Watershed Management, A Tool for Sustainable Safe Reuse Practice, Case Study: El-Salam Canal

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Abstract
In Egypt, drainage and irrigation network receives a complex mixture of industrial and domestic effluent. Therefore, water quality was subjected to rapid deterioration over the past decades. A need for using marginal quality water in agriculture for new expansion projects is becoming a great necessity. Good quality water is no longer available for new irrigation projects. One strategy to increase available water resources is to reuse agriculture drainage water for irrigation. Surface water of low quality along with limitation of current water resources was found to be the largest current environmental threat to the drainage reuse practice in Egypt. The detrimental effects of drainage water reuse can be minimized by adopting appropriate pollution sources management. Although domestic diffuse sources represent very small portion of the total discharge in drains, they contribute to a high percentage of organic load to the water system. Lack of investment and time required to execute proper wastewater treatment plants (WWTPs), become a constrain impeding the improvement in surface water quality. The proper water quality management system along with good planning for constructing, upgrading and upsaling of WWTPs within a certain watershed can positively improve the water quality at the mixing point with fresh water for reuse. In this study, a practical management tool based on watershed as one of the primer water system unit has been introduced. The tool works under GIS environment to help water managers and planners concerned in irrigation system to incorporate the reuse of drainage water to set best prioritization scenario of WWTPs implementation, upgrading or upsaling within the sub-watershed of El-Serw and Bahr-Hadous drains that feed El-Salam canal. The study is based on analyzing the transport and decay of pollutants expressed as BOD load through network analysis of drains network within El-Salam canal watershed as a case study.

Keywords: Water quality management, Watershed, Drainage water reuse, GIS, Point source pollution (PSP), BOD.

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1. Introduction
Based on the measures towards water resources management, Egypt is facing serious challenges such as deterioration of water quality and the growing demand-supply gap (Mohamed 2013). In the 1980s, the reuse of agricultural drainage water became a policy in Egyptian water resources management practice (El Gammal et al. 2010). The amount of annually produced drainage water is 24.12 billion cubic meter (BCM/ year) extracted amount of 15 BCM/ year as surface water outflow (base year 2012) (MEWINA 2015). El-Salam canal is one of the most leading national water reuse projects in Egypt. The drainage water supplied to the project is essential for its sustainability. It is estimated to be 2 BCM/ year. This quantity is harvested from two main drains: El-Serw and Bahr-Hadous. This drainage water is mixed with another 2 BCM/year freshwater drawn from Damietta Branch, to produce a total discharge of 4 BCM/ year in order to supply enough water to irrigate 200,000 feddans in the western Suez canal region and 420,000 feddans in North Sinai.

Since the sub-watershed area of the two drains is located in a highly populated areas, the drainage system within the region is susceptible to pollution from legal and illegal dumping of domestic and industrial wastewater. Furthermore, the current proposed mixing ratio of 1:1 may be changed to a higher percentage of mixed drainage water, due to expected development in North Sinai and a limitation in fresh water. This might put more pressure on water managers and planners to go forward in improving the water quality of reused drainage water.

In 2005 a field study has done and was found that most of the water received by Bahr-Hadous drain (94.3%) is from agricultural diffuse sources. Although domestic diffuse sources contribute only 4% of the total discharge, this fraction contributes 94.7% of the organic load received by Bahr-Hadous, expressed as BOD load (EcoConServ 2005). This percentage of organic load resulting from domestic diffuse is almost the same for drains within El-Salam catchment area. Accordingly, the water quality of the canal has been negatively affected and the reuse plan of increasing the amount of mixing drainage water has been threatened. Therefore, and due to urgent need of irrigation water, important and immediate measures should be taken.
This study identifies watershed management as one of the premier water system unit for best water management. That occurring within the designated watershed rather than administration boundaries. The watershed of El-Salam canal can be classified into three main categories: 1- Fresh water source sub-watershed (Damietta Branch); 2-Mixing drainage water source sub-watershed (El-Serw & Bahr-Hadous drains) and finally 3- Irrigated sub-watershed of El-Salam canal (620,000 feddans). This study will focus on El-Serw and Bahr-Hadous sub-watershed which is located within five governorates (administration boundaries). The Watershed Approach is an ongoing cycle of tasks: setting standards for surface water quality; taking measurements of the conditions; assessing the data and identifying the impairments including establishing priorities; verifying the pollution sources and developing plans for restoring water quality and implementing pollution source controls (Texas Water 2018). Pollution source controls can be permits, rules, and source management practices. The plan should be set to better achievement of protecting watershed, which means clean water in the streams within watershed.

Watershed planning is a continuous process that requires:
- Collect and analyze of water resources data to identify issues and problems;
- Design a watershed plan on the basis of this data to protect and promote resource sustainability;
- Implement the plan;
- Monitor and evaluate the plan while continuously updating it to adapt to new information or technology;
- Enforcement and compliance efforts.

1.1 Problem statement
Since the dawn of time, nature has known how to preserve the internal balance that contributes to a healthy and clean environment (ElKhazragy 2016). The continuous release of wastewater to the water network reaches the level that exceeded capabilities of a natural system to process the pollution resulting to a serious impact on the water quality, which affects the sustainability of reuse projects in Egypt. The low level of sanitation service especially in rural areas makes nearby streams (either canals or drains) the perfect places for inhabitants to dispose of their sewage (Shaban et al 2010). Most water policies adopted conventional strategies and continuing dumping in water streams without serious consideration to its environmental effects on downstream, and when considered, they were superficially touched within isolated administration boundaries and there is a lack of consistent analytical studies on the quantity of pollution load and the reduction target. This raises important questions:
- Does water managers need to consider watershed, rather than isolated administrative boundaries in management and planning?
- What water managers can achieve with limited funds in the near term to improve water quality of surface water?
- What is the appropriate management approach for best implementation of WWTPs, taking into consideration the limited funds and fast impact to downstream water quality?
- How much pollution load - expressed in BOD Total Maximum Daily Loads (BOD TMDLs) - is produced from mixing drains sub-watershed of El-Salam canal?

1.2 Research objectives
- The wide goal of this study is to contribute for solving the problem of water shortage in Egypt, by presenting the most proper management tool for better understanding the problem of pollution sources and plan for reducing pollution.
- Production of environmentally safe drainage water suitable for disposal and/or reuse.
- Put best management tool for water quality management starting by considering point source of pollution (PSP) and ending up by considering all sources of pollutions including nonpoint source of Pollution (NPS).

2. Materials and Methods
The methodology is based on setting a practically distributed and physically based watershed-scale water quality model for estimating the movement of point sources BOD load through in surface water (case study: El-Serw and Bahr-Hadous drains sub-watershed). A pollution load assessment has been carried out by estimating BOD load at both source (upstream) and at mixing point (downstream) of the sub-watershed through the comparison analysis of transport and decay of pollutant (BOD Load) for best management within the study watershed in order to get safe water reuse practice (irrigation and fish farming). The study considers domestic diffuse sources (point source) as initial stage. The system has been designed under a Geographic Information System (GIS) environment, to support development of a comprehensive watershed simple model, for use as a tool for watershed planning, resource assessment and ultimately, water quality management purposes of El-Salam watershed (Appendix 1, shows a sample of the analysis result). The study considers only domestic sewage point
source within the study watershed by knowing how much pollution load is going to El-Salam canal, where it comes from, who is producing it, how it is being contaminated and where it is ends up.

Watershed are important because all point and non-point sources of pollution within the study area ultimately drain to other water bodies. It is essential to consider these downstream impacts when developing and implementing water quality protection and restoration actions. Whatever is dumped in upstream ends up downstream within the watershed. In this case, management and planning in a holistic approach (watershed approach) is much more effective rather than individual management within isolated administrative areas (Figure 1).

2.2 Collecting data and building the network
The major steps in system application process consist of:
1. Collection and development of data;
2. Characterization and segmentation of watershed; and
3. Scenario analyses.
The following detailed steps has been done:
1. A drains network of the study area has been built in a geographical database, as preparation to assist a network analyses based on watershed approach (Figure 2).
2. Digitizing of drains network within the watershed and specify the served area for each WWTP, population data, villages location and clusters planning;
3. The villages, WWTPs and area served by each treatment plant were located, a networking analysis was conducted as well as the determination of the flow of network paths.
4. Evaluate the efficiency of WWTPs within studied watershed: 67.5 % for El-Serw catchment, 68 % for Bahr-Hadous catchment area.

Many of WWTPs in developing countries which were constructed outside of urban regions, have become surrounded by residential buildings. This has prevented the horizontal expansion of these WWTPs (Safwat 2018), accordingly, nearby unserved villages can be served by those WWTPs that have upscaling ability either horizontally or vertically within the same cluster according to land availability. The computational analysis of the network was made to calculate the decay rate of the organic load (BOD) for the distance from production at source to the mixing point with El-Salam Canal, considering villages and clusters as segment units using the decay equation:

\[ BOD(x) = BOD_0 \exp \left( -\frac{k \alpha x}{u} \right) \]  

Where \( BOD_0 \) is the amount of the biochemical oxygen demand at \( x = 0 \);
\( \bar{u} \) is the mean velocity in drains = 1 m/s, with a decay coefficient: \( k = 0.5 \), at average temperature=\( 20^\circ \) C.

3. Urgent pollution treatment strategy:
This is can be achieved by two scenarios: 1- either by implementing new WWTPs within un-served areas; 2- Upscaling neighboring existing WWTPs to accommodate surrounding un-served areas; and/or; 3- upgrading unqualified existing WWTPs within served areas. The decision support system is designed to support analysis at a variety of scales using tools that range from simple to sophisticated.
Figure 1: Two types of management divisions (administration and watershed boundaries)

The methodology is based on pollution treatment strategy. Watershed management traditional approach typically involves many separate steps: collecting data, summarizing information, developing maps and tables, applying and interpreting models. The data can be classified into two categories: 1- Spatial wise data: geographic data; 2- Measurable wise: Quantity and quality data.

For initial quick decision, those interpretations do not require other information on hydrology, agriculture and land, which is not included in this study and can be considered in future studies.

The analysis conceived as a system for supporting the development of BOD Total Maximum Daily Loads (BOD TMDLs). Developing BOD TMDLs requires a watershed-based point source analysis for a point source of pollution. A geographic information system (GIS) provides the integrating framework for network analysis. GIS organizes spatial information so it can be displayed as maps, tables, or graphics. GIS provides techniques for analyzing combined information and displaying relationships.

Figure 2: Integrated water quality framework for watershed management

3.1 Scenario 1: Implementation of new WWTPs for un-served areas

This is achieved by putting prioritization for constructing new WWTPs in phases within the study watershed using network analysis based on updated construction cost/m³ (NOPWASD 2017) as follows:
- Capital cost for new WWTP less than 10,000 m³/day = 8000 LE/m³;
- Capital cost for new WWTP more than 10,000 m³/day = 10,000 LE/m³;
- Running cost for existing (treatment only) = 40–65 piasters/m³;
- Running cost (collection, pumping and treatment) = 1.5 LE/m³.

The sub-watershed of the study area has been divided into villages and clusters (Figure 3) and has been classified as:
- Served villages: those villages that have wastewater treatment facilities;
- Un-served villages: those villages that have no wastewater treatment facilities;
- Cluster: a geographical area that has more than one villages and can be served by one WWTPs;

3.1.1 Prioritization of building a new WWTPs within El-Salam watershed area

Prioritization of the constructing new WWTPs has been identified within the sub-watershed of El-Serw and Bahr-Hadous drains. The analysis has been done through a GIS network to calculate the maximum organic load resulting from each village at the mixing point with El-Salam Canal (BOD Total maximum daily load). The GIS model has been built within the framework of the available information from Ministry of Housing, Utilities and Urban Development (MoHUUD) to determine the priorities from the perspective of water managers, where the geographic data of the villages, main and secondary drains of the study area has been adopted, along with the population data from the Holding Company for Water Supply and Sanitation (HCWSS 2016). This section aims to determine the priorities of the implementation of WWTPs in successive phases in order to reach the accepted quality of mixed drainage water on the El-Salam canal to the degree that commensurate with the importance of this project from both environmental and national prospective.

![Figure 3: Watershed divided to clusters](image)

3.1.2 Network analysis for WWTPs prioritization

Assumption:
Pollution load:
- BOD: 15-80 gm/capita/day, this study considers the figure 54 gm/capita/day (Egyptian Code for Sewage Treatment 2007), and/or 230-560 gm/m³, (the figure 423.5 gm/m³ will be considered in this study) (Henze et al. 2018)

BOD load calculation (Egyptian Code for Sewage Treatment 2007)

\[ Q_{\text{av(Sewage)}/\text{Capita}} = (0.85) \times Q_{\text{av(Water consumption)}} \]

\[ Q_{\text{av(Water consumption)}} = 150 \text{ Liter/capita/day.} \]

By considering the assumptions and applying the network analysis according to flow direction as in figure 4, for the villages within the sub-catchment of ElSerw and Bahr-Hadous, a list of the priorities for the most affective
un-served villages in producing BOD. A map analysis has been done for villages within El-Serw drain, verified with field investigation and the results were as follows:

3.1.3 Un-served villages (discharge directly to El-Serw drain network)

- Served number of villages: 51 Villages;
- Number of villages within sub-watershed: 88 Villages;
- With a total population: 881,786 Capita;
- Number of existing WWTPs: 21 WWTP;
- With population of: 217,546 capita;
- Within Number of clusters: 24 clusters;
- Number of un-served villages and discharge their effluent to drains without treatment (Figure 5): 36 villages;
- With a total population: 277,646 capita;
- Producing raw sewage of: 35,400 m$^3$/day;

Resulting 11,078 kg/day BOD at source (drains) and ending to 9,952 kg/day at the mixing point with El-Salam canal.

3.1.3.1 Proposed new WWTPs

By starting the 1st phase with building the most effective 10 new WWTPs, that impacting high reduction in BOD load at the mixing point with El-Slam canal (Figure 6) as follows:

- 1st phase new WWTPs (Figure 6): 10 plants;
- Serving a population of: 142,167 capita;
- With a capacity of: 18,126 m$^3$/day;
- To remediate a total of BOD: 7,677 kg/day;

This end up to a reduction in the total BOD load of 7,677 kg/day at source and 6,597 kg/day at mixing point, by applying the treatment process for the 1st 10 new WWTPs, the BOD will drop down from 11,078 to 3,401 kg/day at source and from 9,952 kg/day to 3,355 kg/day of BOD at the mixing point.

3.1.4 Un-served villages (discharge directly to Bahr-Hadous drain's network)

A map analysis has been done for villages within Bahr-Hadous sub-watershed, verified with field investigation and the results were as follows:

- Number of villages within sub-watershed: 88 Villages;
- With a total population: 881,786 Capita;
- Number of existing WWTPs: 82 WWTP;
- Served number of villages: 262 Villages;
- Within Number of clusters: 75 clusters;
- Number of un-served villages and discharge their effluent to drains without treatment (Figure 7): 379 villages;
- With a total population: 2,882,123 capita;
- Producing raw sewage of: 367,000 m$^3$/day;
Figure 5: Un-served villages within El-Serw catchment area
Resulting 155.6 tons/day BOD at source (drains) and ending to 123.2 tons/day at the mixing point with El-Salam canal.

Figure 6: Scenario 1: First 10 new establish new WWTPs within El-Serw catchment area

3.1.4.1 Proposed Treatment solution
By starting the 1st phase with building the most effective 126 new WWTPs, that producing high reduction in BOD load at the mixing point with El-Salam canal as follows:
- 1st phase WWTPs (Figure 8) 126 plants;
- Serving a population of 1,810,846 capita;
- With a capacity of 230,882 m³/day;
- To remediate a total of BOD 97,779 kg/day;

This is resulting a reduction of total BOD by 97,779 kg/day at source and at mixing point ending to 62,194 kg/day. By applying the treatment process for the 1st 126 new WWTPs, the BOD will drop down from 155,600 to 57,821 kg/day at source and from 123,200 kg/day to 61,006 kg/day of BOD at the mixing point.
3.1.5 Cost analysis for treatment and pollution control

3.1.5.1 Treatment (Building new WWTPs)

The assumption: Capital cost for less than 10,000 m$^3$/day = 8000 LE/m$^3$ (All treatment plants within the study area are of capacity less than 10,000 m$^3$/day).

a- El-Serw catchment area

b- The 10 first priority of new WWTPs of a discharge 18,126 m$^3$/day (8000 LE/m$^3$) as initial stage cost: 145,010 thousands L.E.;

c- The whole 36 unserved villages of a 35,400 m$^3$/day as final stage cost: 283,200 thousands L.E.

d- Bahr-Hadous catchment area

- The 126 first priority new WWTPs of a discharge 230,882 m$^3$/day as initial stage cost: 1,847 thousands L.E.

- The whole 379 unserved villages of a 367 thousands m$^3$/day as final stage cost: 2,939,000 thousands L.E.
3.2 Scenario 2: Upgrading existing WWTPs for served areas

3.2.1 Served villages (Existing WWTP)

a- WWTPs (discharge directly to El-Serw drain network)
   - Number of existing WWTPs: 21;
   - Serving population: 217,546 capita;
   - With a treatment capacity of raw sewage: 29,840 m$^3$/day (actual capacity);
   - With an average efficiency of: 67.5 %
   - That result to: 9,698 m$^3$/day untreated sewage;

Resulting 4,107 kg/day BOD at source (drains) and ending to 2,854 kg/day at the mixing point with El-Salam canal (taking the assumption 423.5 gm/m$^3$ BOD)

Proposed upgrading and upscaling existing WWTPs:

By applying upgrading for the most effective existing WWTPs, starting the 1$^{st}$ phase with 12 WWTPs, by raising the efficiency from 67.5 to 95% and producing high reduction in BOD load at the mixing point with El-Slam canal as listed:

- 1$^{st}$ phase upgrade/ upscale WWTP: 12 plants;
- Serving a population: 166,090 capita;
- With a capacity of: 22,890 m$^3$/day (actual capacity);
- Untreated amount of sewage: 7,439 m$^3$/day (67.5 % efficiency);
- To remediate a total of BOD of: 3,150 kg/day;
- This end up to a total BOD at mixing point: 2,548 kg/day;

By executing the upgrading and upscaling for the 1$^{st}$ 12 existing WWTP, the BOD will drop down from 4,107 to 957 kg/ day at source and from 2,854 kg/ day to 306 kg/ day of BOD at the mixing point.

b- WWTPs (discharge directly to Bahr-Hadous drain network):
   - Number of existing WWTPs: 62;
   - Served villages: 213;
   - With a population: 3,337,898 capita;
   - With a capacity of: 425,582 m$^3$/day;
   - With an average WWTPs efficiency of: 68 %;
   - That result to: 136,186 m$^3$/day untreated sewage;

Resulting 57,675 kg/day BOD at source (drains) and ending to 38,854 kg/day at the mixing point with El-Salam canal (taking the assumption 425 gm/m$^3$ BOD).

Proposed Treatment solution:

By starting the 1st phase upgrading and upscaling the most effective 40 existing WWTP, that producing high reduction in BOD load at the mixing point with El-Slam canal as listed:

- 1$^{st}$ phase upgrade/ upscale WWTP: 40 plants;
- Serving a population: 275,625 capita;
- With a capacity of: 351,215 m$^3$/day (actual design);
- Untreated amount of sewage: 133,462 m$^3$/day (68% efficiency);
- To remediate a total of BOD: 56,521 kg/day;
- This end up to a total BOD at mixing point: 38,115 kg/day;

By executing the upgrading and upscaling for the 1$^{st}$ 40 WWTP, the BOD due to unqualified treatment will drop down from 57,675 to 1,154 kg/ day at source and from 38,854 kg/ day to 0.739 kg/ day at the mixing point with El-Salam canal.

4- Results summary

- The total sewage produced within watershed area is 882,963 m$^3$/day ; Treated amount is 402,400 m$^3$/day, representing a percentage of 45.6 % of a total sewage with an efficiency of around 68%;
- Scenario 1: Building the most effective new WWTPs for un-served villages (10 new WWTPs out of 36 unserved villages within El-Serw and 126 out of 379 unserved within Bahr-Hadous sub-watershed);
- Scenario 2: Upgrading the most effective existing, unqualified WWTPs for served villages (12 WWTPs out of 21 WWTPs within El-Serw and 40 WWTPs out of 62 within Bahr-Hadous sub-watershed;
Figure 9: Integrated framework for watershed management

- The sum of treated sewage out of both scenarios is **394,892 m³/day** representing 44.7 % of total production wastewater;
- The reduction of the BOD load from 228,460 kg/day to 63,333 kg/day with a reduction percentage of 72.3 % at source;
- Along with a reduction in BOD load from 174,860 kg/day to 65,406 kg/day with a reduction of 62.6 % at mixing point with El-Salam canal.
- Scenario 1: was to build 136 new WWTPs out of expected 454 WWTPs.
- Scenario 2: was to upgrade 62 Existing WWTPs out of 83 WWTPs.

5- Conclusions

Using watershed management approach with a proper tool of analysis resulted in the best scenarios for mitigation of the problem of bad quality of mixing water within El-Salam watershed as follows:
- Building of 30% of required new WWTPs along with upgrading 75% of existing WWTPs results in treating 44.7 % of total sewage water, 98 % of untreated sewage water, reducing BOD load with 72.3 % at source and 62.6 % at mixing point.

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Appendix 1: Example of network analysis output