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Design Methodology of a New Surface Flow Constructed Wetland System, Case Study: East South EL-Kantara Region North Sinai, Egypt

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ABSTRACT

In this paper, a model was developed based on simple equations to design a surface flow constructed wetland system (SFCWL). The hydraulics of the system and the pollutant removal were based on first-order plug flow assumptions (k-C* model) to remove biological oxygen demand (BOD), fecal coliforms (FC), total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP). In addition, the (SFCWL) hydrology was considered. The model was applied to design a new (SFCWL) of vegetated cells (reed) followed by a storage pond system to treat 6000 m^3/day of the degraded agricultural drainage water in the East South EL-Kantara region, North Sinai, Egypt. The model input data were summer air temperature 27 ºC, winter air temperature 15 ºC and influent concentrations for (BOD) 120 mg/L, (FC) 100000 CFU/100 mL, (TSS) 155 mg/L, (TN) 20 mg/L and (TP) 5 mg/L. The model output showed 3.54 days retention time and the total area of the system, including storage pond was 25.7 hectares. The expected overall pollutant removal efficiencies for (BOD), (FC), (TSS), (TN) and (TP) were 83.3%, 99.5%, 88.6%, 66% and 50% respectively. The proposed (SFCWL) system as a promising low-cost treatment alternative can change polluted agriculture drainage water to an unconventional water source that will be utilized for irrigation and environment-friendly.

Keywords: Wastewater treatment, free surface constructed wetland, agriculture drainage water, reed plant, Egypt

1. INTRODUCTION

Pollution of water sources by discharging of inadequate treating wastewater as a result of increasing populations, economic and industrial development and agricultural activities is a rising problem around the world [1] [2] [3]. Constructed wetlands (CWs) treating system have been spread around the world especially in small to medium societies where it provides high removal pollutant efficiencies, simple and reliable operation and low operation/maintenance cost [4] [5] [6]. (CWs) projects have been implemented in a number of countries to address different types of waste [7] [8] [9]. Various design procedures for (CWs) projects have been presented in literature [10 to 13]. As a general conclusion, the constructed wetland treatment systems prove its ability to remove pollutants in a ratio more than 90% of total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD) and Fecal coliforms (FC) from the wastewater. In addition, the removal of total phosphorus (TP) and total Nitrogen (TN) remains, however closer to 50% in most cases [14 to 17]. In Egypt, the free water surface constructed wetland project in Lake EL-Manzala to treat 25,000 m3/day of the wastewater of Bahr El Baqar drain has been evidenced to environmentally remarkable and economically feasible [18] [19]. Water hyacinth, reed and duckweed are the common plants used in the project to remove wastewater pollutants [20]. The study area (Tina Plain and East South EL-Kantars regions are agro-ecological regions (31500 hectares) lie in the North Sinai Peninsula.

It is a part of the North Sinai Development Project (NSDP) to reclaim and cultivate 52500 hectares. The study area has semi-arid climate conditions. The major cultivated crops are Wheat, Barely, Alfalfa, Green Beans, Tomato, Sugar beet, Cotton and Maize. More than 25000 inhabitants whose daily sewage water are about 2500 m^3 is dumped into the drainage network polluting the agriculture drainage water and soil, since the sewerage system in the area has not been constructed. In this study, a design methodology for a surface flow constructed wetland (SFCWL) to treat the degraded agriculture drainage water in East South EL-Kantara region, North Sinai, Egypt was developed. The system model has the capability to remove (BOD), (TSS), (FC), (TN) and (TP). The Wetland hydrologic study was carried out based on the climatic data for the period from 1985 to 2015 from Ismailia weather station, Egypt (the nearest weather station for the study area) that obtained from the CLIMWAT 2.0 tool attached to the CROPWAT 8.0 software developed by FAO (2019) [21]. Treatment performance was based on the classic first-order kinetic rate constants for polluted wastewater (k-C*model) in computing pollutant removal efficiencies in the in (SFCWL) system developed by USEPA (1999) [3] and Reed et al. 1995 [11]. The model methodology was validated by comparing the computed wetland area with the existing surface flow constructed wetland system database in the U.S [12]. To promote sustainable management of natural resources, the model was applied to design (SFCWL) of vegetated surface wetland cells (reed) followed by a storage pond system to treat 6000 m^3/day of the degraded agricultural drainage wastewater in the study area.

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2. MATERIALS AND METHODS

2.1. Site Description

The study area lies in North Sinai, Egypt. It is a part of the North Sinai Development Project (NSDP), Sector of Water Resources and Infrastructure in the North of Sinai is responsible for the operation and maintaining of the irrigation and drainage networks (Fig. 1) [22].

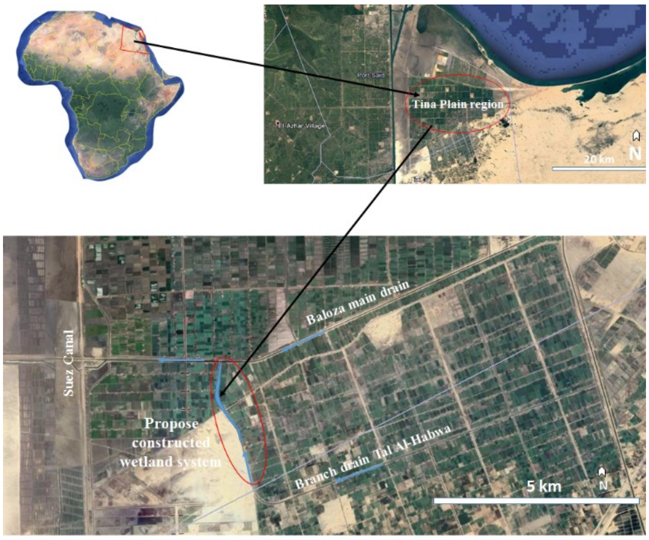

Fig. 1: Location of the study area

EL-Sheikh Gaber Canal is the main freshwater source for (NSDP). Tina plain area is characterized by clay soil ranging from light to heavy clay. As it is originally part of the Nile Delta, which is flat or light inclined, rising at an average of about 5 m above mean sea level [23]. El-Farama main drain is located in the Northern part of Tina plain. It collects the drainage water from branch-drains numbers 1, 3, 5 and 7 with total discharge of 6 m^3/s. El-Farama drainage water is dumping into Suez Canal through El-Farama pump station at Km 21.4 south Port Said (Fig. 2). Baloza main drain is located in the south part of Tina plain. It collects the drainage water from the branch-drains numbers 2, 4, 6, 8 and 10. In addition, Tel Al-Hair and Tal Habwah drains. The length of Baloza main drain is about 17.6 kilometres and Baloza pump station at Km 34 south of Port Said governate which pumping the drainage water (15.6 m^3/s) into Suez Canal. Branch canals numbers 1, 3, 5 and 7 were assigned to El-Farama drainage area, and Branch canals numbers of 2, 4, 6 and 8 are assigned to the Baloza drainage area (Fig. 2) [22]. The climate in this area is characterized by semi-arid conditions hot and dry in summer and cold in winter [23]. Climatic data during 1985 to 2015 in Ismailia weather station (nearest station for East South EL-Kantara Region) were obtained from the CLIMWAT 2.0 model attached to the CROPWAT 8.0 software [21] and the FAO Penman–Monteith equation was utilized to calculation of the reference evapotranspiration (ETo).

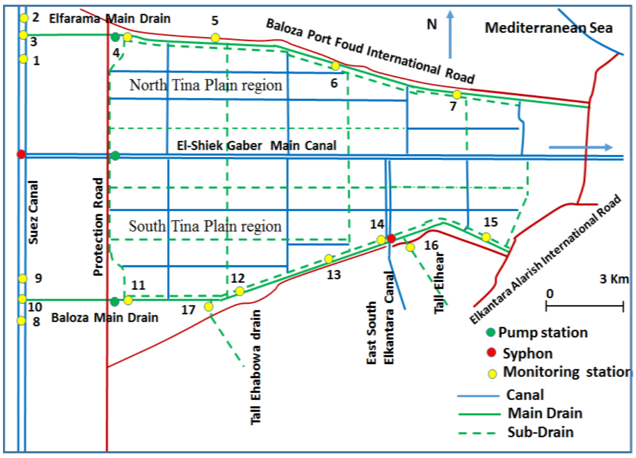

Fig. 2: water quality monitoring stations distributed in the drainage networks in Tina Plain region.

Water quality monitoring stations are distributed in the drainage networks in the Tina Plain region. Table 1 summarizes Ismailia Station monthly normal climate data (minimum temperature in (°C), maximum temperature (°C), wind speed (km/day), relative humidity (%), sun radiation energy (MJ/m²/day), sunshine hours (h), reference evapotranspiration (ETo) (mm/day), rains (mm), and the net precipitation (mm) (precipitation rate subtract evaporation rate). The proposed new constructed wetland site lies at the upstream bank of branch drain Tal Al-Habwa East, South EL-Kantara region (Fig. 3). The selected wetland site is adjacent to an existing road system to reduce the construction cost; moreover, evaluation and maintenance are two major components in constructing wetland operation.

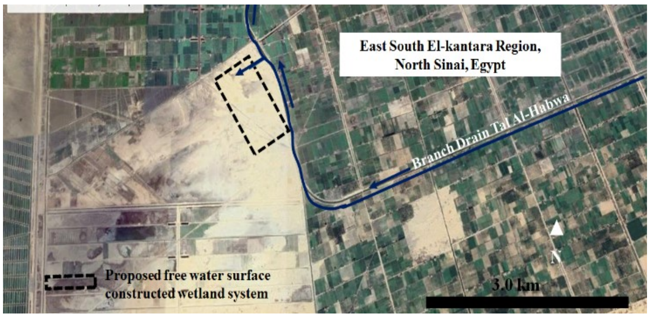

Fig. 3: Proposed surface flow constructed wetland site

2.2 Drainage Water Sampling Data

Drainage water sampling data were collected from 15 monitoring points distributed in the study drains, therefore the monitoring points number 1, 2 and 3 lie in the Suez Canal and the points 4, 5, 6 and 7 lie in El-Farama main drain. Then the points 8, 9 and 10 lie in Suez Canal and points 11, 12, 13, 14 lie in Baloza main drain. Point 15 lies in the outlet of the Tal Habwah branch drain (Fig. 2). Water samples were collected every 3 months (each season) using water sampler according to the principles referenced in [24] between April 2009 to June 2010 [25].

Table. 1 Climatic data rainfall and reference evapotranspiration (ETo) of Ismailia Station [21].

Country: Egypt (location 7) Station: Ismailia
Altitude: 13.0 m Latitude: 30.60 N° Longitude: 32.25 E°

Month	Min. Temp. (°C)	Max. Temp. (°C)	R. Hum. (%)	Wind Speed (km/day)	Sun-shine (hour)	Sun Radiation ($MJ/m^2/day$)	ETo (mm/day)	Rainfall (mm/ month)	Net Rainfall (mm/day)
January	7.6	19.2	53	207	6.2	11.6	2.65	7.0	-2.42
February	8.3	20.9	50	251	6.9	14.4	3.48	6.0	-3.28
March	10.3	23.3	45	285	7.6	17.9	4.65	7.0	-4.42
April	14.1	28.6	38	277	8.5	21.4	6.26	2.0	-6.19
May	16.4	31.8	37	259	9.4	23.9	7.09	2.0	-7.02
June	19.5	34.8	39	277	10.7	26.1	8.03	0.0	-8.03
July	21.3	35.7	40	242	10.4	25.5	7.75	0.0	-7.75
August	21.5	35.3	43	216	10.1	24.0	7.04	0.0	-7.04
September	19.7	33.1	48	199	9.4	21.1	5.82	0.0	-5.82
October	16.6	30.0	53	190	8.4	16.9	4.46	2.0	-4.39
November	12.7	25.4	59	138	7.3	13.1	2.82	6.0	-2.62
December	8.9	20.9	62	173	6.1	10.8	2.31	5.0	-2.14
Average	14.7	28.3	47	226	8.4	18.9	5.20	3.08	-5.09

Min. Temp., Minimum temperature; Max. Temp., Maximum temperature; and R. Hum., Relative Humidity.
-The negatives value means evaporation is higher than precipitation.

Table 2: Statistical measured seasonal water quality parameters for Tall EL-Habowa branch-drain [25].

Water parameter/ Season	**(TDS) (mg/L)**	**(pH)**	**(TSS) (mg/L)**	**(BOD) (mg/L)**	**(NO_3) (mg/L)**	**(Fe) (mg/L)**	**(Zn) (mg/L)**	**(FC) (CFU/100 mL)**
Spring	7200	8.03	342	35	17.00	1.53	1.09	152
Summer	7379	8.05	79	64	80.00	0.55	0.11	100
Autumn	10277	7.6	155	70	6.56	3.24	1.46	755
Winter	8166	7.99	42	80	10.17	1.93	1.86	1065
Average	8256	7.92	155	62	28.46	1.83	1.13	518
Max.	10277	8.05	342	80	80	3.24	1.86	1065
Min.	7200	7.6	42	35	6.56	0.55	0.11	100
Standard deviation	1222.38	0.18	115.66	16.74	30.01	0.97	0.65	407
Egypt Decree (92/2013) [26]	2000	6-9	-	6	-	0.5	0.01	-

(TDS), Total dissolved solids; (TSS), total suspended solids; (BOD), Biological oxygen demand; (NO_3), Nitrate; (Fe), Iron; (Zn), Zinc; and (FC), fecal coliform.

The water samples were sent to the Center Laboratory for Environmental Quality Monitoring, National Water Research Center, Cairo, Egypt. They were analysed for the water quality parameters total dissolved solids (TDS), pH, (TSS), (BOD), Nitrate (NO_3), Iron (Fe), Zinc (Zn) and fecal coliforms (FC). Table 2 summarizes the drainage water quality parameters for Tal Al-Habwa branch drain on Baloza Drain where, pH concentration ranges from 7.6 to 8.05 with an average (7.9 ∓0.18). (BOD) concentration ranges from 35 to 80 mg/L with an average (62.25 ∓16.74) mg/L. (TSS) concentration ranges from 42 to 342 mg/L with an average (154.5 ∓115.66) mg/L. NO_3 concentration ranges from 6.56 to 80 mg/L with average (28.43∓30.01) mg/L. Fe concentration ranges from 0.55 to 3.24 mg/L with an average (1.81∓0.97) mg/L. Zn concentration ranges from 0.11 to 1.86 mg/L with an average (1.16∓0.65) mg/L. (TC) concentration ranges from 100 to 1065 FCU/100mL with an average (518∓407) FCU/100 mL. Additional details of this study about the site investigations and drainage water quality are provided in [25]. In addition, the permissible limits of pollutants according to Egyptian Decree 92/2013 [26] for the protection of the Nile River and its waterways from pollution are summarized in Table 2.

2.3 Wetland Hydrology

The wetland hydrological balance is designed according to Kadlec and Wallace [17] as follows:

$$Q_e = Q_i + (P - ETo - ETc)\ A \tag{1}$$

Where: Q_e is the effluent flow rate (m^3/day), Q_i is the untreated influent (inlet flow rate) (m^3/day), P is the rainfall rate in (m/day), (ETo) is the potential evaporation rate (m/day), (ETc) is the evapotranspiration rate (m/day) and (A) is the water surface area of the wetland (m^2).

2.4 Treatment Performance

In this study, the first-order kinetic rate constants for polluted wastewater was applied to compute pollutant removal efficiencies in the (SFCWL) [3] [11]. The water temperature is assumed nearly equal to the mean ambient temperature according to the principle of Kadlec and Knight [12]. The Nitrogen and (BOD) removal rate is estimated according to [11] as follows:

$$\frac{C_e}{C_i} = e^{-K_T\,RT} \tag{2}$$

where: C_e is the outlet concentration (mg/L) of (BOD) and Nitrogen, C_i is the inlet concentration of (BOD) and Nitrogen in (mg/L), K_T is a reaction rate factor (day^{-1}) dependent on the water temperature T (°C). According to [11] for (BOD), $K_T = 0.678\,(1.06)^{T-20}$, for Nitrogen Nitrification, $K_T = 0.0389\ T$ where $(0 < T < 1$ °C), $K_T = 0.1367\,(1.15)^{T-10}$ where $(1.0 < T < 10$ °C), $K_T = 0.2187\,(1.048)^{T-20}$ where, $(T > 10$ oC), for Nitrogen Denirification $K_T = 0.023\ T$ where $(0 < T < 1$ °C) and $K_T = (1.15)^{T-10}$ where $(T > 1$ °C), and RT is the hydraulic residence time for the system in days. Fecal coliforms (FC) and total Phosphorus (TP) removal by Kadlec and Knight [12] principle is as follows:

$$\frac{C_e}{C_i} = e^{-\frac{K_1}{RL}} \tag{3}$$

Where: C_e is the pollutant outlet concentration (number of fecal coliforms/100 mL) or Phosphorus (mg/L), C_i is the inlet influent concentration (number of fecal coliforms/100 mL) or total phosphorus (mg /l), K_1 is a reaction rate parameter (m/day) [12], for (FC), $K_1 = 0.3$, and for (TP) $K_1 = 0.0273$), and RL is the hydraulic loading rate (m/day). The RL and RT parameters are defined as follows:

$$RL = \frac{Q}{A} \tag{4}$$

$$RT = \frac{V}{Q} = \frac{A\,d\,n}{RL\,A} = \frac{d\,n}{RL} \tag{5}$$

Where, V is the system volume (m^3), Q is the constant design discharge rate (m^3/day), A is the average surface area of the system (m^2), d is the flow depth (m) and n is the soil porosity given by [11]. Reed et al. (1995), based on operational experience of several constructed wetland systems in the United States reported that the organic loading in free water constructed wetland systems should not greater than 10 g/m^2/day as a limit value, which can be expressed as follows:

$$C_i\,\frac{Q}{A} \leq 10 \tag{6}$$

For new system the designed area is not known therefore the estimation of the organic loading needs a trial-and-error technique, to assure oxygen availability for nitrification in (SFCWL) and maximize ammonia removal efficiency [11]. Reed and Brown [27] advice of a minimum design RT of about 6 to 8 days. In addition, the removal of Phosphorus is in a range between 30 to 50% in the long term.

2.5 Wetland Hydraulic Design

The general equation for the hydraulic design of (SFCWL) recommended by Kadlec and Knight [12] is as follows:

$$Q = x\,B\,d^y\,S^z \tag{7}$$

Where Q is the design flow rate (m^3/day), d is the flow depth in (m) usually ranges from 0.1 m to 0.6 m [11], B is the wetland width (m), x, y, and z are coefficients assumed to be of the following values $x = 10^7\ day^{-1}m^{-1}$ for dense vegetation, $x = 5\times 10^7\ day^{-1}m^{-1}$ for sparse vegetation, y = 3.0, and z = 1.0, and S is the water surface slope (dimensionless) estimated as follows:

$$S = \alpha\,d / L \tag{8}$$

where L is the wetland length (m), and α is the fraction of the depth serving as head differential [11]. Economopoulou and Tsihrintzis [13] developed the following equation to estimate the free surface wetland water depth:

$$d = \left(\frac{\frac{L}{B}\,Q}{x\ \alpha}\right)^{0.25} \tag{9}$$

The suggested aspect ratio of the length to the width (L: B) should be greater than 2:1 to ensure plug flow conditions. Commonly used aspect ratios are between 2:1 and 5:1.

2.6 Nitrogen Removal Simplification

Economopoulou and Tsihrintzis [13] suggested the following equation for the total nitrogen removal efficiency:

$$\frac{C_e}{C_i} = e^{-K_{TN}\,RT} + e^{-K_{TD}\,RT} - e^{-K_{TN}\,t}\,e^{-K_{TD}\,RT} \qquad \textbf{(10)}$$

Where: C_i is the total Kjeldahl nitrogen inlet concentration (assumed all converted to ammonia) (mg/L), and C_e is the total nitrogen outlet concentration (mg/L), K_{TN} and K_{TD} are the reaction rate parameters for nitrification and denitrification (day^{-1}). To simplify the computation of the total nitrogen removal ratio in the new constructed wetland sizing problem, the curves of Fig. 4 provides a graphical solution to Equation (11), permitting for direct approximation of RT for total Nitrogen removal as a function of temperature (T) and $\frac{C_e}{C_i}$.

2.7 Estimation of the Organic Loading

The water surface area (A) of the system is not known in advance in case of the design of a new free water surface constructed wetland system, thus if the (BOD) removal is required, the value of KT in Equation (1) should satisfy the following formula:

$$K_T \leq -\frac{10\,ln\left(\frac{C_e}{C_i}\right)}{C_i\,d\,n} \qquad \textbf{(11)}$$

2.8 (TSS) Removal

TSS removal processes depend on the filtration and retention times, the removal equation developed by Reed et al. 1995 [11] in (SFCWL) as follows:

$$C_e = C_i\,\{0.1139 + 0.00213\,(RL)\} \qquad \textbf{(12)}$$

where C_e is the outlet TSS (mg/L); C_i is the inlet (TSS) (mg/L). The wetland treatment performance (CR) is given as follows,

$$CR = \frac{C_i - C_e}{C_i} \qquad \textbf{(13)}$$

2.9 Design Methodology

A flow chart diagram for the methodology used in the sizing a new free water surface constructed wetlands system is shown in Fig. 5.

2.10 Methodology Validation with Existing Data

Model validation was carried out by computing the area of some SFCWL in the U.S based on the available database in terms of temperature (°C), discharge (m^3/day), influent (BOD) (mg/L), effluent (BOD), total influent nitrogen (TN) (mg/L), total effluent (TN), total influent total phosphors (TP) (mg/L) and total effluent. The computed (SFCWL) area was matched with the existing real wetland area.

Table 3 summarizes the collected available data about five (SFCWL) in the USA in terms of temperature, discharge, and the inlet and outlet concentrations of (BOD), (TN), and (TP) [12]. The water temperature was considered equal to the mean air temperature. The following assumptions were made for some design parameters need in the model application and not available in the collected data: soil porosity (n) = 0.65, α = 0.1 were assumed in estimating the system's surface area and use of Equation (9) with x = 10^7 day^{-1}m^{-1} (dense vegetation). Length and width of the free water surface constructed wetland (L: B) ratio was taken equal to 2:1, and 5:1. The matching ratios for the area show an average reduction in the area of 17.3% for aspect ratios L: B = 2:1 and 29.2% for aspect ratios L:B = 5:1.

3. RESULTS AND DISCUSSION

3.1 Drainage Water Quality

The measured water quality parameters values (Table 2) were at the permissible limits of the Egyptian Decree 92/2013 [26] for the protection of the Nile River and its waterways from pollution except for the (TDS), (Fe), and (Zn) concentration. Therefore, the drainage water needs treatment prior to discharge in the Suez Canal. The study area has a shortage in sanitary and potable water services and landowners started to build houses and livestock cattle on the drain, banks, it is expected to have pollution sources that will deteriorate the water drains.

Moreover, solid wastes, food and industrial wastes might be sharing the municipal wastewater sources. These pollution sources might be duplicated with population increasing rates. The growing agricultural activity in the region will also lead products, mills, rice paddies and the mobilization of agricultural products, which in turn use water in their industrial processes and thus produce quantities of water contaminated organic and chemical loads [28, 29].

3.2 Design Steps of (SFCWL) System in Tal El-Habow.

The irrigation served area of Tal EL-Habow drain is about 4200 hectares, the population intensity in its area is about 5000 capita in winter and 6000 capita in summer. Summer population is greater than winter population as some farmers come to the study region for employment [26]. For a unit wastewater flow of 0.15 m^3/capita/day, the winter and summer wastewater discharge are 750 m^3/day, 900 m^3/day respectively. For (BOD) concentration of 50 g /capita/day of the untreated influent (330 mg/L) and after dilution by the agriculture drainage water of Tal EL-Habow drain (average discharge of 20000 m^3/day) reduced to an average of 62 mg/L (Table 2). Therefore, the proposed design flow in this study is 6000 m^3/day that will be diverted from Tal EL-Habow drain into the (SFCWL) system. The proposed (SFCWL) system is followed by a storage pond to the store treated wastewater (Fig. 6).

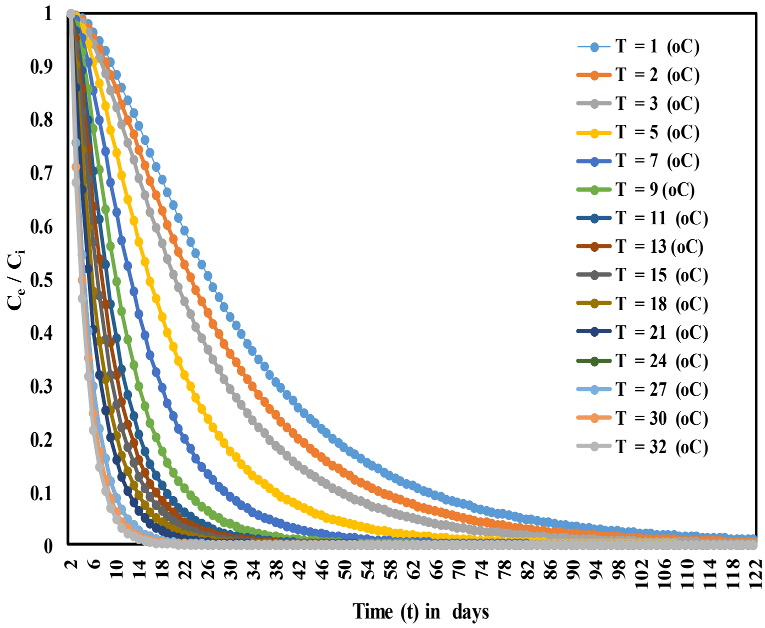

Fig. 4: Nomo-graph for nitrogen removal efficiency for (SFCWL) [11].

Table 3. Existing and predicted area of the SFCWL systems based on Kadlec and Knight (1996) database [12].

System Name	**(Temp.)** **(°C)**	**(Q)** **(m^3/ d)**	**Concentrations**		**Wetland surface area existing (ha)**	**Wetland surface area Predicted (Ap) (Hectare)**		**Matching Ratio (%)**	
			Influent (C_i) (mg/ L)	**Effluent (C_e) (mg/L)**		**(L: B) (2:1)**	**(L: B) (5:1)**	**(L: B) (2:1)**	**(L: B) (5:1)**
W. Jackson County, USA	5.0	6268	(BOD) = 25.93	(BOD) = 7.40	22.7	12.8	10.2	-77.3	- 51
Bear Bay, SC, USA	6.0	877	(BOD) = 13.50 (TN) = 17.58 (TP) = 3.88	(BOD) = 1.90 (TN) = 2.35 (TP) = 0.40	28.3	18.2	14.5	-35.7	- 48.8
Fort Deposit, AL, USA	9.0	674	(BOD) = 32.90	(BOD) = 6.90	6.0	2.4	1.9	- 60.0	- 68.3
Mt View CA, USA	5.0	2821	(BOD) = 33.40	(BOD) = 23.10	4.3	2.1	1.6	- 51.2	- 62.8
Boggy Gut, SC, USA	6.0	5827	(BOD) = 6.30 (TN) = 11.22 (TP) = 4.26	(BOD) = 3.0 (TN) = 3.53 (TP) = 3.35	20.2	48.0	38.2	137.6	89.1

(Temp.), Temperature; (Q), discharge; and (L: B), length to width ratio.

The discharge is divided into 8 surface flow constructed wetland each one has a discharge of 750 m^3/day. The performance criteria consider (BOD), (TSS), (TN), (TP) and (FC), the input data of the model is summarized in Table 4. Design winter and summer air temperature are 15 °C and 27 °C, respectively. Influent (BOD) and (FC) are 120 mg/L and 100000 CFU/100 mL respectively. Influent (TN) and (TP) are 20 mg/Land 5 mg/L respectively, and influent (TSS) = 155 mg/L. In addition, L/B =3, x = 10^7, porosity (n) = 0.65, $\alpha_{\text{winter}} = 0.1$, $\alpha_{\text{summer}} = 0.09$ (α is the fraction of the depth serving as head differential depending on (TSS) and porosity), effluent (BOD) = 16 mg/L, and effluent (FC) = 500 CFU/100 mL. The model output results (Table 5) shows that winter conditions controls (BOD) area removal winter computed from Equations (2, 4) indicates (BOD) area removal of 18736.2 m^2 with a (RT) = 3.54 days, and the value of Coliforms area removal in summer computed from Equations (3, 4) is 13245.8 m^2.

Therefore, width (B) is 79 m, and length (L) is 237 m. Fig. 7 shows the design plan of the proposed (SFCWL) system, it consists of full vegetated zone of length 100 m followed by open water surface zone of length 37 m followed by full vegetated zone (reed plants) of length 100 m. According to the USEPA 1999 [3] considerable open water area between fully vegetated zones increases effluent quality and disinfection of the effluent through the aerobic transformations and removal opportunities.

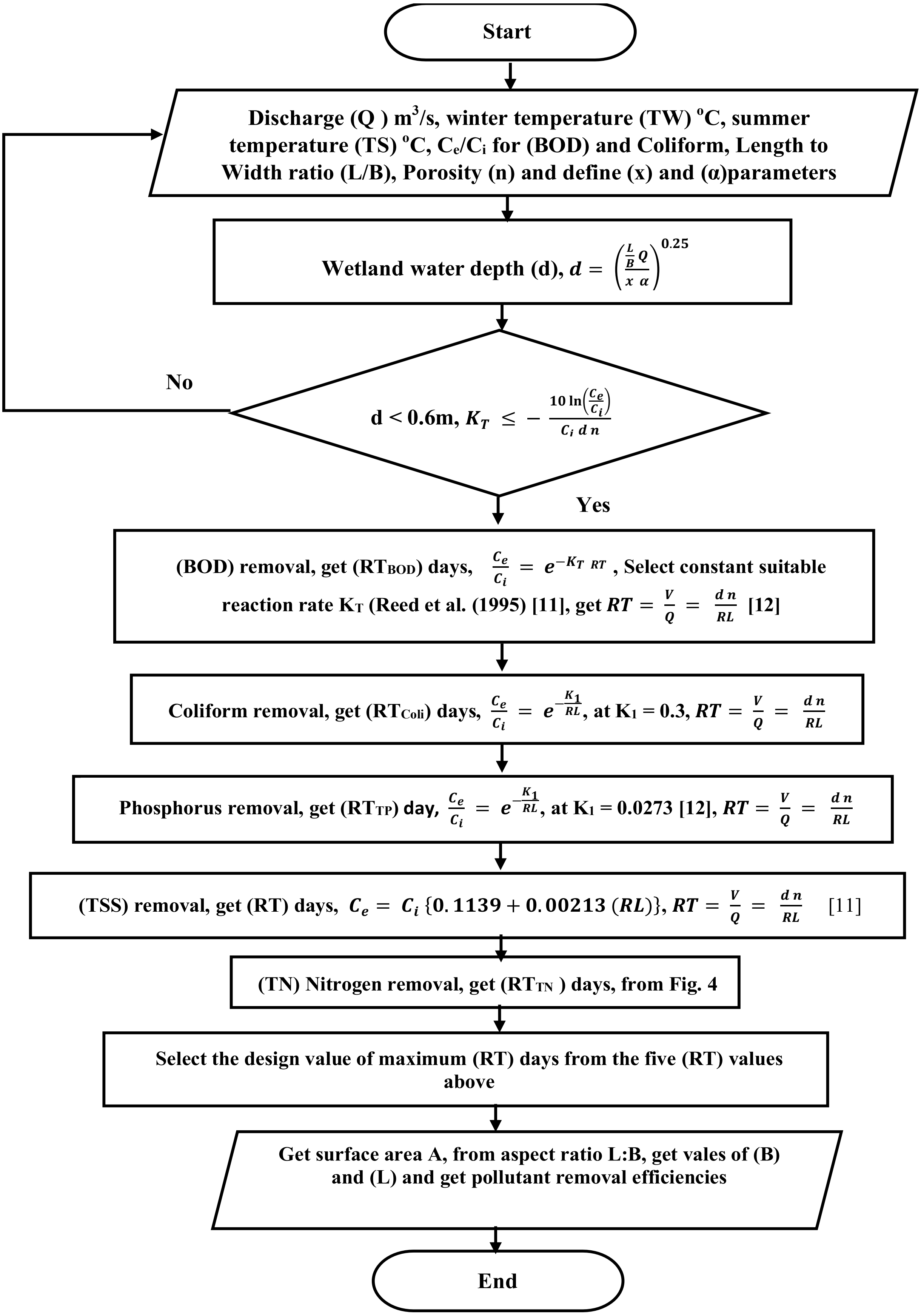

Fig. 5: Flow chart diagram for the methodology adopted

Table 4. Model input data

Summer population = 6000 Capita	Design influent fecal coliforms (FC) = (100000 CFU/100 mL)
Winter population = 5000 Capita	Influent total Nitrogen (TN) = 20 mg/L
Unit wastewater flow = 0.15 m^3/capita/day	Influent total Phosphorus (TP) = 5 mg/L
Wastewater winter discharge = 750 m^3/day	Influent (TSS) = 155 mg/L
Wastewater summer discharge = 900 m^3/day	$x = 10^7$
Design discharge = 750 m^3/day diverted from Tal Al–Habwah branch-drain.	L/B = 3
Design winter air temperature =15 °C	Porosity (n) = 0.65
Design summer air temperature = 27 °C	$\alpha_{\text{winter}} = 0.1$ $\alpha_{\text{summer}} = 0.09$
Primary influent (BOD) = 330 mg/L	Effluent (BOD) = 20 mg/L
Design influent (BOD) = 120 mg/L (after dilution in drainage water of Tal Al–Habwah branch-drain)	Effluent fecal coliforms (FC) = 500/100 mL

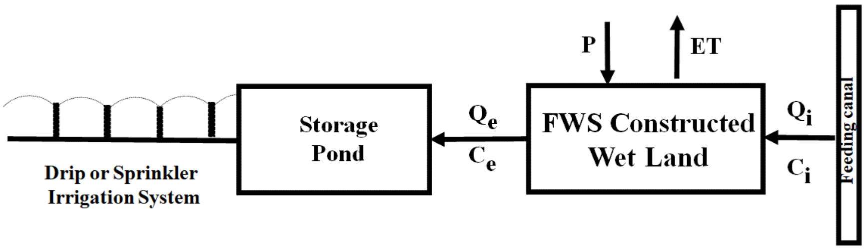

Fig. 6: Diagram of the proposed (SFCWL) treatment system

Table 5. Model output

Winter and summer water depth (d) = 0.22 m	
(BOD) residence time (RT) = 3.54 days	Wetland (BOD) area = 18736.2 m^2
Hydraulic load (RL) = 0.0566 m/day	Wetland Coliforms area = 13245.8 m^2
Winter condition control the design	
(RT) = 3.54 days	
(A) = 18736.2 m^2	
L/B = 3, B = 79 m, L = 237 m	
Effluent (TP) winter = 2.8 mg/L	Effluent (TP) summer = 2.5 mg/L
Effluent (TN) winter = 6.83 mg/L	Effluent (TN) summer = 6.8 mg/L
Effluent (TSS) = 17.7 mg/L	
(BOD) removal efficiency = 83.33%	(FC) removal efficiency = 99.5%
(TP) removal efficiency = 50%	(TN) removal efficiency = 66%
(TSS) removal efficiency = 88.6%	

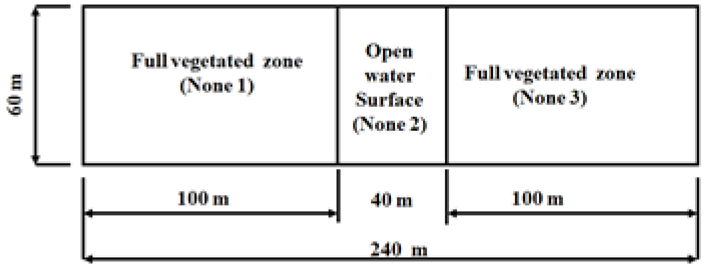

Fig. 7: Design plan of the proposed constructed wetland

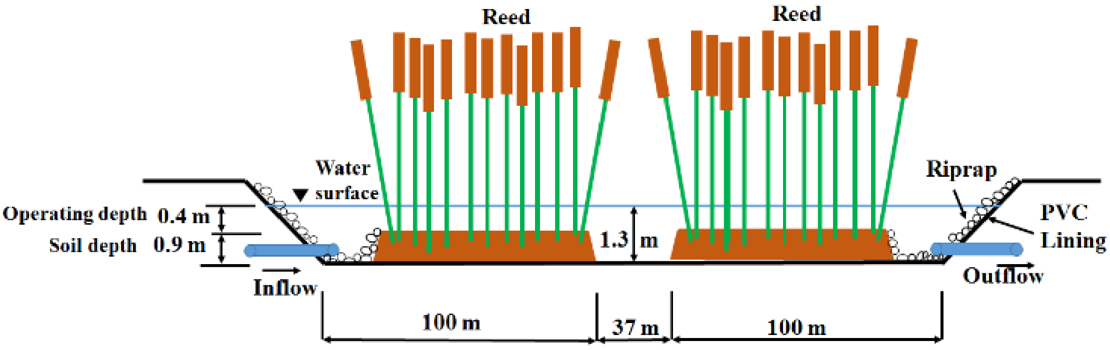

Fig. 8: Cross-section elevation of the proposed constructed wetland.

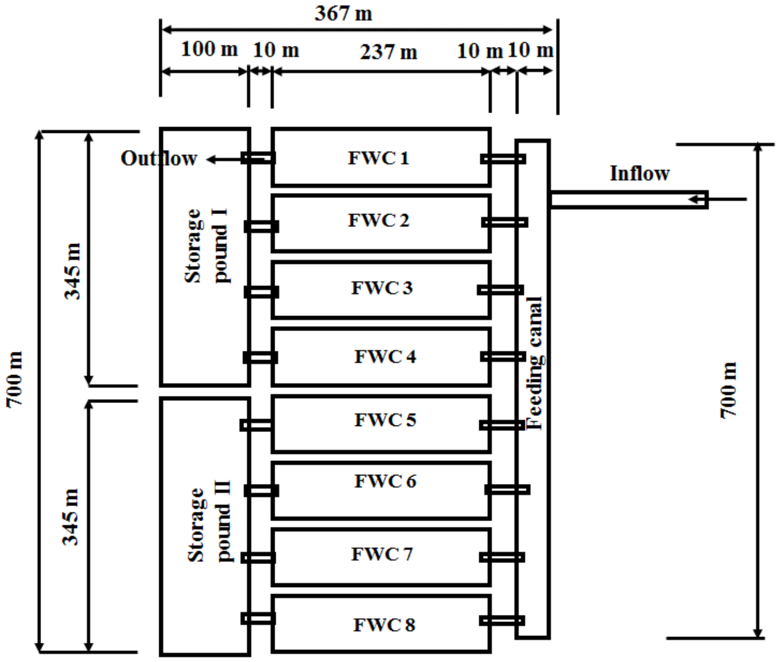

Fig. 9: Proposed (SFCWL) system plan.

Table 6. Estimated water balance for (SFCWL) (18 ha) in Tina plain region, North Sinai Egypt.

Month	Proposed Average Inflow (m^3/day)	Net Precipitation (mm/month)	Water Loss (m^3/day)	Outflow (m^3/day)
January	6000	-72.5	-435	5565.00
February	6000	-98.4	-590.4	5409.60
March	6000	-132.5	-795	5205.00
April	6000	-185.8	-1114.8	4885.20
May	6000	-210.7	-1264.2	4735.80
June	6000	-240.9	-1445.4	4554.60
July	6000	-232.5	-1395	4605.00
August	6000	-211.2	-1267.2	4732.80
September	6000	-174.6	-1047.6	4952.40
October	6000	-131.8	-790.8	5209.20
November	6000	-78.6	-471.6	5528.40
December	6000	-64.3	-385.8	5614.20
Total	72000	-1833.8	-11002.8	60997.20
Average	6000	-152.817	-916.9	5083.1

-The negatives value means evapotranspiration is higher the precipitation

Fig. 8 shows the cross-section elevation of the proposed (SFCWL) system for 0.4 m operating depth and 0.9 m soil depth. Poly Venial Chloride (PVC) sheets to prevent seepage losses line the wetland. For total discharge 6000 m^3/day, the required (SFCWL) area is about 16.6 hectares. The computed overall pollutant removal efficiencies for (BOD) and (FC) are 87% and 99.7% respectively. The (TN) removal efficiency is 66%, and (TP) removal efficiency is 50%. (TSS) removal efficiency is 88.6%. Storage pond is necessary to adjust application rates. Therefore, the tank is designed to store a minimum of 30 days of design flow (6000×30 m^3). It is proposed to have two storage ponds each one of 5.2 m depth, 100 m width, and 345 length (Fig. 9). The proposed total area of the free water surface constructed wetland system and the storage tank is 25.7 hectares (700 m×367 m) including service roads to treat a discharge of 6000 m^3/day (Fig. 9).

3.3 Wetland Hydrology

The climatic data of the study area indicate a semi-arid region therefore the catchment runoff and snowmelt were neglected. In addition, a lining or geo-textiles is consider for the wetland bed and side slopes for no water infiltration. According to Equation (1) (Kadlec and Wallace [17], climatic data in Table 1 and the design discharge of 6000 m^3/day for computed wetland area of 18 hectares, the average net precipitation (net amount of received water from the atmosphere) is an evapotranspiration of 917 m^3/day. Table 6 summarizes Wetland Hydrology computation. In this study, the design discharge is constant therefore, the loss by evaporation can be substituted from the flow diverted from Tal EL-Habow drain (20000 m^3/day) to the proposed (SFCWL).

4. CONCLUSIONS AND FUTURE DIRECTIONS

The wetland treatment system is a promising low-cost wastewater treatment alternative that can protect watercourses and lakes from pollution. A model is developed based on simple equations to design free water surface constructed wetland system, taking into consideration the removal requirement biological oxygen demand (BOD), fecal coliform (FC), total suspended solids (TSS), Total Nitrogen (TN) and total Phosphorus (TP) based on first-order kinetics and the assumptions of plug flow requirements (k-C*model). The model was utilized to assess the feasibility of constructing a (SFCWL) system to reclaim degraded agricultural drainage water in East South EL-Kantara Region (Tal Al–Habwah branch-drain) North Sinai, Egypt.

The results of the agriculture drainage wastewater quality for Tal Al–Habwah branch-drain show an average concentrations of 7.9, 62 mg/L, 150 mg/L, 28 mg/L, 1.8 mg/L, 1.1 mg/L and 500 FCU/100 mL for the (pH), (BOD), (TSS), (NO_3), (Fe), (Zn) and (FC) respectively. Therefore, the drainage water needs treatment prior to discharge into Suez Canal or to be reused in other purposes. The proposed (SFCWL) treatment system comprises of a secondary treatment unit consists of a densely vegetated (reed) surface wetland cells and a storage pond. The constant influent discharge of 6000 m^3/day at summer air temperature of 27 °C, winter air temperature 15°C, (BOD) concentration of 120 mg/L, (FC) 100000 CFU/100 mL, (TSS) 155 mg/l, (TN) and (TP) concentrations of 20 and 5 mg/L, respectively. Effluent (BOD) and (FC) are 20 mg/L and 500 CFU/ 100 mL respectively. The results show total treatment system area of 25.7 hectares including storage tank and service roads (700 m long and 370 m width), expected overall (BOD) 87%, (FC) removal 99.7%, and (TSS) 88.6% after a treatment detention time of 3.54 days. The system has a capacity to irrigate about 140 hectares every day of the popular cultivations.

The contributions of this study can be summarized as follows: first, the proposed wastewater treatment system will assist in East South EL-Kantara Region by treating its daily domestic wastewater through an environmentally friendly manner. Second, the study tackled the pressing water shortage problems and provided a low-cost strategy that can bring multiple benefits to the water resource management. Third, environmental health and public health conditions are expected to be improved after the enhancement of wastewater quality. Forth, this study serves as an exemplary case for other communities that are facing similar water shortage problems or lack of financial resources to construct costly traditional wastewater treatment plants. Community and stakeholder cooperation are the key issue in such system success. Sustainable operation and maintenance by local governorate will reduce treatment expenses.

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منهجية تصميم نظام الأراضي الرطبة السطحية المشيدة، دراسة حالة: منطقة جنوب القنطرة شرق شمال سيناء ، مصر

ان نظام معالجة الأراضي الرطبة يعتبر بديلاً واعداً منخفض التكلفة لمعالجة مياه الصرف الصحي ومياه الصرف الزراعي الملوثة، كما انه يوفر حماية للمجاري المائية والبحيرات من التلوث. في هذا البحث تم تطوير نموذج رياضي يعتمد على معادلات بسيطة لتصميم نظام الأراضي الرطبة المشيدة المكشوفة (سطح ماء حر) (SFCWL) ، مع الأخذ في الاعتبار متطلبات إزالة الأكسجين البيولوجي المستهلك (BOD)، العد البكتريي الكلي (Fecal coliforms) ، إجمالي المواد الصلبة العالقة (TSS) ، والنيتروجين الكلي (TN) و الفسفور الكلي (TP) وعلى افتراضات متطلبات تدفق المكونات وهيدروليكا النظام طبقا لنموذج (Kadlec).

تم التحقق من صحة منهجية النموذج مع البيانات الحالية المتاحة لانظمة الاراضي الرطبة المشيدة بالولايات المتحدة الامريكية. تم استخدام النموذج لتقييم جدوى معالجة مياه الصرف الزراعي الملوثة بمصرف تل الحبوة بشمال سيناء ، مصر. أظهرت نتائج تحليل مياه الصرف الزراعي لمصرف تل الحبوة بشمال سيناء أن متوسط تركيز الأس الهيدروجيني ، (BOD)الأوكسجين البيولوجي المستهلك ، وتركيز المواد الصلبة العالقة (TSS) ، النترات (NO_3)، الحديد (Fe) ،الخارصين (Zn) ، والعد الكوليفورم الكلي (FC) هي 7.9 ، 62 مجم / لتر ، 150 مجم / لتر ، 28 مجم / لتر ، 1.8 مجم / لتر ، 1.1 مجم / لتر ، و 500 FCU لكل 100مل على التوالي. تحتاج مياه الصرف إلى المعالجة قبل تصريفها في قناة السويس أو لإعادة استخدامها في أغراض الري.

تم تطبيق النموذج لتصميم نظام معالجة الأراضي الرطبة المقترح إنشاؤه والمكون من وحدة معالجة ثانوية تتكون من خلايا أرض رطبة كثيفة الغطاء النباتي (الغاب) ، وخزان للمياه المعالجة، لتصرف ثابت مقداره 6000 متر مكعب في اليوم ، عند درجة حرارة الهواء في الصيف 27 درجة مئوية ، ودرجة حرارة الهواء في فصل الشتاء 15 درجة مئوية ، وتركيز الأوكسجين البيولوجي المستهلك 120 مجم / لتر ، وعدد بكتري كلي 100000 لكل 100 مل ، وتركيز المواد الصلبة العالقة 155 مجم / لتر ، وتركيزات النيتروجين والفوسفور الكلية 20 و 5 ملجم / لتر ، على التوالي. أظهرت النتائج أن مساحة نظام المعالجة تبلغ 25.7 هكتار بما في ذلك خزان التخزين وطرق الخدمة (بطول 700 متر وعرض 370 متر) ، وكفاءة إزالة الأوكسجين الحيوي المستهلك المتوقع (BOD) 87٪ ، وكفاءة إزالة العد البكتري الكلي هي 99.7 ٪ ، وكفاءة إزالة المواد الصلبة العالقة الكلية (TSS) 88.6٪ لزمن مكث مقدارة 3.54 يوم.
تم دراسة الاتزان الهيدرولوجي لنظام المعالجة المقترح وكان متوسط معدل البخر هو 917 م3/يوم والذي يمكن تعويضة من مياه الصرف بمصرف تل الحبوة للحفاظ علي تصرف النظام و هو 6000 م3/يوم.
يساعد نظام معالجة مياه الصرف المقترح في منطقة جنوب القنطرة شرق على: أولا: تنظيف مياه الصرف المنزلية اليومية بطريقة صديقة للبيئة. ثانيا: يمثل استراتيجية منخفضة التكلفة يمكن أن تحقق فوائد متعددة لإدارة الموارد المائية. ثالثًا: يحقق تحسن للظروف الصحة البيئية والصحة العامة نتيجة تحسين نوعية المياه العادمة. رابعا: تعتبر هذه الدراسة حالة مثالية للمجتمعات الأخرى التي تواجه مشاكل مماثلة في نقص المياه أو نقص الموارد اللازمة لبناء محطات معالجة مياه الصرف الصحي باهظة التكلفة. خامسا: يمثل التعاون المجتمعي دور هاما في نجاح هذا النظام اثناء التشغيل والصيانة لضمان المستدامة .