of 420 m. El-Mahsama WWTP has a capacity of 1.0 million m^3/day, and is being developed to provide additional agricultural scheme in Sinai with sufficient and safe irrigation water.

The first identified irrigation agricultural scheme in west central Sinai is about 70,000 feddans (about 30,000 ha) of reclaimed sandy soil, “Phase I”, that could be extended in the future. Modern irrigation technologies (sprinkler, drip and sub-surface system) are constructed. In addition, advanced preparation, harvesting, collection, processing, storing and transport machineries and facilities are being availed. According to ECP 501 (2015), it is planned that all types of industrial crops, non-edible raw agricultural crops and wood trees shall be safely cultivated (Hassan Allam, 2020). Also the Egyptian environmental laws strictly forbid the disposal of any low quality waters in Suez Canal, as it is an international navigational route.

Figure (2): Location of El-Mahsama wastewater treatment plant east of Suez Canal

2.2 Method

In this research paper a simple multi criteria qualitative evaluation approach was developed, so that the following objectives were covered:

- Identifying the baseline situation in the case study

- Verifying the compliance of El-Mahsama WWTP with standards and safeguards for human health, crop productivity, soil conservation and the environmental quality.
- Analyzing the safe and sustainable uses of the treated wastewater of El-Mahsama WWTP in irrigating different types of agricultural crops, either industrial crops, fiber crops, cattle and sheep fodders, wood trees, compost and biogas/fuel without incurring risks to human health and environmental quality.
- Determining the destinations for safe disposal of the remaining effluent from El-Mahsama WWTP as well as of the drainage water out of the agricultural scheme.
- Proposing a suitable management scenario that values the human and environmental health, has socio-economic rewards and copes-up with the climate change, probable water shortage or El-Mahsama WWTP emergency stopping.

Multiple cropping pattern scenarios were proposed, evaluated and compared. Long-term impacts of residuals of chemical constituents in soil were evaluated and assessed. Impacts on human (direct- and indirect-contact), and cattle and sheep production and the environmental system quality under various scenarios/alternatives were determined and evaluated according to the international and national standards and codes.

2.3 The impacts matrix used

The comparison matrices developed in this research paper included impacts scores of treated wastewater use on: 1) human health such as diseases, death and health implications, 2) crops productivity, 3) cattle and sheep production, such as meat and milk, 4) environmental quality, such as ecology, flora, fauna, hygiene and carbon emission, 5) socioeconomic aspects, 6) disposal of the remaining harmful effluent sludge waste of the WWTP in the nearby marches, injecting it into the deep GW aquifer or dumping in protected evaporation ponds, 7) disposing the agricultural drainage water from the agricultural scheme, and 8) any possible impacts under climate change conditions, such as temperature rise or drought events. Also it includes weight for each sub-risk.

2.4 Proposed crop pattern scenarios

crop composition scenarios proposed for the agricultural scheme of 70,000 feddans planned to be irrigated using the resulting treated wastewater of El-Mahsama WWTP. That water strictly complies with the safeguards and standards specified in the ECP 501 (2015). In the same time, it could contribute to national food self-sufficiently from some strategic crops and/or add to the national revenue as trade crops or products. The proposed scenarios could be implemented solely or combined in sets of alternatives. In each alternative, risks to human health and environmental system were analyzed to determine the best sustainable uses of that treated wastewater of El-Mahsama WWTP in agriculture. Those proposed cropping pattern scenarios (CPSs) were as follows:

- Cropping pattern scenario (1): traditional (classical) eatable crops such as: wheat, barley and beans (winter crops), and maize (summer crop).
- Cropping pattern scenario (2): pasture crops
- Cropping pattern scenario (3): fiber crops such as: cotton, flax and kenaf
- Cropping pattern scenario (4): oil crops such as: jojoba, jatropha, canola and sunflower
- Cropping pattern scenario (5): flowers such as: rose, gladiolus and jasmine
- Cropping pattern scenario (6): wood trees “mahogany”

3. Results

The operation of El-Mahsama WWTP is planned for not less than 100 years, therefore the short and long-term human and environmental impacts were the concern in this analysis. The relevant risk criteria proposed, analyzed and evaluated were: human health risks, crop productivity risks, environmental quality risks, socio-economic risks, shortage of water in El-Mahsama Drain risks, temporary stopping the WWTP risks, disposal of the remaining harmful effluent sludge waste of the WWTP risks, disposal of agricultural drainage water from the agricultural scheme risks, and climate change risks. Each one of those risk criteria was subdivided into several ones (Table 5).

3.1 Points distribution among the various evaluated risk criteria

The authors conducted an opinion survey among a group of relevant specialists and experts of considerable knowledge in relevant fields to this research topic in order to reach a reasonable and logic distribution of points among those risk- and sub-risk criteria and to reach reasonable and reliable weights. That survey was guided by the instructions and precautions mentioned in FAO paper 47 on Wastewater treatment and use in agriculture (FAO, 2002). That task was followed by a simple multi criteria analysis (MCA) of the results. Agreement was reached that points to be divided among the risks as follows: human health risks (40 pts), crop productivity risks (22 pts), environmental quality risks (16 pts), socio-economic risks (13 pts), shortage of water in El-Mahsama Drain risks (4 pts), stopping El-Mahsama WWTP risks (1 pt), Disposal of remaining harmful effluent sludge waste of the WWTP risks (2 pts), disposal of agricultural drainage water from the agricultural scheme risks (1 pt) and lastly climate change risks (1 pt). The distribution of points among the various evaluated sub-risk criteria are shown in Table (5).

Table (5): Distribution of points among the various evaluated sub-risk criteria

Evaluation risk criteria	Sub-risk criteria	Points
Human health risks	direct contact infection	8.00
	in-direct contact infection	10.00
	health implications	16.00
	sever diseases	5.50
	death	0.50
Crop productivity risks	yield/productivity	6.00
	salts residuals	2.00
	Chemicals	0.50
	salts in soil	1.50
	plants nutrients (major/minors)	2.00
	chloride in soil	1.50
	waterlogging in soil	0.50
	cattle and sheep meat production	3.00
	profitability	2.00
	social valuing	3.00
Environmental quality risks	groundwater salinization	3.00
	ecological un-equilibrium	4.00
	fish mortality	4.50
	Flora, fauna and hygiene	1.50
	carbon emission	3.00
Socio-economic risks	livelihood	2.00

	jobs creation	2.50
	household income	3.00
	commodities availability	1.00
	market price	1.50
	inter-trade	1.00
	accessibility	1.50
	safety	0.50
Shortage of water in El-Mahsama Drain risks	crop stress/productivity	2.50
	environmental quality	1.50
Temporary stopping El-Mahsama WWTP risks	crop stress/productivity	0.75
	environmental quality	0.25
Disposal of remaining harmful effluent sludge waste of the WWTP risks	marches health	0.75
	injection in groundwater aquifer	1.00
	evaporation ponds	0.25
Disposal of agricultural drainage water from the agricultural scheme risks	marches health	0.50
	wooden trees forest	0.10
	evaporation ponds	0.40
Climate change risks	impact of temperature rise	0.75
	impact of drought events	0.25
Total points		**100**

The rules used in order to make good estimate of weights were that high weights should be given to the sub-risk criteria that achieve impacts (positive or negative) with high probability of occurrence on human, crop, soil and the environment. On the contrarily, those sub-risk criteria that achieve impacts (positive or negative) with low probability of occurrence were given low weights. Examples of sub-risk criteria that were assumed to achieve impacts with high probability of occurrence were (health implications, in-direct contact infection, crop yield/productivity, cattle and sheep's meat and milk production, fish mortality, ecological equilibrium, household income, water shortage on crop stress/productivity, disposal of effluent on groundwater aquifer and impact of temperature rise). Examples of sub-risk criteria that were assumed to achieve low probability of occurrence were (death, waterlogging in soil, impact on flora and fauna, social safety, impact of temporary stopping of WWTP on environmental quality, disposal of remaining harmful sludge waste in evaporation ponds and impact of drought events). Figure (3) illustrates the rules used in this research paper to estimate criteria weights. Those assumptions were considered by the authors -up to the best of knowledge- based on the results of the opinion survey that was conducted and in addition based on the confidence that El-Mahsama WWTP shall have strict quality control and assurance procedure during its operation as it follows preciously the ECP 501 (2015) as well as the Egyptian law 4 in 1994 modified by law 9 in 2009 with its bylaws (Hassan Allam, 2020).

3.2 The risks identification and evaluation matrices

In order to conduct a proper qualitative analysis to determine the safe and sustainable uses of the treated wastewater of El-Mahsama WWTP, a logical evaluation scale was determined to all risk and sub-risk criteria of human health, crop productivity, soil conservation and the environmental quality. That risk scale ranged from high score (close to 100%), moderate (50%), low (25%) and nil (0%). Those logical risk scores were afterwards converted into weighted scores aiming at selecting a suitable sustainable management alternative of wastewater use in agriculture.

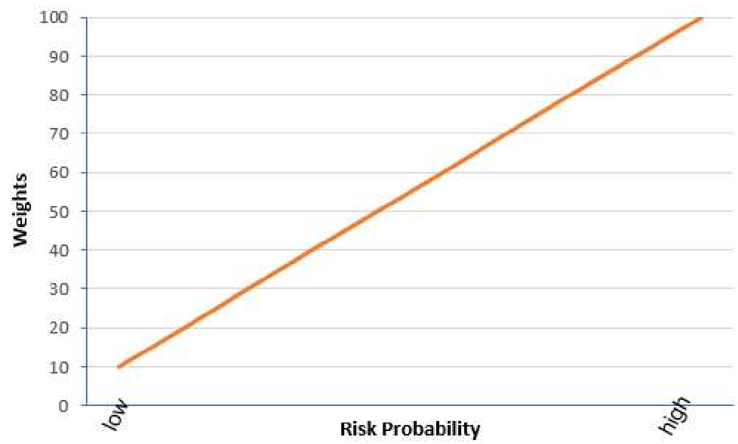

Figure (3): The rules used to estimate weights for the sub-risk criteria

3.2.1 Human health risks

During the operation, El-Mahsama WWTP strictly follows the ECP 501 (2015), there shall be almost nil probability for death, sever diseases, health implications and in-direct contact infection. However, could be rare probability for infection with mild diarrhea or skin itching for those farmers in direct contact with the irrigation and agricultural activities. Table (6) shows human health risk scales upon exposure to the treated wastewater of El-Mahsama WWTP.

Table (6): Matrix of human health risk scales upon exposure to the treated wastewater

Sub-risk criteria	Short-term exposure	Long-term exposure
direct contact infection	moderate	low
in-direct contact infection	nil	low
health implications	nil	low
sever diseases	nil	low
death	nil	nil

(Note: risk scales are high, moderate, low and nil)

Based on the sub-risk criteria scale and proposed weighted scores, human health criteria scored 36 points on the short-term exposure to the treated wastewater out of 40 points and scored 30.1 points on the long-term exposure. Both scores are seemed appreciable with no human health risks.

3.2.2 Crop productivity risks

The proposed cropping pattern scenarios were: CPS (1) composed of wheat, barley and beans (winter crops), and maize (summer crop), CPS (2) composed of pasture crops, CPS (3) composed of cotton, flax and kenaf and CPS (4) composed oil crops as jojoba, jatropha, canola and sunflower. CPS (5) composed of flowers such as: rose, gladiolus and jasmine and CPS (6) composed of wood trees "mahogany" which shall be postponed to future project extension phases. Each one of those CPSs was suitable to be grown in the agricultural scheme in Sinai according to the soil classifications, climate conditions and properties of the treated wastewater during winter and summer seasons, as the practice used in the new reclaimed lands in Egypt (Zidan M. S. and Daoud M.A. 2013). Table (7) shows comparison of risk scales among those CPSs, so as to select the most convenient one for application.

Table (7): Matrix of crop pattern scenarios versus risk scales

CPSs / Sub-risk criteria	CPS (1)	CPS (2)	CPS (3)	CPS (4)
Yield/productivity	high/moderate	moderate	low	low
Salts residuals	nil	nil	nil	nil
Chemicals	nil	nil	nil	nil
Salts in soil	nil	nil	nil	nil
Plants Nutrients (major/minors)	nil	low	nil	nil
Chloride in soil	nil	low	nil	low
Waterlogging in soil	nil	low	nil	nil
Cattle and sheep meat & milk production	moderate	high	low	low
Economic return	high-moderate	moderate	moderate	moderate
Social valuing	high-moderate	moderate	low	moderate

(Note: risk scales are high, moderate, low and nil)

Based on the sub-risk criteria scale and proposed weighted scores, the proposed crop pattern scenarios: CPS (1), CPS (2), CPS (3) and CPS (4) scored 17.8, 13.3, 16.5 and 14.5 points out of 22 points respectively. Accordingly, CPS (1) composed of (wheat, barley, beans and maize) was selected for application in the agricultural scheme that shall be irrigated from El-Mahsama WWTP in Sinai, provided that quality of the used treated wastewater is within the permissible limits specified in the ECP 501 (2015).

3.2.3 Environmental quality risks

As soil classification of the agricultural scheme is dominantly sandy soil, the continuous modern irrigation with such marginal water containing insignificant concentrations of salts, nutrients, and chloride (as illustrated in Tables 2, 3 and 4) still could cause moderate salinization of the groundwater on the long-term due to the accumulation of salts, but not on the short term. Regarding fish production in case of disposing the remaining WWTP's effluent water or drainage water from the agricultural scheme into the marches, it could be expected that moderate fish mortality on the short-term occurs but not on the long-term. No hazard or negative impacts are expected to the flora and fauna, hygiene or the ecological equilibrium in the case study considering the operation of El-Mahsama WWTP will strictly follow and respect the ECP 501 (2015). Furthermore, it is expected that less carbon emission will occur. Table (8) illustrates the estimated environmental quality sub-risk criteria due to using the treated EL-Mahsama WWTP versus risks scales.

Table (8): Matrix of environmental quality sub-risk criteria due to using the treated water of El-Mahsama WWTP versus risk scales (short- & long-term)

Sub-risk criteria	Short-term exposure	Long-term exposure
groundwater salinization	nil	moderate
ecological un-equilibrium	nil	nil
fish mortality	moderate	low

flora, fauna and hygiene	nil	nil
carbon emission	nil (+ve)	nil (+ve)

(Note: risk scales are high, moderate, low and nil)

With the operation of EL-Mahsama WWTP, it is expected that less carbon emission will occur. Based on the sub-risk criteria scale and proposed weighted scores, the environmental quality sub-risk criteria due to using the treated water EL-Mahsama WWTP scored 13.8 points on the short-term and 13.4 points on the long-term respectively, out of 16 points.

3.2.4 Socio-economic risks/benefits

Utilizing the treated wastewater of El-Mahsama Drain in agriculture converted the risks into opportunities and benefits to the societies and communities living in the areas benefiting from that case study and nationwide too. Giving a second life to wastewater makes it beneficial resource not a challenging hazard (Rodriguez, D. J. *et at.,* 2020). All sub-evaluation criteria scored high as opportunities and benefits on the short- and long-terms, as shown in Table (9).

Based on the sub-evaluation criteria scale and proposed weighted scores, the socio-economic sub-benefits criteria due to using the treated El-Mahsama WWTP scored 13 points on both the short- and long-term respectively, out of 13 points.

Table (9): Matrix of socio-economic sub-benefits criteria due to using the treated water of El-Mahsama WWTP versus benefits scales (short- & long-term)

Sub-evaluation criteria	Short-term	Long-term
livelihood	high	high
jobs creation	high	high
household income	high	high
commodities availability	high	high
market price	high	high
inter-trade	high	high
accessibility	high	high
safety	high	high

(Note: benefit scales are high, moderate, low and nil)

3.2.5 Risks of effluent disposal and external factors risks due to using the treated water of El-Mahsama WWTP

Based on the DRI records, El-Mahsama Drain receives agricultural drainage water from large agricultural schemes along its path as well as sewage water from several big cities, towns and villages. Therefore, it is not expected that shortage of water might occur at El-Mahsama WWTP in the future. Disposal of remaining harmful effluent sludge waste of the WWTP is critical and inherits risks as it might still include some chemicals and salts. Therefore, its disposal destination was evaluated cautiously in this research paper. Climate change associated with temperature rise and probable drought events are not expected to negatively influence the selected CPSs, which are drought and salt tolerance species. Accordingly, Table (10) articulates the short- and long-term risk scales.

Table (10): Effluent disposal and external risks due to using the treated water of El-Mahsama WWTP

Aspect	Components of risk	Short-term	Long-term
shortage of water in El-Mahsama Drain	crop stress/productivity	nil	nil
	environmental quality	nil	nil
temporary stopping the WWTP	crop stress/productivity	nil	nil
	environmental quality	nil	nil
disposal of remaining harmful sludge waste of the WWTP	marches health	moderate	high
	injection in GW aquifer	moderate	high
	evaporation ponds	low	nil
disposal of agricultural drainage water from the agricultural scheme	marches health	low	low
	wooden trees forest	low	low
	evaporation ponds	nil	nil
Climate change	impact of temperature rise	nil	nil
	impact of drought events	nil	nil

(Note: risk scales are high, moderate, low and nil)

Based on the sub-risk criteria scale and proposed weighted scores, it was estimated that shortage of water in El-Mahsama Drain, temporary stopping the WWTP, disposal of remaining harmful effluent sludge waste of the WWTP, disposal of agricultural drainage water from the agricultural scheme, and climate change sub-risks scored 4.0, 1.0, 1.1, 0.9 and 1.0 on the short term and 4.0, 1.0, 2.0, 0.9, and 1.0 on the long-term, respectively (total scores were 7.9 and 8.9 on the short- and long-term, respectively out of 9.0).

4. Analysis and discussion

4.1 The safe and sustainable management alternative

Consequently, as the CPS (1) including wheat, barley and beans (winter crops) and maize (summer crop), was selected for application in the 1st scheme (70,000 feddans), then the "favorable alternative" that achieved the highest score being a safe and sustainable management alternative for using El-Mahsama WWTP water could be as shown in Table (11). The short- and long-term (S.T. & L.T.) scores were also estimated and presented.

Table (11): The proposed favorable safe and sustainable management alternative for using El-Mahsama WWTP water

Details of the safe and sustainable management alternative	Description	S.T. Score	L.T. Score	Total score
Crop pattern scenario areas: 1st scheme: 70,000 feddans	1st scheme: wheat, barley, beans, and maize	17.8	17.8	22.0
2nd scheme: 52,000 feddans	2nd scheme: cotton, flax, kenaf, oil crops as jojoba, jatropha, canola and sunflower	15.5	15.5	22.0
Human health risks	not expected	36.0	30.1	40.0
Environmental quality risks	not expected	13.8	13.4	16.0
Socio-economic benefits	high	13.0	13.0	13.0

Shortage of water in El-Mahsama Drain risks	not expected	4.0	4.0	4.0
Stopping El-Mahsama WWTP risks	not expected	1.0	1.0	1.0
Disposal of remaining harmful sludge waste of the WWTP risks	in evaporation ponds	1.1	2.0	2.0
Disposal of agricultural drainage water from the agricultural scheme risks	wooden trees forest "mahogany"	0.9	0.9	1.0
Climate change risks	not expected	1.0	1.0	1.0
Total Scores of the selected management alternative		**88.6**	**83.2**	**100**

The high scores of the "sustainable favorable management alternative" for using El-Mahsama WWTP water mainly for agriculture purposes reflected the potential of using the treated wastewater in irrigating industrial crops and non-edible raw agricultural crops. There are no negative impacts on the human health nor on the environment ecosystem, provided that the safeguards are met and such waters are being strictly used according to ECP 501 (2015) and law 4 in 1994 modified by law 9 in 2009 with its bylaws.

4.2 Proposed favorable sustainable management plan

The "favorable sustainable management" was proven with the highest score (88.6% on the short-term and 83.2% on the long-term), as a safe and sustainable management alternative for using El-Mahsama WWTP water (Table 11). That the "favorable alternative sustainable management" includes CPS for the 1st scheme (70,000 feddans) as wheat, barley, beans, and maize, then CPS for the 2nd scheme (about 52,000 feddans) as cotton, flax, kenaf, oil crops as jojoba, jatropha, canola and sunflower. The disposal of agricultural drainage water from the agricultural scheme shall be diverted to irrigate wooden trees forest "mahogany". The socio-economic benefits associated with its application is high. The risk of shortage of water in El-Mahsama Drain (or temporary stopping El-Mahsama WWTP) could be compensated by developing a number of groundwater wells to be readily standby for irrigating the agricultural schemes in such unlikely water shortage situations.

The sludge waste of El-Mahsama WWTP can be used after anaerobic digestive processes to produce compost as animal fodder and could further be processed to produce biofuel, that can effectively reduce the problem of short fall of fuel in El-Mahsama WWTP. On the other hand, the excess of that biofuel can be also a source of energy for the nearby communities' daily life activities. The disposal of remaining effluent harmful sludge waste of the WWTP shall be done in secured and impervious evaporation ponds. The dried accumulated harmful sludge in the evaporation ponds should be removed periodically and cautiously, then carried in closed trucks to remote safe dumping sites in the deserts according to the safeguards procedure stated in the international dumping manuals of hazardous materials (Mercer B. *et al.,* 2004, Environment Agency, 2004 and Nawrocki M., 1976).

The climate change risks shall be minimal due to crop high resilience to climate change, furthermore less carbon emission shall occur. All types of human health risks and environmental quality risks are not expected when the "favorable alternative sustainable management" is applied.

4.3 Future expansion in agricultural use of treated wastewater from El-Mahsama WWTP

According to the operating rules of El-Mahsama WWTP, and since the annual treated wastewater discharged by El-Mahsama WWTP is about 365 million m^3 per year, it is estimated that only 210 million m^3/year shall be allocated to irrigate (Phase I) which is 70,000 feddans (crop water duty per feddan is about 3000 m^3/year) to cultivate wheat, barley, beans and maize, using modern drip and sprinkler irrigation systems. Then, the expected drainage water shall not exceed 10% equivalent to about 21 million m^3/year (FAO, 2002). That drainage water should be safely collected through a subsurface drainage system and diverted with no risks to the human or the environment to irrigate wooden trees forest "mahogany" for high-quality wood production. The remaining treated wastewater from El-Mahsama WWTP (which is about 365-210=155 million m^3/year) should be diverted to irrigate another scheme which shall be industrial crops, possibly "CPS (3) as the second highest score, composed of cotton, flax and kenaf and then CPS (4) as the following highest score, composed of oil crops as jojoba, jatropha, canola and sunflower" using modern drip and sprinkler irrigation systems. The estimated area of that agricultural scheme – phase II- is approximately 52,000 feddans. Again, the drainage water produced should be safely collected through a subsurface drainage system and diverted with no human or environment risks to irrigate other wooden trees forest "mahogany" for future high-quality wood production. Pasture as animal fodder that was included in CPS (2), could be considered by reusing the residuals of crop biomass of CPS (1), CPS (2) and CPS (3) as possible by-product animal fodder.

4.4 Safeguards associated with the sustainable management of wastewater use

The following safeguards and precautions are necessary to be taken when using treated wastewater in agricultural activities:

- Concerning crop handling, it is prohibited to harvest crop yields, which were irrigated with treated wastewater until two weeks after stopping irrigation. It is also prohibited to use treated wastewater (primary or secondary treatment) for cattle and sheep drinking.
- Maintaining the infrastructure of the WWTP and providing it with the advance developments in wastewater treatment technology is essential to eliminate all likely health risks associated with wastewater use.
- Developing a proper periodic monitoring of key water quality parameters at the inlet and outlet of the WWTP to timely detect any change/deterioration in the water quality that might occur.
- Applying due caution during producing, handling and processing of the biofuel and compost from the remaining effluent sludge of the WWTP.
- Dumping harmful remaining sludge waste in suitable landfill/evaporation ponds constructed below soil surface and including walls lined with cement layers or be engraved in the remote desert.
- It is important to identify and prepare an emergency source of irrigation water (groundwater wells) in case of break downs at the wastewater treatment plant or occurrence of operation difficulties, so that crops can survive without stress or damage.
- Designing sufficient awareness program to the individuals and communities (with direct and indirect contacts) to the treated wastewater.
- Banning and monitoring the cultivation of edible-raw agricultural crops using treated wastewater and instead wood trees could be an economic and safe alternative.

5. Conclusion and recommendations

The research paper focuses on valuing human health, crop productivity, soil conservation and the environmental ecosystem quality through selecting the most sustainable management for using treated wastewater in agriculture. The simple multi criteria qualitative evaluation approach as well as the experts' opinion survey implemented were able to identify the "favorable sustainable management" in the study area, that strictly comply with the new Egyptian Code (ECP 501, 2015). It was proven that the use of "favorable alternative sustainable management" does not cause any human health or environmental quality risks.

The safe use of treated wastewater has many economic and environmental advantages, such as improving the quality of drainage water, saving freshwater resources for utilization in more reasonable and appropriate agricultural and domestic purposes in needy localities, protecting the receiving areas against pollution and restoring healthy ecosystem. Yet, several safeguards associated with the sustainable management of wastewater use should be met strictly. In addition, more applied scientific research is needed to assure that safely on the long-term. The construction of more wastewater treatment facilities for agricultural purposes is recommended. This would enable saving significant amounts of freshwater for domestic uses in the growing urban areas, rural communities and cities in arid and semi-arid countries.

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