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Sustainable Management of Treated Wastewater, the New El-Mahsama Wastewater Treatment Plant in Sinai

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Abstract

As part of the national water resources strategy 2030 of Egypt, safe usage of treated wastewater should be expanded in newly reclaimed lands. In 2020, the first mega-waste water treatment plant (El-Mahsama WWTP) was constructed in the east of the Suez Canal in the Sinai Peninsula to treat 1.0 million m^3 per day of El-Mahsama agricultural drain and other small drains, mainly for agricultural purposes in Sinai. However, treated wastewater utilization unwisely may incur several risks to human health, crop yields, livelihood, social and economic conditions, and environmental sustainability. This can be attributed to the possible existence of chemical, biological, or salts in poorly or partially 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 human and environmental health. Using a qualitative evaluation approach, it was proved that the "favorable sustainable management scenario" 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 that favorable management scenario is high. The disposal of agricultural drainage water from the agricultural schemes should be diverted to irrigate forest trees "mahogany". The compost produced should be safely used after appropriate processing and special treatment of the effluent sludge as animals' fodder. Furthermore, the sludge should be used after anaerobic digestive processes to produce biofuel energy for the nearby communities' daily life activities. Wastewater treatment could reduce carbon emissions and accordingly mitigate the climate change risks. Expansion in non-conventional water use could give wastewater a second life with the target to reduce water scarcity, reduce environmental deterioration, increase resilience to climate change and improve people's livelihoods.

Keywords: Treated wastewater reclamation and use, Water management, Human health, Environmental quality, Qualitative evaluation approach, Carbon emission, Sinai development, El-Mahsama wastewater treatment plant

1 Introduction

1.1 Wastewater reclamation and use

Wastewater may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts. The indiscriminate use of wastewater for irrigation as a result of freshwater shortage could impair soil functions and cause environmental pollution [1]. Consequently, the mismanagement of wastewater irrigation would create environmental and health problems for the environment and human beings [2]. Excessive amounts of nutrients and toxic chemical constituents could simultaneously be applied to the soil-plant system. That would cause unfavorable effects on productivity and quality parameters of crops and the soil [3]. Although treated wastewater irrigation reduces the pressure on freshwater usage, it could lead to the accumulation of heavy metals residuals in soils. The indicators commonly used for risks of utilizing such water with marginal quality in agriculture include a concentration of heavy metals residuals in crops and salts concentration, nutrients, phosphorus, metals, and chloride in soils [4],[5]. References [6] to [9] suggested that degradation of soils using alkali water constitutes a major threat to irrigate agriculture especially for the cultivation of sodicity-sensitive crops, where long-term sodic water irrigation increased sodium adsorption ratio (SAR).

The modern WWTPs are equipped with sludge drying, separation, and utilization facilities. The solid sludge produced by the WWTPs is rich in nutrients and good for the production of compost for agricultural purposes. Biofuel could be a by-product of 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 [10]. Such technologies enable the safe utilization of both compost and biofuel.

1.2 Water resources status in Egypt

Water scarcity is a serious and growing concern in Egypt. The River Nile, few coastal seasonal precipitations, small non-renewable groundwater generates all together about 60 billion m^3/year [11]. 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, industrial and tourism sectors. This

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situation results in water shortage (deficit) estimated at 54 billion m^3/year. Multiple reuse of the agricultural drainage water fills about 20 billion m^3 per year of that deficit gap [12]. Importing virtual water (mainly key crops are wheat, meat and oils) closes the remaining deficit of about 34 billion m^3 per year.

1.3 Development projects in Sinai

Egypt embarked in constructing large agricultural development projects in north, middle and south Sinai [13]. The National Water Resources Strategy of Egypt focused more on the effective sustainable development of the Sinai Peninsula [11]. It includes the establishment of several agricultural projects in the desert areas and promotes attractive communities' settlements in Sinai. Agriculture development projects in North Sinai depends on mixing the Nile water with agricultural drainage water providing more than 5 billion m^3/yr, which could be mainly pumped from Bahr El-Baqar wastewater treatment plant into the agricultural schemes in north Sinai [14]. Additionally, in middle Sinai, treated wastewater of El-Mahsama Drain could be pumped into Sinai adding about 365 million m^3/yr to irrigate other agricultural schemes.

1.4 Problem Definition

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 [15]. El-Mahsama Drain is mainly an 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 and the DRI's water quality monitoring network in Nile Delta of Egypt. El-Mahsama Drain used to mix its water into El-Ismailia Canal for irrigation purposes and dispose its remaining water at its outfall into El-Temsah Lake (through Gabal Miriam pump station). After the expanded urbanization in that region and due to the local governments and communities' pressure due to health risks, the government stopped the mixing of El-Mahsama Drain into El-Ismailia Canal [16].

The full discharge of El-Mahsama Drain continued to flow into El-Temsah Lake causing significant environmental damage to the Lake's ecosystem [17]. Based on DRI's Year Book (2015-2016), Table (1) shows the typical annual average concentrations of some water quality parameters at El-Mahsama Drain outfall before the construction of El-Mahsama WWTP [18]. It was noted that Coliform bacteria number at El-Mahsama Drain outfall does not meet the FAO Standards [6] nor the Egyptian Code developed by the Ministry of Housing, Utilities and Urban Communities (MHUUC) of Egypt [19].

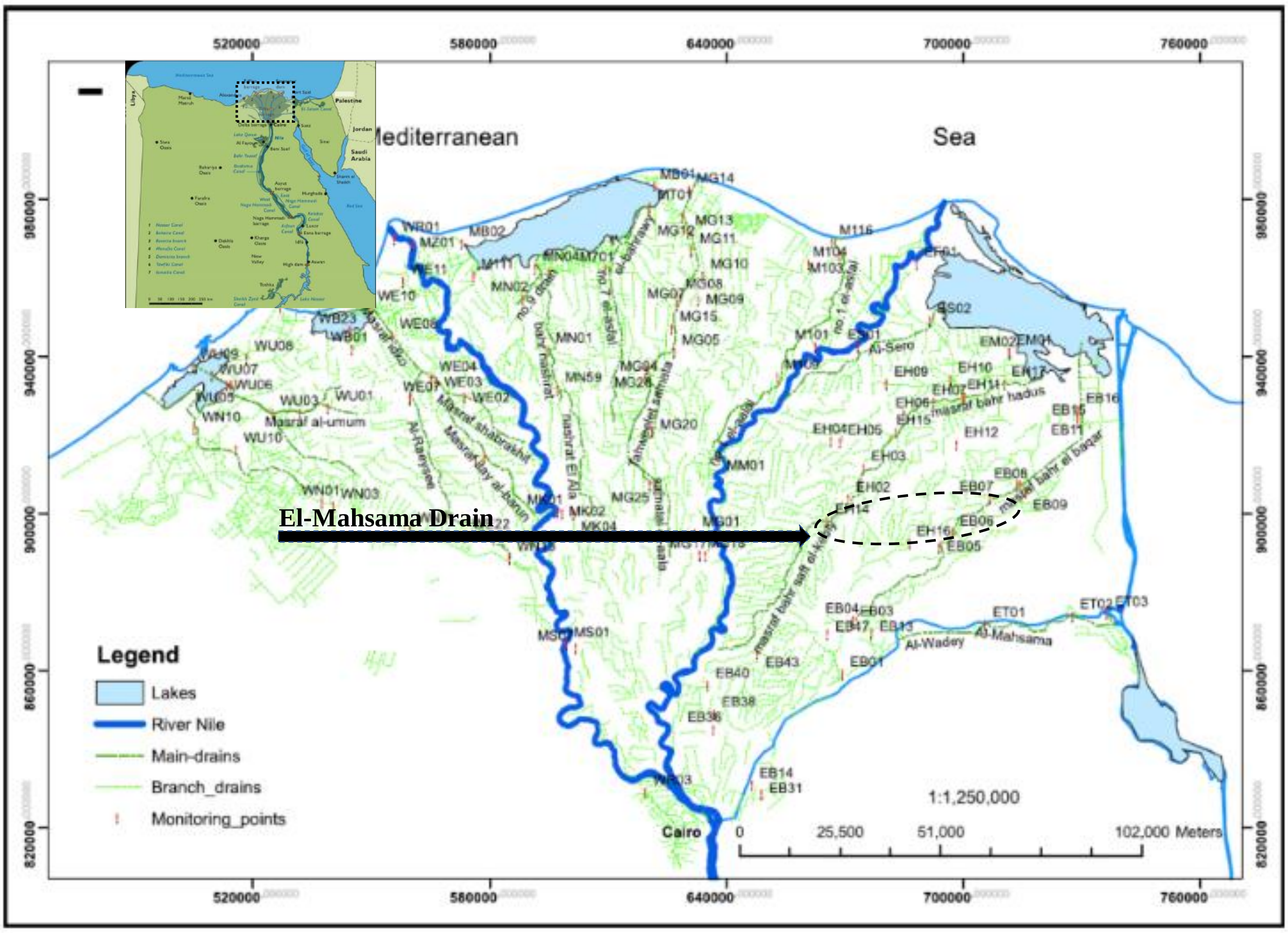

Figure 1: Location of El-Mahsama Drain (south of El-Ismailia Canal) and the water quality monitoring network in the Nile Delta (source: [18])

1.5 National wastewater treatment policy and legislations in Egypt

Eventually, in arid and highly urban-populated countries like Egypt, treated wastewater can serve as an additional water resource to augment the increasing irrigation water requirements, as far as strict safeguards for human health and environmental protection are met. About 7.6 billion m^3 of domestic wastewater is produced every year in Egypt, out of which about 3.8 billion m^3 are treated [20]. The safe use of that treated wastewater is mainly to irrigate forest trees in the fringes of Cairo under the supervision of HCWW, with the target to contribute to empowering the national wood industry in Egypt.

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

WQ Parameter	Measured Value	Unit
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 [21]

Specific laws such as; law 93 in 1962, law 12 in 1984, (law 213 & law 4) in 1994 modified by law 9 in 2009 with its bylaws defined the use and management of marginal water for irrigating crops. Then, MHUUC issued the Egyptian Code for using treated wastewater in agriculture [19]. It permits using the treated water in irrigating traditional crops, some non-edible crops, fiber crops, grass, and oil trees taking into consideration the required health safety measures, following the approach recommended by [22]. The Egyptian 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, it abides by all aforementioned laws. Table (2) presents the maximum thresholds of major water quality concentrations after treatment as stated in [19].

The key factor for achieving safe and sustainable use of treated wastewater is selecting suitable crops to be irrigated with such treated wastewater [23]. For example, oil crops such as canola and sunflower could safely be irrigated with treated wastewater [24]. Furthermore, irrigating jatropha with treated wastewater is favorable because of the socio-economic benefits associated with its high compost and biofuel by-products [25]. Reference [19] 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 vegetable crops such as cucumber or tomatoes. Moreover, [19] specifies the allowable crops for each treated wastewater category.

The outflow of El-Mahsama WWT Plant (secondary treatment processes) is classified as "Grade A", which is good for irrigating all types of crops (except raw vegetables) as well as grass and trees. Nevertheless, the Government of Egypt puts strict operation safeguards of it to follow [19]. The design threshold values of water quality generated by El-Mahsama WWTP [26] are as shown in Table (4).

Table 2: Permissible limits of major water quality parameters after wastewater treatment processes, according to [19]

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: MHUUC, Egyptian code for treated wastewater use in agriculture, [19])

Table 3: Criteria for different grades of wastewater treatment, [19]

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"

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

WQ Parameters	Unit	Max value
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: [25])

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. That water originally included a blend of agricultural drainage water and municipal wastewater, mainly for agriculture purposes. The authors developed and used a simple qualitative management criteria evaluation tool in Microsoft Excel, to determine the “favorable safe and sustainable management scenario” that can be used as a planning guide. The management formulated in this research paper can minimize the risks to human health and environmental quality, reward socio-economic benefits, and reduce carbon emissions to the atmosphere.

2 Materials and methods

2.1 The case study - El-Mahsama wastewater treatment plant

The year 2020 witnessed the completion of the first agricultural drainage water treatment plant in Egypt for safe use in irrigating newly reclaimed lands for agricultural purposes, as one of the promising non-conventional solutions for contributing to overcoming water scarcity challenges in Egypt. El-Mahsama WWTP is a mega secondary treatment facility, located in the Sinai Peninsula east of the Suez Canal (area of 42,000 m^2, cost of 100 million US dollars), as shown in Figure (2), [14].

El-Mahsama WWTP was recognized internationally in years 2019 and 2020 as the best engineering infrastructure project and best world water recycling project, respectively. It aims at treating the entire El-Mahsama Drain water rather than letting it run into Lake El-Temsah causing significant environmental damage to the lake’s ecosystem. That plant is planned to treat a blend of domestic wastewater and agricultural drainage water from El-Mahsama Drain and other small agricultural drains. El-Mahsama WWTP is equipped with sludge anaerobic digestive, drying, and utilization processing facilities. The 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 the 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 the newly reclaimed lands with safe irrigation water for agriculture in Sinai.

The first identified 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 systems) are constructed. In addition, advanced preparation, harvesting, collection, processing, storing, and transport types of machinery and facilities are being availed. According to [19], it is planned that all types of fiber and/or oil crops (for example cotton, flax and kenaf, jojoba, jatropha, canola, and sunflower), non-edible crops, and wood trees could be safely cultivated [27]. The Egyptian environmental laws strictly forbid the disposal of any low-quality waters in Suez Canal, as it is an international navigational route.

2.2 Methodology

In this research paper, a simple qualitative evaluation tool was developed in Microsoft Excel and then used to identify the most “favorable safe and sustainable management scenario”. The evaluation criteria and management components were identified and then verified through an opinion survey. Multiple cropping patterns were proposed, evaluated, and compared. Short- and long-term impacts were evaluated. Impacts on human (direct- and indirect-contact), and cattle and sheep fodder production, and the environmental system quality under various scenarios/alternatives were determined and evaluated according to the international and national standards and codes.

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

The approach used is as follows:

- Identifying the baseline conditions.
- Verifying the compliance of El-Mahsama WWTP with [19].
- Analyzing the possible management components.
- Determining the destinations for safe disposal of the remaining effluents.
- Proposing the best safe and sustainable management scenario that protects the human and environmental health, rewards socio-economic benefits to the inhabitants, and copes-up with the climate change, probable water shortage, or El-Mahsama WWTP emergency stop.

2.3 The management criteria identified

The simple qualitative evaluation analysis included the following management criteria: 1) human health such as diseases, death, and health implications, 2) crops productivity, 3) cattle and sheep's fodder production, 4) environmental quality, such as ecology, flora, fauna, hygiene and carbon emission, 5) socio-economic aspects, 6) disposal of the remaining harmful effluent sludge waste of the WWTP either in the nearby marches, injecting it into the GW aquifer or dumping it in protected evaporation ponds/depressions, 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. Weights for each sub-management scenario were estimated and verified by the opinion survey. Relevant cropping patterns, various sources of water for emergencies, and various disposal sites were also analyzed. Points for the identified criteria and sub-criteria as well as weights were all considered, estimated, and verified in the analysis, on both the short- and long-terms.

2.4 Proposed crop patterns

Cropping patterns proposed for the 1st agricultural scheme of 70,000 feddans planned to be irrigated using the treated wastewater outflow of El-Mahsama WWTP, in full compliance with the safeguards and standards specified in [19]. The proposed management components could be implemented solely or combined. In each case, risks to human health, socio-economic and environmental systems were qualitatively analyzed to determine the best and sustainable uses of that treated wastewater of El-Mahsama WWTP in agriculture. Those proposed cropping patterns (CPs) are as follows:

- CP (1): traditional crops: wheat, barley, and beans (winter crops), and maize (summer crop).
- CP (2): pasture crops
- CP (3): fiber crops such as cotton, flax, and kenaf
- CP (4): oil crops such as jojoba, jatropha, canola, and sunflower
- CP (5): flowers such as rose, gladiolus, and jasmine
- CP (6): wood trees "mahogany", could be postponed to future project extension phases.

Reference [24] informed that soil classifications, climate conditions, and properties of the treated wastewater in the newly reclaimed lands (sandy soil) of Egypt enable the majority of crops to grow. Therefore, the authors considered that each one of those CPs is suitable to be grown in the newly reclaimed lands in middle Sinai.

2.5 Points distribution among the identified management criteria and sub-criteria

The authors conducted an opinion survey among a selected group of specialists and experts with considerable knowledge in relevant fields to this research topic. The participants are specialized in water resources management, soil management, agriculture management, water quality management and guidelines, climate change, wastewater treatment, socio-economics analysis, crops economics, and water economic analysis and assessment. That opinion survey aimed to reach reasonable and logical distribution of points and scores among the identified management criteria and sub-criteria. That survey was designed by the authors and guided by the standards and precautions mentioned in FAO paper 47 on Wastewater treatment and use in agriculture [28],[29]. Each expert was given 100 points to distribute among the proposed criteria and sub-criteria, then to estimate the score of each one in the case of El-Mahsama WWTP. The average estimated scores given by all experts for each management criteria and sub-criteria were used. To reach reasonable and reliable estimates of points and scores, the authors considered the judgment of all experts were equal regardless of their credentials.

2.6 Weights distribution among the identified management criteria and sub-criteria

Weights were estimated by the authors and given to the experts to make verification (direct weights method). High weights should be given to the sub-criteria that achieve impacts (positive meaning benefit or negative meaning risk/loss) with a high probability of occurrence on humans, crops, soil, and the environment. On the contrarily, those sub-criteria that achieve impacts (positive or negative) with a low probability of occurrence were given low weights. Examples of sub-criteria that were assumed to achieve impacts with a high probability of occurrence are (health implications, in-direct contact infection, crop yield/productivity, cattle and sheep's fodder 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-criteria that were assumed to achieve a low probability of occurrence are (death, waterlogging in soil, impact on flora and fauna, social safety, the impact of temporary stopping of WWTP on environmental quality, disposal of remaining harmful sludge waste in evaporation ponds, and impact of drought events). A logical evaluation scale was determined to all management criteria and sub-criteria. The scale ranged from high (close to 100%), moderate (50%), low (25%) and nil (0%). The experts verified the estimated scale and the final weights for each management criteria and sub-criteria. The average values by all experts were used. To reach reasonable and reliable estimates of weights, the authors considered the judgment of all experts were equal regardless of their credentials. The final estimates of management criteria and sub-criteria used in this research paper were done up to the best of the authors' knowledge and based on the results of the opinion survey. That work was followed by a qualitative comparative criteria analysis in Microsoft Excel sheets.

3 Results

Operation of El-Mahsama WWTP is planned for not less than 100 years, therefore both short and long-term impacts were the concern in this analysis. The final estimates of points of the management criteria and sub-criteria are as follows: human health (40 pts), crop productivity (22 pts), environmental quality (16 pts), socio-economic (13 pts), shortage of water in El-Mahsama Drain (4 pts), stopping El-Mahsama WWTP (1 pt), Disposal of remaining harmful effluent sludge waste of WWTP (2 pts), disposal of agricultural drainage water from the agricultural scheme (1 pt) and climate change (1 pt). The final distribution of points among the various management criteria and sub-criteria is shown in Table (5).

3.2 The management components identification and evaluation

Based on the results of the opinion survey and to conduct a proper qualitative analysis to determine the safe and sustainable management of the treated wastewater of El-Mahsama WWTP, the estimated average scores were afterward converted into weighted scores aiming at selecting a suitable safe and sustainable management scenario of El-Mahsama WWTP in agriculture.

3.2.1 Human health

During the operation of El-Mahsama WWTP. it strictly follows [19]. There should be almost nil probability for death, severe diseases, health implications, and in-direct contact infection. However, a rare probability for infection with mild diarrhea or skin irritation and rash for farmers in direct contact with the irrigation and agricultural activities could rarely happen. Table (6) shows human health’s management sub-criteria and scales upon exposure to the treated wastewater of El-Mahsama WWTP, in the short- and long terms.

Using the developed qualitative management criteria evaluation tool in Microsoft Excel and based on the management sub-criteria and scale with verified points and 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

Table (7) shows the comparison of management sub-criteria and scales among those CPs, to select the most convenient one for the application.

Table 5: Distribution of points among the various evaluated Management sub-criteria

Evaluation management criteria	**Management sub-criteria**	**Points**
Human health (40 pts)	direct contact infection	8.00
	in-direct contact infection	10.00
	health implications	16.00
	sever diseases	5.50
	death	0.50
Crop productivity (22 pts)	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 (16 pts)	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 (13 pts)	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 (4 pts)	crop stress/productivity	2.50
	environmental quality	1.50
Temporary stopping El-Mahsama WWTP (1 pt)	crop stress/productivity	0.75
	environmental quality	0.25
Disposal of remaining harmful effluent sludge waste of WWTP (2 pts)	marches health	0.75
	injection in GW aquifer	1.00
	evaporation ponds	0.25
Disposal of agricultural drainage water from the agricultural scheme (1 pt)	marches health	0.50
	wooden trees forest	0.10
	evaporation ponds	0.40
Climate change (1 pt)	impact of temperature rise	0.75
	impact of drought events	0.25
Total points		**100**

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

Management sub-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: scales are high (close to 100%), moderate (50%), low (25%) and nil (0%)

Table 7: Matrix of crop patterns versus management sub-criteria and scales

Management sub- criteria \ CPs	CPS(1)	CP (2)	CP (3)	CP (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: scales are high (close to 100%), moderate (50%), low (25%) and nil (0%)

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

Management sub-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: scales are high (close to 100%), moderate (50%), low (25%) and nil (0%)

Using the developed qualitative management criteria evaluation tool in Microsoft Excel and based on the management sub-criteria and scale with verified points and weighted scores, the proposed crop patterns: CP (1), CP (2), CP (3), and CP (4) scored 17.8, 13.3, 16.5 and 14.5 points out of 22 points respectively. Accordingly, CP (1) composed of (wheat, barley, beans, and maize) was selected for application in the 1st agricultural scheme that should be irrigated from the outflow of El-Mahsama WWTP in Sinai, provided that the quality of the used treated wastewater is within the permissible limits specified in [19].

3.2.3 Environmental quality

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 in 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 or drainage water from the agricultural scheme into the nearby marches, it could be expected that moderate fish mortality in the short-term occurs but not in the long term. No hazard or negative impacts are expected to the flora and fauna, hygiene, or the ecological equilibrium, provided that the operation of El-Mahsama WWTP will strictly follow and respect [19]. Furthermore, it is expected that less carbon emission shall occur [30]. Table (8) illustrates the estimated environmental quality management sub-criteria scales due to using the treated El-Mahsama WWTP.

Using the developed qualitative management criteria evaluation tool in Microsoft Excel and based on the management sub-criteria and scale with verified points and weighted scores, the environmental quality sub-management 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 benefits

Utilizing the treated wastewater of El-Mahsama Drain in agriculture converted the risks into opportunities and benefits to the communities living in the areas. Giving a second life to wastewater makes it a beneficial resource, not a challenging hazard [31]. All evaluation management sub-criteria scored high as benefits on the short- and long-terms, as shown in Table (9). Using the developed qualitative management criteria evaluation tool in Microsoft Excel and based on the management sub-criteria and scale with verified points and weighted scores, the socio-economic benefits sub-criteria from the treated wastewater of El-Mahsama WWTP scored 13 points on both the short-and long-term, out of 13 points.

3.2.5 The remaining management criteria due to operation of El-Mahsama WWTP

Based on DRI's records, El-Mahsama Drain historically has been receiving agricultural drainage water from large agricultural schemes along its path as well as domestic water from several big cities, towns, and villages. Therefore, it was assumed that a shortage of water might not occur at El-Mahsama WWTP in the future. The temporary stopping of the WWTP could be compensated by groundwater to supplement the irrigation of the crops for a short period. Disposal of the remaining harmful effluent sludge waste of the WWTP is critical and inherits risks as it might still include some chemicals and salts [32]. Therefore, its disposal destination was evaluated cautiously in this research paper. Climate change associated with temperature rise and probable drought events is assumed not with negative impacts on the selected CPs (salt tolerance species). Table (10) articulates the short- and long-term management sub-criteria and scales

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

Management sub-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: scales are high (close to 100%), moderate (50%), low (25%) and nil (0%)

Using the developed qualitative management criteria evaluation tool in Microsoft Excel and based on the management sub-criteria and scale with verified points and 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 management sub-criteria 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 scenario/alternative

As the CP (1) including wheat, barley, and beans (winter crops) and maize (summer crop), was recommended for application in the 1st scheme (70,000 feddans), calculation of the summations of scores in Tables (6) to (10) were done. Details of the “favorable safe and sustainable management scenario” that achieved the highest score for using El-Mahsama WWTP water were identified and are shown in Table (11). In addition, the short- and long-term (S.T. & L.T.) scores for each management sub-criteria are presented in Table (11).

The high scores of the “favorable safe and sustainable management scenario” reflected the potential of using the treated wastewater in irrigating traditional crops, fiber crops, and non-edible crops. There are no negative impacts on human health nor the environment ecosystem, provided that all specified safeguards at El-Mahsama WWTP and at the agricultural scheme are met as designated and such waters are being strictly used according to [19].

4.2 Proposed favorable sustainable management plan

Based on the findings of Table (11), the “favorable safe and sustainable management” was proven with the highest score (88.6% on the short-term and 83.2% on the long-term), as the best management scenario for using El-Mahsama WWTP water in agriculture purposes. That management scenario includes CP (1) for the 1st scheme (70,000 feddans) as wheat, barley, beans, and maize, then CP (3) and CP (4) 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 schemes should be diverted to irrigate CP (6) “forest trees mahogany”. The socio-economic benefits associated with its application are high. The risk of shortage of water in El-Mahsama Drain (or temporary stopping El-Mahsama WWTP) is almost unlikely, and if happens could be compensated by developing some groundwater wells to be readily standby for supplementary irrigating the agricultural schemes. The sludge waste of El-Mahsama WWTP could be used after anaerobic digestive processes to produce compost as animals’ fodder and could further be processed to produce biofuel, which could effectively reduce the problem of shortfall of fuel in El-Mahsama WWTP. On the other hand, the excess of that biofuel could be also a source of energy for the nearby communities’ daily life activities. The disposal of remaining effluent harmful sludge waste of El-Mahsama WWTP should be dumped in secured and impervious evaporation ponds or depressions.

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Table 10: The remaining management criteria due to operation of El-Mahsama WWTP

Management criteria	Management sub-criteria	Short-term	Long-term
Shortage of water in El-Mahsama Drain	Crop Stress/Productivity	Nil	Nil
	Environmental Quality	Nil	Nil
A temporary stopping of 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: scales are high (close to 100%), moderate (50%), low (25%) and nil (0%)

The dried accumulated harmful sludge in those evaporation ponds should be removed periodically, then cautiously carried in closed trucks to remote safe dumping sites/depressions in the remote deserts, according to the safeguards and procedure stated in the international dumping manuals of hazardous materials [32],[33],[34]. The climate change impacts could be minimal due to crops species' salt tolerance and high resilience to climate change, furthermore, less carbon emission should occur. All types of human health risks and environmental quality risks are not expected when the "favorable safe and sustainable management scenario" is applied.

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

The planned annual treated wastewater discharge of El-Mahsama WWTP is about 365 million m^3 per year (1.0 million m^3/day). The average crop water duty per feddan is about 3000 m^3/year for cultivating wheat, barley, beans, and maize using modern drip and sprinkler irrigation systems in Saini [24]. Accordingly, it is estimated that only 210 million m^3/year could be sufficiently allocated to irrigate the 1st agricultural scheme, which is 70,000 feddans. Then, the expected drainage water does not exceed 10% of the irrigation water, equivalent to about 21 million m^3/year [35]. 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 CP (6) "forest trees mahogany" aiming at producing high-quality wood for export purposes. The remaining treated wastewater from El-Mahsama WWTP should be diverted to irrigate the 2nd agricultural scheme. CP (3) and CP (4) in the 2nd agricultural scheme shall be fiber and oil crops. This is composed of cotton, flax, kenaf, jojoba, jatropha, canola, and sunflower. That 2nd scheme should be also irrigated using modern drip and sprinkler irrigation systems. The estimated area of the 2nd scheme according to the estimated available irrigation water could be about 52,000 feddans. Similarly, the resulting drainage water from the 2nd scheme should also be diverted to irrigate further CP (6) "forest trees mahogany". Fodder for animals that were included in CP (2), could be considered by processing the residuals of crop biomass of CP (1), CP (3), and CP (4) as nutritious by-product animals fodder.

5 Safeguards associated with the sustainable management of wastewater use

The following safeguards and precautions adopted by the authors according to [22],[28],[29],[32],[33],[34] are needed to be strictly taken when using treated wastewater in agricultural activities:

- Concerning crops 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 advanced developments in wastewater treatment technology is essential to eliminate all likely health risks associated with wastewater use.
- Developing 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 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 or depressions below the soil surface and including walls lined with cement layers or could be as an alternative be safely buried in the remote desert.
- It is important to identify and prepare an emergency source of irrigation water (groundwater wells) in case of breakdowns at the wastewater treatment plant or occurrence of operation difficulties so that crops could survive without stress or damage.
- Designing sufficient awareness programs for the individuals and communities (with direct and indirect contacts) to the treated wastewater.
- Continuous monitoring of the treated wastewater quality to ensure its compliance to [19] and law 4 in 1994 modified by law 9 in 2009 with its bylaws, particularly when used to irrigate edible-raw crops.

6 Conclusion and recommendations

The research paper focuses on valuing human health, crop productivity, soil conservation, and the environmental ecosystem quality through selecting the safest and favorable sustainable management scenario for using treated marginal water in agriculture. The qualitative management criteria evaluation approach as well as the experts' opinion survey implemented were able to identify the "favorable safe and sustainable management" in the study area, that strictly complies with the new Egyptian Code (ECP 501, 2015), [19]. It was proven that the use of that favorable management scenario causes no harm to the human health or environmental system, furthermore rewards to the socio-economics and livelihoods of the local communities.

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

Details of the safe and sustainable management scenario	**Description/effect**	**S.T. Score**	**L.T. Score**	**Total score**
Crop patterns areas: 1st scheme: 70,000 feddans	Wheat, barley, beans, and maize	17.8	17.8	22.0
2nd scheme: 52,000 feddans	Cotton, flax, kenaf, and oil crops (jojoba, Jatropha, canola, and sunflower)	15.5	15.5	22.0
Human health	Not expected	36.0	30.1	40.0
Environmental quality	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	Not expected	4.0	4.0	4.0
Stopping El-Mahsama WWTP	Not expected	1.0	1.0	1.0
Disposal of remaining harmful sludge waste of the WWTP	In evaporation ponds	1.1	2.0	2.0
Disposal of agricultural drainage water from the agricultural scheme	Forest trees "mahogany"	0.9	0.9	1.0
Climate change	Not expected	1.0	1.0	1.0
Total Scores of the selected management scenario		**88.6**	**83.2**	**100**

The safe use of treated wastewater has many socio-economic and environmental advantages, such as improving the quality of drainage water, saving freshwater resources for utilization in more reasonable and appropriate uses such as irrigating crops and securing water for human domestic uses in needy localities, improving livelihoods of people, protecting the receiving areas against pollution and restoring the healthy ecosystem. Yet, several safeguards associated with the sustainable management of wastewater use should be met strictly. The construction and operation of wastewater treatment facilities are emerging in Egypt similar to other countries proceeded and advanced in that track. The safe and sustainable use of treated wastewater for agricultural purposes is promising and recommended, particularly in arid and semi-arid countries. More detailed scientific research and quantitative analysis are needed to accurately determine the safe limits of the treated wastewater uses in the short- and long terms. Further applied research using numerical modeling tools and physical experimental pilots is important for thoughtfully studying the long-term impacts of using treated wastewater for irrigation, before wide-scale replication.

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Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language. Also, all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All procedures performed in this study involving animals were following the ethical standards of the institution or practice at which the studies were conducted.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution to data collection, data analyses, and manuscript writing.

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