Enhancing agriculture drainage water quality to improve water use efficiency in Middle Delta region

Abstract:

The overall annual supply of water from conventional water resources in Egypt is approximately 59.2 BCM. However, 29% of this water is reused to meet the annual demand which is approximately 76.21 BCM, (Barnes J., 2012). Agricultural drainage reuse is one of the main areas where water is reused in Egypt. However, constant increase in pollution loads in drain waters forms a major constraint under the drainage water reuse policy. Therefore, the main objective of this research is to enhance water quality in drains to be reused in irrigation purpose using low cost treatment technologies. The research presents a Water Quality Model, a Decision Support Tool (DST), and proposes remedial solutions to decrease Biological Oxygen Demand (BOD) concentrations and salinity in drain waters. The water quality model and the DST have been applied at 21 drains in Kafr EL Sheikh Governorate.

The water quality model is mainly used to calculate the BOD concentrations along the drain. Different parameters are included during the calculations such as; cross sections of the drains, water velocity, discharge, population of the surrounding villages, distances between villages, effluent of sewage-waste from each village, biodegradability factor (k_t) of BOD, temperature (t), and measured BOD value at the beginning of the drain. The model assumes complete flow mixing at the point of sewage discharge and plug flow mixing elsewhere.

The DST is designed to select the most suitable treatment technology; highest efficiency with least cost to reduce the BOD concentrations, to be utilized at each drain taking into account different site and technology parameters. The site specific parameters include, drain discharge, available space, and water table, while the technology specific parameters include, capital cost, operation and maintenance cost, and the removal efficiency.

The research also checked through water quality field measurements the relation between Dissolved Oxygen (DO) concentration and BOD dilution, and the effect of increasing DO values on BOD bio-degradability.

After running the model and the DST for the 21 drains, it was concluded that the Anaerobic Baffled Reactor (ABR) is proposed to be used in 9 out of 21 drains because of its high reduction of organics, moderate capital and operating costs. Anaerobic Filter (AF) is used in 6 drains, Up-flow Anaerobic

Sludge Blanket (UASB) is used in 5 drains, and the In-stream wetland is used in 1 drain. However, by increasing the removal efficiency of the typical in-stream wet-land to be 70% instead of 50 % through increasing air entrainment, and rerunning the DST, the modified in-stream wet-land is recommended to be used in 9 drains out of 21. This technology is a suitable remedial solution in terms of the required space, construction, and operational / maintenance cost.

It was also concluded that drains with discharges greater than 5 m3/sec are less affected with BOD effluents from villages with population up to 60,000 inhabitants.

1.1BACKGROUND

Egypt is among those countries that face several water challenges, as the annual share per capita of renewable water resources (mainly provided by the Nile) is dramatically reduced from more than 2500 cubic meters at the year 1950 to less than 700 cubic meters at the year 2013, and is expected to fall to about 600 m3/cap/yr by the year 2025 according to the National Water Resources Plan (NWRP, 2005). That happened because the population has been growing in the last 25 years from 38 million in 1977 to 86 million in 2013 and is expected to reach about 120 million capita in 2025 with approximately 2% annual growth rate.

The Ministry of Water Resources and Irrigation (MWRI) is the official authority in charge of development, allocation and distribution of all conventional and non-conventional water resources of the country. Since 2002, MWRI started to formulate the National Water Resources Plan (NWRP) based on a strategy called “Facing the Challenge” (FtC) (NWRP, 2005). Facing the challenge strategy included measures to develop additional resources, make better use of existing resources, and measures in the field of water quality and environmental protection.

The plan has three major pillars; (i) Increasing water use efficiency; (ii) Water quality protection and; and (iii) Pollution control and water supply augmentation.

Conventional water resources in Egypt are limited to the Nile River; groundwater in the deserts and Sinai, and precipitation (Rainfall) along the Northern coast, and non-conventional water resources include renewable groundwater aquifers in the Nile valley and Delta, agricultural drainage water, and treated wastewater.

Zhu et al. (1998) concluded that non-conventional water resources especially agricultural drainage water is considered relatively a cheap source since it does not require much infrastructure – just pumps to lift the drainage water from drains back to the irrigation network – for example, desalinating seawater costs almost one US dollar per cubic meter, whereas one cubic meter of recycled drainage water costs few cents. A main concern when considering drainage water reuse is whether the drainage water quality is within the allowable limits for irrigation uses as outlined by the water quality standards and laws. Thus more attention needs to be directed to improve drainage water quality (Biswas, A.1988) and (El Sayed, A. 1997).

Dispose sewage waste directly to the drains without treatment leads to deterioration of drainage water quality, and pollution of water courses by wastewater which causing health and environmental risks and effect on the reuse of drainage water plans (Peter, K. et al., 2005).

Because of this, the research focus on finding a suitable method to improve drainage water quality and reuse this water in irrigation purpose through development of a model that can calculate the Biological Oxygen Demand (BOD) concentration, along agricultural drains, and propose the appropriate remedial solutions or technologies that can be managed by the local people, cost effective, and environmentally sound.

Decentralized treatment technologies have been developed particularly over the last two decades, and it may be capable to reduce the treatment cost and the complexity of operation without sacrificing the degree of pollution control.

1.2 PROBLEM STATEMENT

There is a severe shortage in irrigation water supply in the Northern Delta governorates especially in the tail end of irrigation canals, and it is proposed to substitute shortage in fresh water supply by the available agriculture drainage water.

Poor drainage water quality is increasingly becoming a constraint for the drainage water reuse policy causing deterioration of soil and crop yield. In addition farmers are subjected to health hazards and effect on the future expansion plans for cultivated areas.

Domestic wastewater is discharged directly to drainage canals without any treatment and nowadays many of open drains are carrying a mixture of agricultural drainage water, domestic, industrial wastewater, and solid waste debris. Increasing pollution loads in some drains reduce the capabilities to reuse their water in irrigation. A fact sheet prepared by Drainage Research Institute (DRI, 2005) showed that increasing the pollution of agriculture drains forced MWRI to close some re-use pump stations to avoid contamination of irrigation canal where reuse is practiced.

1.3 OBJECTIVES

The overall objective of the research is to propose an appropriate methodology to help in improving drainage water quality and increasing water use efficiency in Middle Delta region. This objective will be achieved through calculation of the Biological Oxygen Demand (BOD) concentration along the drains and proposing the most suitable decentralized sewage-waste treatment technologies to reduce the BOD concentrations coming from surrounding villages to enhance drainage water quality in the study area.

1.4 RESEARCH METHODOLOGY

The research methodology is applied through two main parts to improve drainage water quality.

The first part is to develop a water quality model to calculate water quality parameters along the drain - the research will focus on the Biological Oxygen Demand (BOD) - where most of agriculture drains nowadays carry untreated sewage–waste.

Develop a decision support tool that can help in selecting the most suitable decentralized sewage-waste treatment technologies that can reduce BOD concentration values coming from surrounding villages to enhance drainage water quality.

Through water quality measurements, salinity values have been checked in the study area and remedial solutions have been proposed to overcome salinity problems.

The above methodology is applied through:

Reviewing the literature in the field of drainage water reuse, degradation of Biological Oxygen Demand, decentralized wastewater treatment technologies, and salinity problems.

Desk and field survey to collect the essential data. The survey reviewed all documents and maps related to the study area to present a clear vision about the drains and canals in the area and the suitable location for water quality samples and the proposed mixing stations.

Field visits to the study area to collect water samples and apply required analysis related to BOD and EC concentration values in the selected drains.

Calculate the BOD concentration along the drains and compare the BOD calculated with BOD measured on a monthly basis.

Develop decision-making support tool to assist the decision maker in selecting from among several alternatives the best suitable wastewater treatment technology that can be effectively used in rural areas of Egypt taking into consideration the acceptability of its effluent for reuse in agriculture purpose.

Decision support tool developed in the research is based on certain criteria such as; the drain discharge, the population of the surrounding villages along the drain, the available space, the required removal efficiency, the capital cost and operation and maintenance cost, and the ground water table. The selection of the suitable technology having the maximum score. Different scenarios of selecting the suitable treatment technology and the appropriate location have been examined to reduce BOD concentration values to the allowable range.

2. DRAINAGE WATER REUSE PRACTICES IN EGYPT

There are three levels of drainage water reuse practiced in Egypt. The first is called "official drainage reuse" this level of reuse is implemented through the government programs. The second level is called" unofficial drainage reuse level" which is practiced by farmers and water users according to the water deficit. The third level of reuse is called "intermediate drainage reuse level". This type of reuse is implemented by the local irrigation directorates in their respective province jurisdiction. These levels of reuse differ from one region to another in terms of reuse pattern, quantity, and quality. The drainage water reuse plan will be formulated based on the policy frame of the NWRP. The Following table (2.1) shows the planned drainage water reuse in Delta regions.

Table 2.1: Existing and Planned Drainage Water Reuse in Delta (NWRP, 2005)

Pump Stations	1997 MCM/ yr	2007 MCM/ yr	2017 MCM/ yr
Eastern Delta	1,774	2,699	3,639
Middle Delta	808	2,659	3,159
Western Delta	637	1,070	1,670
Total	3,219	6,428	8,468

2.1 OFFICIAL REUSE.

In the year 1930, a pump station has been completed on a main drain (Bahr EL Bakar) in the eastern delta. The station was designed to pump water along the drain to its outlet point in the Manzala Lake. However MWRI officials found that the water being lifted at the pumping station was of a reasonable quality, they decided to channel it back into one of the branches of the Nile instead of disposing of it in the lake (El-Quosy, 1989).

In the 1970s, with increasing pressure on the nation's water resources from agricultural expansion and intensification, the Ministry of Water Resources and Irrigation developed a new policy for drainage water reuse. Ministry officials saw that drainage water offered a good short-term solution for enhancing the country's water supply. The ministry started an ambitious program to construct large reuse pumping stations on the main drains in the Delta region and Fayoum. By 1984, it was pumping 2.9 BCM of drainage water back into the main canals and the Nile's branches for reuse. Since then, the ministry has further expanded its network of pumping stations and by 2011 official reuse had reached 7.5 BCM (Ismail, A. 2011) and is considered a part of the national water budget. Many thousand feddan in the Delta and Fayoum depend on drainage water for irrigation (NAWQAM, 1999). Although this is a government program, farmers also play a role, in many cases actively campaigning for the ministry to establish reuse pumping stations in their areas because of the severe shortage of irrigation water.

2.2 UNOFFICIAL DRAINAGE REUSE

The unofficial drainage water reuse can be defined as farmer's direct reuse from drains without permission from MWRI. It exists where there is a shortage in irrigation water in the tail end of canals. This drainage reuse practice was recorded in the last decade as the water demand increased versus the constant supply. There are two types of unofficial reuse observed in the Egyptian irrigation system.

The first one is using a pump to lift the drainage water directly from the drain to the field. The second is reusing drainage water through blocking the sub-surface drainage system to hold the water in the field so as not to escape out. This practice happens in rice fields when water demand could not be met through canal water. But the two types of unofficial reuse have negative impacts on the irrigation system although they solve the problem of deficit irrigation on field level.

The negative impacts of unofficial reuse can be listed as follows:

Irrigation with low water quality causes deterioration of soil and crop yield.

Farmers are subjected to health hazards as the drainage water may contain sewage and industrial waste effluent.

Blocking the subsurface drains and collectors in rice fields, causes rise of water table in the neighboring fields cultivating non-rice crops such as maize.

There is no accurate survey available on the unofficial drainage reuse in Egypt. The reason is that it changes from one location to another and from time to time depending on water shortage in the canal and the need for water to meet the crop demand. A figure of about 2.8 BCM/y was accepted (Abdel-Azim, el. 1999).

2.3 INTERMEDIATE DRAINAGE REUSE

The third level of reuse can be defined as intermediate drainage reuse. In this level it is proposed to mix the drainage water with the fresh irrigation water of branch canals located in irrigation directorates. It is totally controlled by the irrigation directorate within its jurisdiction. The intermediate reuse system is constructed by irrigation directorates in order to solve the water shortage problem in branch canals. This reuse system is mainly to replace the unofficial reuse practices to minimize the negative environmental impacts (Abdel-Azim, el. 1999).

3. MASS TRANSPORT AND DECAY PROCESS

It was reported in the study conducted by (Onyejekwe 1996) "Simplified Numerical Treatment of a Transient Water Quality Model" that BOD-DO dynamics are considered as a mass transport problem, and it is necessary to combine the transport process with re-aeration / decay processes in a model. Through considering the following physical processes: i) axial convective transport of mass ii) axial dispersion of mass (iii) interaction between BOD and DO, and (iv) re-aeration and decay

In this study the approach described by Bear [1972] has been adopted to write a set of one-dimensional convective dispersive equations for the BOD-DO dynamics with the inclusion of chemical reaction rates

$$\frac{\partial B}{\partial t}+\frac{\partial (uB)}{\partial x}=\frac{\partial}{\partial x}(E_B\frac{\partial B}{\partial x})-K_B B+L_B+\sum_{j=1}^{M}\frac{Q_j B_j^*}{A_j}\delta\,(X-Xj) \qquad (1)$$

$$\frac{\partial DO}{\partial t}+\frac{\partial (uDO)}{\partial x}=\frac{\partial}{\partial x}(E_D\frac{\partial DO}{\partial x})-K_B B+R_D+K_R\,(DO^{SAT}-DO)+\sum_{j=1}^{M}\frac{Q_j DO_j^*}{A_j}\delta\,(X-Xj) \qquad (2)$$

Where, (B) is the Biological Oxygen Demand BOD concentration, (DO) is the Dissolved Oxygen concentration, (DOSAT) is Saturation DO concentration, (EB) is the BOD dispersion coefficient, (ED) DO dispersion coefficient, (KB) BOD Decay rate, (LB) BOD distributed source, (KR) Re-aeration rate, (RD) DO distributed source U: stream velocity $(X$) axial distance, (Q_j) Volumetric flow rate at j,(DO_j^*, B_j^*) concentration of inflow loads BOD/DO at j, $(Xj$)Position of loading, $(A_j$)Cross-sectional area of the stream at the load point,(M) Number of concentrated loads, t: time.

The above equations have been simplified as shown in the following semi empirical equations that describe the decay of BOD.

$$C_i=-C_o e^{-k_t*t} \qquad (2.1)$$

Where, C_o is the original concentration at any point, (t) is (the travel time exerted by water at any cross-section), C_I the concentration at any section in a time (t).

(k_t) is a measure of the biodegradability at temperature (T) of BOD and varies with the type of organic substance and temperature it can be calculated as:

$$k_t = k_0 \theta^{T-20} \qquad (2.2)$$

where, (k_0) is the decay coefficient, (θ) coefficient is equal 1.135 for temperature (T) between 4 C° and 20 C°, and θ is equal 1.056 for (T) between 20 $^{\circ}C$ and 30 $^{\circ}C$.

3.1 MIXING TYPES

Models in environmental engineering are based on reactor theory, with three reactor analogs commonly employed: the completely mixed flow reactor (CMFR), the batch reactor and the plug flow reactor (PFR).

3.1.1 THE COMPLETELY MIXED FLOW (CMF)

The completely mixed flow is a control volume for which spatially uniform properties may be assumed. The reactor may represent a small pond, closed lake, or an urban air shed (Leeder, & Arlucea, 2009)

The mass balance provides a means for constructing a budget for a material (mass).

$Mt+\Delta t = Mt + Min,t \rightarrow t+\Delta t - Mout,t \rightarrow t + Mreacted\ t \rightarrow t+\Delta t$

The analysis is performed over the time period Δt. Moving the initial mass to the other side and dividing by Δt yields:

$$\frac{Mt+\Delta t - Mt}{\Delta t} = \frac{Min,t \rightarrow t+\Delta t}{\Delta t} - \frac{Mout,t \rightarrow t}{\Delta t} + \frac{Mreacted\ t \rightarrow t+\Delta t}{\Delta t}$$

The left hand side of the equation is the rate of change in chemical mass, i.e.

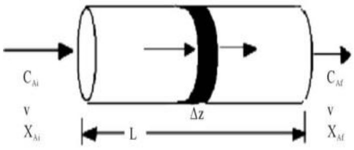
$$\frac{Mt+\Delta t - Mt}{\Delta t} = \frac{\Delta M}{\Delta t} \text{ and as } \Delta t_{\rightarrow 0}, \frac{\Delta M}{\Delta t} = \frac{dm}{dt}$$

The terms on the right hand side are each a mass flux (m• units of mass per time), i.e. the rate at which mass enters, exits or reacts within the system. This can then be written:

$$\frac{dm}{dt} = m\bullet_{in} - m\bullet_{out} + m\bullet_{rec}$$

This is the governing equation for mass balances throughout environmental engineering. It remains to identify an approach for quantifying the terms in this equation.

Terms in the Mass Balance



There are four terms in the mass balance:

$m = V.\ C$

It can be assumed that the volume of the reactor is constant. Thus:

$$\frac{dm}{dt} = V.\ \frac{dC}{dt}$$

At steady state $\frac{dC}{dt}$ = zero

Unsteady state $\frac{dC}{dt} \neq$ zero

$$C_{out} = \frac{Cin\ Qin + CrQr}{Qout}$$

The assumption of constant volume requires that inflow equals outflow.

$m\bullet_{in} = Q_{in}\ C_{in}$

$m\bullet_{out} = Q_{out}\ C_{out}$

$m\bullet_{rec} = V\ (\frac{dC}{dt})_r = (-KC^n)$

At zero order decay n = 0, $m\bullet_{rec} = -\ KV$

First order decay n = 1, $m\bullet_{rec} = -\ KVC$

It can safely be assumed that it is a steady state the concentration resulting from rapid mixing of the stream and the effluent flows, therefore it can be considered the control volume to be small.

3.1.2 THE PLUG FLOW MIXING

The plug flow reactor (PFR) is used to model the chemical transformation of compounds as they are transported in a system resembling a “pipe”. The pipe may represent a river. A schematic diagram of a PFR is shown in figure (2.1).

The plug is assumed to be well mixed in the radial direction. As the plug flows downstream, chemical decay occurs, and concentration decreases. The mass balance for mass within the moving plug is the same.

$$\frac{dm}{dt} = m_{in} - m_{out} + m_{rec} \qquad (2\text{-}3)$$

$$V\frac{dC}{dt} = 0 - 0 + \left(V\frac{dC}{dt}\right)_{reaction} \qquad (2\text{-}4)$$

Where min and mout are set equal to zero because there is no mass exchange across the plug boundaries.

Equation (2-4) can be used to determine concentration as a function of flow time within the PFR for any reaction kinetics. In the case of the first-order decay,

$$\left(V\frac{dC}{dt}\right)_{reaction} = - VkC \qquad (2\text{-}5)$$

Which result in

$$\frac{C1}{C0} = \exp(-kt) \qquad (2\text{-}6)$$

This equation generally describes the concentration at the outlet of the PFR in terms of the inlet concentration and time spent in the PFR (Leeder, & Arlucea, 2009).

4. THE IMPACT OF SEWAGE EFFLUENTS ON SOIL AND PLANTS

In developing countries, with the low income there is no emphasis on the installation of sewage treatment plants and the sewage waste is directly discharged into the water ways which is used for irrigation and cultivation of vegetables and fodder crops which are directly or indirectly consumed by human. A recent study conducted by (Antil R. 2008) showed that soil contamination by sewage and industrial effluents has adverse effect on both soil health and crop productivity. Sewage and industrial effluents are rich sources of both beneficial as well as harmful elements. The untreated sewage and industrial waste effluents may have high concentration of several heavy metals such Cd, Ni, Pb and Cr (Arora et al., 1985; Narwal et al., 1993).

(Gupta et al. 1988) reported that the long-term application of using sewage waste which contains high organic matter resulted in soil sickness due to poor aeration and accumulation of salts.

Experiments conducted at National Environmental Engineering Research Institute, Nagpur (Antil, R. 2005) revealed that the continuous use of untreated sewage for irrigation significantly reduced the yield of wheat, cotton and paddy.

Several investigators have reported positive effects of using sewage water irrigation on crop yield. (Mahida, 1981) conducted a study and reported higher yields of vegetable crops irrigated with untreated sewage water compared to irrigation with canal water

5. CONSTRUCTED WETLANDS

Many researchers investigated the potential of constructed wetlands to improve the drainage water quality.

The Ramsar Convention Bureau, (Iran, 1971; Article 1.1), defined wetland as "areas of marsh, fen, peat land, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty."

Wetlands have been termed as "Kidneys of the planet" because of the natural filtration processes that occur as water passes through (Wallance, 1998).

According to (William, 1997) wetlands can provide water quality improvement and cycling of nutrients.

Constructed wetland is defined as an engineered area designed for treating wastewater or through optimal physical, chemical and biological conditions (Hammer, 1989; USEPA, 1993) (Luise et al. 1999).

5.1 FREE-WATER SURFACE CONSTRUCTED WETLAND

Free-Water Surface Constructed Wetland is defined as an area submerged by water, and water slowly flows through the wetlands. The slowly moving water ensures settlement of solids, removal of pathogens and nutrients that are consumed by plants.

In Free-Water Surface Constructed Wetland water flows above ground, exposed to the oxygen and sunlight. The wetland area is lined with an impermeable barrier (clay or geotextile) covered with rocks, gravel and soil and planted with native vegetation (e.g. cattails, reeds and/or rushes).

Surface flow wetlands are considered an economical technology for treating large volumes of wastewater (Sinclair, 2000). The wetland is flooded with wastewater to a depth of 10 to 45cm above ground level. Sewage waste should be pretreated through sedimentation zone, to prevent the accumulation of solids and garbage.

Plants, and the microorganisms support (on plants stems and roots), take up nutrients like nitrogen and phosphorus. The roots, stems, leaves, and litter of wetland plants work as small surface area where wastes can be trapped and waste-consuming bacteria can attach themselves to the plant. By natural decay pathogens are removed from the water. Although the soil layer below the water is anaerobic, the plant roots release oxygen into the surrounding area near root hairs, thus creating an environment for complex biological and chemical activity.

According to (Tilley, E. et al, 2014) Free-Water Surface Constructed Wetlands achieve high removals of suspended solids and moderate removal of pathogens, nutrients and other pollutants such as heavy metals. This technology is only appropriate for low strength wastewater, by using primary treatment to lower the BOD.

Wetlands are appropriate for pre-urban and rural communities. This is a good treatment technology for communities that have a primary treatment facility (e.g. Septic Tanks), and where land is cheap and available. This technology is best suited to warm climates.

Advantages:

- Aesthetically pleasing and provides animal habitat
- High reduction in BOD and solids; moderate pathogen removal
- Can be built and repaired with locally available materials
- Construction can provide short-term employment to local laborers
- No electrical energy required
- No real problems with flies or odors if used correctly

Disadvantages:

- May facilitate mosquito breeding
- Long start up time to work at full capacity
- Requires large land area
- Requires expert design and supervision
- Moderate capital cost depending on land, liner, etc.; low operating costs.

5.2 SUBSURFACE FLOW CONSTRUCTED WETLAND

According to (Kyambadde, 2005) the Subsurface Flow Constructed Wetland originated in Europe over 40 years ago. The wetland area is filled by gravel and sand and planted with aquatic vegetation, where wastewater flows horizontally through the channel, the filter material filters out particles and the organics are degraded by microorganisms.

The water level in a Horizontal Subsurface Flow Constructed Wetland is below the surface of the media at 5 to 15cm to ensure subsurface flow (USEPA, 1993; Luise et al., 1999; Martha, S. 2003).

Pre-treatment is essential to prevent clogging and ensure efficient treatment.

The removal efficiency of the wetland is a function of the surface area (length multiplied by width),. The filter media works as a filter for removing solids, and as a base for the vegetation. Although facultative and anaerobic bacteria degrade most organics, the vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics as well.

Phragmites, Australis (reed) is a common plants choice because it forms horizontal rhizomes that penetrate the entire filter depth. Pathogen removal is accomplished by natural decay, predation by higher organisms, and sedimentation.

Clogging is a common problem and therefore the influent should be well settled with primary treatment before entered into the wetland.

This is a suitable treatment technology for communities that have primary treatment (e.g. Septic Tanks or WSPs). This is a good option where land is available and cheap.

Advantages:

- Requires less space than a Free-Water Surface Constructed Wetland
- High reduction in BOD, suspended solids and pathogens
- Does not have the mosquito problems of the Free- Water Surface Constructed Wetland
- Can be built and repaired with locally available materials
- Construction can provide short-term employment to local labourers
- No electrical energy required

Disadvantages:

- Requires expert design and supervision
- Moderate capital cost depending on land, liner, fill, etc.; low operating costs
- Pre-treatment is required to prevent clogging.

5.3 IN-STREAM WET-LAND

A recent technical study conducted by Drainage Research Institute (DRI 2007) at three pilots in Egypt mentioned that the in-stream wetland is a modified design of surface flow constructed wet-land. In this kind of treatment the water slowly flows through the plants cultivated in the water way after passing from sedimentation pond to prevent the excess accumulation of solids and garbage.

The in-stream wetland is considered a good treatment technology for communities that have a primary treatment facility (e.g. Septic Tanks), and where land is very expensive and un-available. This technology is best suited to warm climates.

The in-stream wetland in brief consists of a sedimentation pond, a wooden gated weir and a steel plants screen that governs a series of floating and emergent aquatic plants reaches. The sedimentation pond is created in the drain inlet by deepening the drain cross section at the sewage water point source to make a settling basin with slow velocity and enough storage capacity to enhance primary retention treatment time in the form of sand and big solid particles and sludge as well.

The control weir is located at drain outlet. Its function is to control drain water depth and the treatment detention time according to pollutant loads.

The vegetation system of the drain is located on a certain distance before drain outlet (based on design criteria) and consists of a steel screen for vegetation.

The treatment processes were sedimentation, filtration, biodegradation and nutrient plants uptake as well as pathogens eradication. Effluent water from In-stream systems moves in an open water zone until the drain outlet to enhance oxygen content and water disinfection with the sun light penetration.

Advantages:

- High reduction in BOD and solids; moderate pathogen removal
- Can be built and repaired with locally available materials
- Construction can provide short-term employment to local laborers
- No electrical energy required
- No real problems with flies or odors if used correctly

Disadvantages:

- May facilitate mosquito breeding
- Long start up time to work at full capacity
- Requires large land area
- Requires expert design and supervision
- Moderate capital cost depending on land, liner, etc.; low operating costs.

6. Research Methodology

The main objective of the research is to increase water use efficiency through enhancing drainage water quality to make it suitable for reuse in irrigation purpose. To achieve this objective, the research methodology is based on developing a BOD Model, develop a Decision Support tool, and propose remedial solutions to overcome water salinity.

In this regard a sample of 21 drains at Kafr EL Sheikh Governorate that suffers from severe shortage in irrigation water have been selected as a study area to calculate the BOD concentration along the drain then propose the suitable decentralized waste treatment technology through DST. The sensitivity of the developed DST to different scenarios such as different stream cross section, temperature, discharge and removal efficiency and its effect on the selected treatment technologies and the change in capital and maintenance /operational cost is also checked.

Drains selection is based on suggestions from Kafr EL Sheikh General Directorate, farmers' complaints especially in summer season, and drainage water quality (the selected drains classified as slightly polluted).

The above methodology is applied through a user friendly water quality model (an excel spreadsheet) as shown in Annex (1) which has the capability for simulating the hydrologic and water quality components of a drain system and the calculation will focus on the Biological Oxygen Demand (BOD) and its concentration along the drain. Data related to water quality, nature of the waste being discharged at the drains and hydraulic characteristics of drains have been collected.

The data related to drains characteristics were obtained from the Egyptian Public Authority for Drainage Projects in August 2013.

A desk and field survey has been conducted in Kafr EL Sheikh drainage directorate, the desk survey reviewed all documents and maps related to the study area to present a clear vision of the drains and canals in the area, suitable location for water quality samples, and the field survey was conducted with a co-operation with local municipalities, to determine the number of villages surrounding the proposed drains and its populations.

Water samples have been collected during routine trips, on monthly basis for 3 months (June, July, and August 2013) to measure water quality parameters for 21 irrigation and drainage canals in the study as shown in water quality tables Annex (2). Through these measurements BOD concentration values and drainage water salinity at the beginning of each drain have been calculated.

The Electrical Conductivity (EC) has been also measured and analyzed as an indicator of drainage water salinity.

The output data of the water quality model illustrate the capacity of drains to accept and receive the pollutants and shows BOD concentration values along the drain. According to Law 48 the BOD concentrations for the reused water in agriculture shouldn't exceed 10 mg/l.

Check measurements have been taken on monthly basis to compare the calculated and measured BOD at certain locations to ensure that the decay table output values is correct, valid and reflect the real situation.

Through applying the developed Decision support tool (DST) on the selected drains by entering the required data which is based on drain discharge, available space, water table, capital cost, O&M cost, and the removal efficiency, the DST will propose the most promising waste-water treatment technology that can reduce the high BOD values to the allowable range.

6.1 CALCULATION OF THE BIOLOGICAL OXYGEN DEMAND

The water quality model includes the essential data to calculate (BOD) values along the drain such as drains cross section, water velocity (t), drain discharge, the surrounding villages population, distance between villages, the effluent of sewage-waste from each village, the biodegradability factor (k_t), temperature (T), and measured BOD value at the beginning of the drain. As shown in figure (3.1) we will consider the location where the village discharges its sewage-waste as a complete mixing process with small control volume as it seems reasonable to assume that both the drain and village waste discharge have been flowing for some time and will continue to flow. In addition this may be considered as a steady-state with a concern the concentration resulting from rapid mixing of the drain and effluent flows. In this case the effluent concentration can be calculated through using mass balance equation

$$C_{out} = \frac{Cin\ Qin + CsQs}{Qout},$$

where the total discharge (Qout) multiplied by the total concentration (Cout) is equal to the sum of sewage discharge from each village (Qs) multiplied by the concentration of waste from village (Cs) plus the drain discharge (Qin) multiplied by the concentration of drainage water (Cin). From village (A) to village (B) BOD concentration decays at this distance as the water flows down the drain, and the concentration at B can be calculated by using first order decay equation where, C_i is the initial concentration at any point, (t) is (the travel time for water from village (A) to village (B) and it can calculated by dividing distance by water velocity, (C_{out}) concentration at final cross section reached after time (t).

The concentration through transport of pollutants between villages can be calculated as a plug mixing process and the effluent concentration can be calculated by using first order decay equation $C_{out=-}C_{in}e^{-k_t*t}$.

where (k_t) is biodegradability coefficient for BOD at temperature (T) can be calculated by using the following equation

$$k_{t=}k_0 e\theta^{T-20}.$$

(k_0) is the decay coefficient, θ is a parameter that depends on the temperature (T). θ equal 1.135 for temperature (T) between 4 °C and 20 °C, and θ is equal 1.056 for temperature (T) between 20 °C and 30 °C, we use θ equal 1.056 for T equal 30 °C

To start calculating the BOD concentration, first we should measure the BOD concentration at the beginning of the drain before the village (A). Then calculate the effluent BOD concentration coming from village (A) where concentration of disposed BOD and raw waste strength from villages is a function of the population of each village, and water consumption per capita.

In Egypt, the average water consumption per capita in the rural areas ranges from 100 Liters to 150 Liters per day (for village less than 50000 capita). The average sewage waste produced by capita ranges from 80 % to 90 % of the water consumed (Egyptian code, 1998).

After the effluent of sewage waste from village reaches to the drain and is mixed with drain water, the new BOD concentration is calculated using mass balance equation, then the travel trip from village A to Village B the BOD concentration can be calculated through first order decay equation.

In the calculations, it was assumed that all villages dispose their sewage waste in the main drain and that the discharge from branch drains is null.

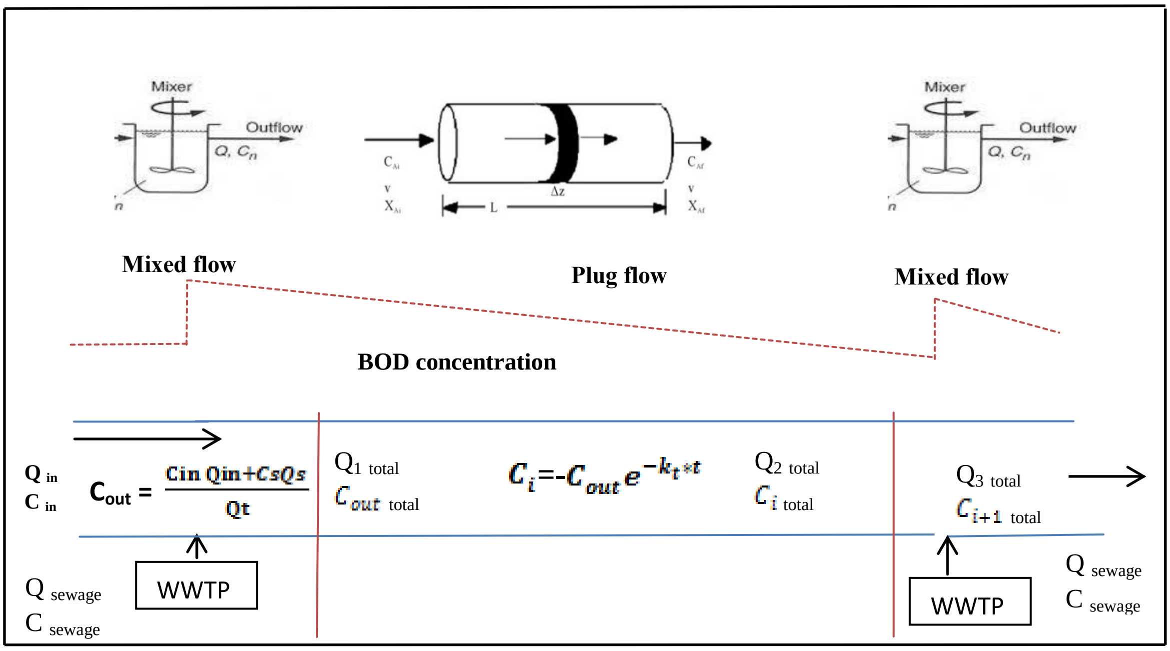


Figure 3.1 stages of BOD degradability along the drains

7. STUDY AREA LOCATION

Kafr El Sheikh Governorate is located in the Middle Delta Region at the Northern part of Egypt 120 km from Cairo. It is bordered by the Lake Burullus and Mediterranean Sea from the northern side, by Nile Rosetta branch in the west side, by Dakahleyia Governorate in the east side, and by Gharbeyia Governorate in the south side. The approximate area of Kafr El Sheikh Governorate is about 3,748 Km2 which is 0.34% of the total area of Egypt. The Governorate consists of 10 administrative districts, 10 major cities and 49 rural local units annexed by 206 villages and 1,559 Hamlets. The capital of the Governorate is Kafr El Sheikh City.

7.1 SAMPLING LOCATIONS AND FREQUENCY

The sampling point is located in fast-moving water, in the middle of the drain at least 15-20cm deep from the water surface. The sample was taken from the middle od drains. Drains are always sampled upstream from any bridge, culvert, aqua-duct, or other artificial structure. A GPS has been used to identify the location of the sampling point where the collections are repeated over time. The grab samples are collected in dark clean bottles and put in ice box to be transferred and tested in the laboratory.

The samples have been collected during routine trips, on monthly basis for 3 months (June, July, and August) at year 2013 to test water quality parameters for 23 irrigation and drainage canals in the study area as shown in table (4.6) and (4.7).

Table 4.6: East Kafr EL Sheikh drains

Code	Drain	Design Discharge (m^3/s)	Length (km)	Total Population (Capita)	Served area (Feddan)
E-1	Farsh Alganaen	3.05	18	40775	12000
E-2	Elbahrawy	8.45	19.2	18209	35000
E-3	Naser	13.81	20	19283	44000
E-4	Mekhazan	0.86	4.9	14796	1470
E-5	Abo khashaba	0.7	3.25	21064	1750
E-6	Erin	0.64	7.15	9583	3950
E-7	Farsh Alganaen	3.05	18	24256	12000
E-8	Abo Rayaa	3.12	15.45	22847	10000

Table 4.7: West Kafr EL Sheikh Drains

№	Drain	Discharge m3/s	Length KM	Total Population	Served area Feddan
W-1	Elhedood	0.8	5.3	25613	2300
W-2	No. 11	23.53	18.86	21205	56950
W-3	Elminshah	3.47	15.6	36664	10000
W-4	Faraon	2.09	17	26752	11500

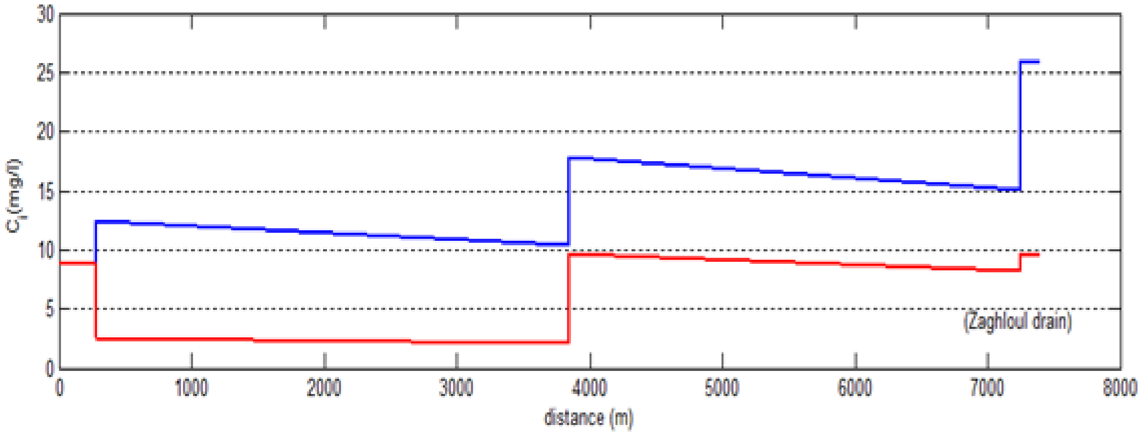
№	Drain	Discharge m3/s	Length KM	Total Population	Served area Feddan
W-5	Sandela	3.2	13.76	12556	9220
W-6	No.10 *	5.9	21.5	43105	17000
W-7	Tahwelet Nashart	1.6	12.8	24716	10250
W-9	No.9 Elasfal	1.43	12.23	35110	187850
W-10	Tharwat	16.67	10.4	26918	39300
W-11	Bahr El-nashart	28.5	33.799	29347	97850
W-12	Zaghloul Elsharkei	0.17	7.4	10511	5000
W-13	Moheet Elzeiny	7.64	12.5	15271	22000
W-14	Howd Elhagar	3.8	9.849	23139	10750
W-15	No.9 Elraesy	8.15	19.8	18962	21000

7.2 MONITORED PARAMETERS

This research will focus on calculation of Biological Oxygen Demand (BOD) concentration and salinity along the selected drains, as shown in table (4.8). The suitable technologies to reduce BOD concentration and overcome the salinity problems will be specified.

Water quality parameters selected to be measured at each location are:

- Oxygen Budget: BOD, COD, and DO
- Salts: EC, TDS, Ca, and Na.



The figure shows BOD concentration along Zaghloul drain as the blue line illustrate there is increasing in BOD concentration along the drain the value started by concentration equal 9 mg/l and ended by 25.83 mg/l.

The proposed technology to reduce the BOD concentration in Zaghloul drain is to apply an Up-flow Anaerobic Sludge Blanket Reactor (UASB) technology with BOD removal efficiency equal 80%, at the beginning of the drain where is the land is available, to treat the sewage waste disposed from Khaal AL Garaa village with total population equal 4583 capita, which discharge waste of .0053 m3/s with BOD concentration equal to 500 mg/l, Using that technology will reduce BOD concentration comes from the village to 100 mg/l. After the complete mixing with drain water the BOD concentration will be reduced to 2.48 mg/l, this value falls within the allowable limits of BOD which enables the reuse of drainage water in irrigation.

After (3.9) Km from the beginning of the drain at Izbt AL Sayada an In-stream wetland will be applied with BOD removal efficiency equal 50% to reduce the BOD concentration to 8.71 mg/l.

The red line illustrate that the BOD concentration value starts by 2.48 mg/l then this value increased to 9.59 mg/l at the drain end.

8. CONCLUSIONS

- It was observed that drains with discharges more than 5 m3/sec is less affected with BOD effluent from villages with population up to 60,000 inhabitants.
- There is a relation between BOD concentration and crop pattern in the area, where in the summer season BOD values concentration decrease with rice cultivation.
- Irrigation with direct drainage water leads to increase soil salinity Northern East part of Kafr EL sheikh Governorate.
- The change of temperature, stream cross section, and stream discharge has an effect on the BOD concentration and the selected treatment technologies through decision support system.
- Using a decentralized treatment station in the beginning of the drains keep BOD concentration values within the allowable limits which enable to direct reuse of drainage water in irrigation.
- Increasing air entrainment in the in-stream wetland technology will increase the BOD removal efficiency from 50% to 70%, and that modified scenario increase using instream wetland to be used in 8 sites out of 21.
- The modified in-stream wetland technology is the most suitable solution in the study area in terms of the required space and construction, operational and maintenance cost (especially drains with discharge less than 5 m3/S.)
- Irrigation with direct drainage water leads to increase soil salinity (according to the statistics of Ministry of Agriculture and Land Reclamation MALR, the unit yields of the major crops in Kafr El Sheikh ***tend to lower*** in recent years due to the deterioration of water quality), and that result was observed in Northern part of kafr EL sheikh salinity that appear in EL Baharawy drain and Abo Raya drain EC = 8.6

and 6.4 DS/m respectively, and It is recommended to cultivate Halophytes in the surrounding area.

- Enhancing agriculture drainage water may not increase the quantity of drainage water used in irrigation, that's because farmers already used these water although its bad quality, but improving drainage water quality will reflect on enhancement of soil characteristics and the productivity of crop yield for long term of using enhanced drainage water quality.
- Using anaerobic sewage waste treatment technologies for rural and semi-rural is considered the best investment as a short term solution due to its low cost.
- It was concluded that using the Anaerobic Baffled Reactor (ABR), and Aeriated filter (AF) are considered the most promising alternatives for sewage waste treatment.
- Modified in-stream wetland is recommended small villages in Kafr El sheikh, with low BOD loads
- It is recommended to replicate the same procedure for choosing a suitable treatment technology for all areas suffering from severe shortage in irrigation water.

9. RECOMMENDATIONS FOR FURTHER WORKs

In the context of the study the author considered the point source pollution from villages. It is recommended

1. The research focused on the point source of sewage waste pollution comes from villages, it is recommended to consider branch drains and sub-surface drainage effect in the calculation in further works.
2. It also recommended calculating the nitrate decay along the drains.
3. Further works should study the behavior of the industrial wastes and heavy metals concentration values in samples of water and sediment along the drains.
4. There is no an accurate survey available on the unofficial drainage reuses in Egypt. The reason is that it changes from one location to another and from time to time depending on water shortage in the canal and the need for water to meet the crop demand, so it is recommend to survey the points of direct reuse along agriculture drains.

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