SPATIAL MODELING APPROACH TO WATER POLLUTION MONITORING OF DRAINAGE SYSTEM (EL-FAYOUM)

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ABSTRACT

The rate at which we deplete and degrade our fresh aquatic resources poses a great threat to our future life support system. The present study is taken up for the monitoring, identification and suggesting preliminary measures of water pollution control in the Lake Qaroun Basin, Egypt (with the help of Geographic Information System (GIS)). First, spatial and temporal databases such as maps on geology, geomorphology, soils, land uses and attributes on meteorology, population, water quality etc., were effectively stored and analyzed within the GIS system. Second, the spatial analysis on depicting the source-pollutant relationship was conducted. Third, the graphical presentations, visual impacts and spatial distribution of graphical outputs on water quality changes, pollution load and relationship with sources were illustrated and finally, buffer zones were generated on the basis of water quality criteria a final management tool for the lake basin.

INTRODUCTION

Water is a precious resource essential for the well being of all living organisms. However, water is under potential severe threats from all human activities. Deteriorating water quality is a particular threat in countries with scarce water resources as the case of Egypt. The network of irrigation canals and drainage in Egypt currently suffer from increasing pollution caused by the discharging of agricultural drainage, untreated or partially treated domestic and industrial wastewater. Water quality problems are often linked to land use, such as increases in pollutant loads due to increasing human activities.

The Ministry of Water Resources and Irrigation (MWRI) in Egypt has a long history in water management. The water quantity management practice in Egypt is a national heritage that is passed on from one manager generation to the other. Population inflation and national development together with the new approach of sustainable development have necessitated that water quality management be incorporated into the traditional water quantity management practices. One of the important efforts that have been done is the integration of the water quality measurements and information of
pollution source in order to analyze the possible alternative for reducing the pollution effect on surface water. Since Pollution sources are spatially distributed, the Geographic Information System (GIS) is a powerful tool to deal with these spatial data and has the scalability for spatial modeling. The present study is taken up for the monitoring, identification and suggesting preliminary measures of water pollution control in the El-Batts drain (one of the most heavily polluted drains in Fayoum City) with the help of Geographic Information System (GIS).

FRAMEWORK FOR DEVELOPED GEO-INFORMATION SYSTEM

Water quality management has been identified as one of the elements of sustainable development. Water quality information has to regularly monitored, well organized and stored in proper format. Constructing an information system for water quality data of the monitoring network and different sources of pollution would be an initial step for spatial analysis to get a suitable alternative for pollution control. Development of a spatial information management strategy and the implementation of suitable database capacity are key factors to the success of any water quality management program. Spatial analysis is considered very effective tool for pollution control. Thus, this research presents a framework for spatial water quality management for the drainage system. The proposed framework includes geo-database, spatial modeling and a graphical user interface to facilitate data analysis and the presentation of effects of the water quality variables according to the various criteria. Different factors those affect the water quality are physical, chemical and socio-economic parameters of the drainage basin. A detailed framework is shown in the figure 1. The present case study is followed up as per this framework. Using GIS, the database on pollution load, the relationship between pollution loads with population have been assessed and graphically presented. The prime objectives of using GIS over traditional methods are:

- Effective storage and analysis system for spatial and temporal databases such as maps on, land uses, population and water quality,
- Spatial Modeling on depicting the source-pollutant relationship,
- Graphical presentations, visual impacts and spatial distribution of graphical outputs on water quality changes, pollution load and relationship with sources using spatial analysis techniques.

EL-FAYOUM AREA DESCRIPTION

The surface area of El-Fayoum Governorate is approximately 6000 km². This Governorate is of a particular nature, differing from the Delta and Upper Egypt and from the Oasis as well. The differences are not limited to agriculture; they extend to geographical and topographical features as the environment is a mix of agricultural nature, desert and coastal. Also, Fayoum's population includes Bedouins and rural inhabitants. The Fayoum Depression looks like an oasis and it is directly linked to the Nile through the Youssef Sea which derives its waters from Al Ibrahimiah Canal at
Dairout up to Al Lahoon barrages 284 km from Dairout. The waters are distributed through the Youssef Sea and Hassan Wassef Sea. Youssef Sea serves the northeastern and central parts, whereas Hassan Wassef Sea serves the southern and western parts (ARCADIS, 1999), see figure (2).

![Figure 1. Detailed Framework for Water Pollution Management](image)

**IRRIGATION AND DRAINAGE SYSTEMS**

Fayoum receives fresh water from one source, Bahr Youssef. Fayoum's share of irrigation water amounts to nearly 2.5 (bcm) annually. Qarun Lake’s surface area amounts to 55,000 feddans and Wadi Al Rayan Lake’s surface area amounts to 35,000 feddans. Both are considered the main sink of drainage water for the agricultural lands in the Governorate. El-Fayoum Governorate has a special irrigation system due to the topography of its land which slopes downward steeply from south to north for
67 meters along a distance of 35 km towards Qaroun Lake, with a sloping average of 2m/km. Therefore, most of the Governorate’s land (93%) is being irrigated directly through waterfalls.

The waste water flows from south to north towards the slope where it discharged into Qaroun and Wadi Al Rayan Lakes. The drainage system in Fayoum consists of three major natural drainage systems and one man-made system. El-Batts drainage system at the east side, El-Wadi drainage system on the west side and minor drains in the central part of the Fayoum. In addition, Wadi El-Rayyan drain (man-made) is constructed to decrease the drainage water reached to the Qaroun Lake and services the new reclaimed land.

The major problem of Fayoum’s agriculture is soil degradation, caused by poor drainage, under-irrigation and inadequate soil leaching, due to a lack of adequate water supply to “tail end” sites of the Fayoum basin, and a lack of an adequate field drainage system in low lying areas of the basin (UNDP, 2003). Sanitary conditions are negatively influenced by the inadequate organization of sewage and liquid waste disposal. Drain water quality violates water quality standards and poses health risks.

Figure 2. General Layout of El-Fayoum Area
WATER QUALITY MODEL

This study is focused on El-Batts drain catchment area. El-Batts drain is one of the most heavily polluted drains in Fayoum City. Figure 3 presents a schematic diagram of El-Batts drain, pollution loads and monitoring station. The drain discharges its drainage water into Lake Qaroun. The monitoring locations are located at (18.3, 45.0, 58.5 km), respectively. Two sources of pollution are identified along El-Batts drain, which potentially affect its quality.

The first source is the domestic wastewater which can be classified as point load comes from the discharges of the Waste Water Treatment plant (WWTP’s). The four WWTP’s are Old and New Fayoum at 7.8 km, El-Edwa 21.6 km at and El-Roda at 44.3 km. Some sewage is discharged directly either to drainage channels causing high peak organic loads, this type of pollution is considered as distributed load (non-point source). The values of untreated domestic water are estimated from overlaying GIS map. The intersection of the drain catchment and the administration districts gets domestic wastewater relative to population density based on the population is distributed normally distribution. Figure 3 shows the map overlaying.

Figure 3. The intersection of the Catchment area of El-Batts drain and Admin. Districts

The second source is the agricultural drainage that comes from the agricultural activity. The quantities and characteristics of drainage from cultivated areas are highly variable. The most important pollutants found in runoff from agricultural areas are sediments, plant nutrients, crop residues, inorganic salts and minerals, chemical fertilizers and pesticides. The load type is considered as distributed load. Figure 3 shows the schematization of the distribution of the pollutants loads and monitoring station. The industrial wastewater is not considered in the scope of analysis because most of industries are located at Kom-Oshim area. The industrial waste is injected in the soil.
The water quality model is built using the DUFLOW package for simulating the three water quality parameters (BOD, NH4 and TDS) for EL Batts Drain and the model output is automatically linked to the geo-information system. The drain system is represented by a 7 sections. The input wastewater discharges and water quality variables (BOD, TDS, NH4) values for pollution sources are in Table 1.

### Table 1. Pollution sources discharge to El-Batts drain (BOD, TDS, NH4) concentrations

<table>
<thead>
<tr>
<th>Pollution</th>
<th>Source</th>
<th>Discharge (m³/s)</th>
<th>BOD (mg/l)</th>
<th>TDS (mg/l)</th>
<th>NH4 (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Old Fayoum</td>
<td>0.260</td>
<td>45.0</td>
<td>1240</td>
<td>7.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.250</td>
<td>43.7</td>
<td>1210</td>
<td>6.70</td>
</tr>
<tr>
<td>P2</td>
<td>New Fayoum</td>
<td>0.460</td>
<td>25.0</td>
<td>1020</td>
<td>4.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.440</td>
<td>23.8</td>
<td>1005</td>
<td>3.80</td>
</tr>
<tr>
<td>P3</td>
<td>El-Edwa</td>
<td>0.011</td>
<td>75.0</td>
<td>1360</td>
<td>7.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.010</td>
<td>73.7</td>
<td>1330</td>
<td>6.90</td>
</tr>
<tr>
<td>P4</td>
<td>El-Roda</td>
<td>0.020</td>
<td>110.0</td>
<td>1360</td>
<td>8.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.018</td>
<td>950.0</td>
<td>1328</td>
<td>7.60</td>
</tr>
<tr>
<td>P5</td>
<td>Re-use Pump station</td>
<td>0.850</td>
<td>40.3</td>
<td>1050</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.980</td>
<td>44.3</td>
<td>950</td>
<td>0.68</td>
</tr>
</tbody>
</table>

In this scenario improving treatment methodology applied for the all treatment plants. The impact on the water quality parameters (BOD and TDS) are illustrated in Table 2. It is observed that, the reduction in BOD concentration is predicted 29.0, 17.0 and 23.0 mg/l for the three locations compared in base case. The percentage of reduction of BOD is about 12%. The reduction of TDS is about 200 mg/l, 30% percentage of reduction compared with TDS values in base case. The increasing in the cost associated with the improvement of the treatment methodology applied is presented in Table 2.

### Table 2. The increasing of total cost/m³/day when improving the treatment methodology applied

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Capacity (2000) m³/day</th>
<th>Capacity (2017) m³/day</th>
<th>Total cost (2000) 1000 L.E/m³/day</th>
<th>Total cost (2017) 1000 L.E/m³/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Fayoum</td>
<td>22600</td>
<td>40000</td>
<td>28250</td>
<td>50000</td>
</tr>
<tr>
<td>New Fayoum</td>
<td>40000</td>
<td>60000</td>
<td>88000</td>
<td>132000</td>
</tr>
<tr>
<td>El-Edwa</td>
<td>972</td>
<td>3000</td>
<td>972</td>
<td>3000</td>
</tr>
<tr>
<td>El-Roda</td>
<td>1000</td>
<td>6100</td>
<td>1000</td>
<td>6100</td>
</tr>
<tr>
<td>Materties</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>22000</td>
</tr>
<tr>
<td>Kaser Rashwan</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>22000</td>
</tr>
</tbody>
</table>
DEVELOPING GEO-INFORMATION

The source for El-Fayoum area and context features is the topographic maps generated from the Egyptian Surveying Agency (ESA). They are of scale 1:50,000 compiled in 1990-1991 from aerial photography and were verified and completed in 1992-1993. El-Fayoum area is covered in ten sheets. The main features are digitized (drainage and irrigation network, administration boundaries). The boundary for the catchment area of El-Batts drain is obtained from EPADP. The location of the WWTP’s and WTP’s outfall, which is obtained from the NWRP project survey, is added to the features of
the base map. The water quality monitoring locations are distributed over the drainage and irrigation system of El-Fayoum is defined using Global Position System (GPS) technique and loaded to the base map.

Drainage and irrigation network consist of two main drains (El-Batts and El-Wadi drain) and three irrigation canals (Bahr Wahbi, Bahr El-Nezle and Bahr El-Gharaq). The feature class is Line

Administration Boundary Theme consists of five districts (Fayoum, Tamiya, Ibshaway, Senoures and Itsa). The feature class is Polygon.

Water quality monitoring stations Theme consists of 12-location distribution over the drains and canals. The feature class is Point.

Waste water treatment plants Theme consists of 41 plants. The feature class is Point. Water treatment plants Theme consists of 32 plants. The feature class is Point

Industrial zone Theme consists of one industrial zone at Kom-oshim. The feature class is Polygon.

The geo-database is constructed within the ARC-GIS package based on a relational database. The attribute data is classified to references data such as the water quality laws, treatment methodologies, information of water quality monitoring stations, .. etc. Basic data such as units, governorates districts, irrigation sectors, .. etc., computable data such as water quality analysis data for the monitored water bodies, water treatment plants and industrial plants.

**LINEAR REFERENCING MODEL**

Linear referencing model is defined as the total set of procedures for determining and retaining a record of specific points along linear features. It is applied to visually represent features on a map which coordinates are not geographic, but are recorded as relative along another linear feature, led to development of dynamic segmentation. The data is linearly referenced; multiple sets of attributes can be associated with any portion of an existing linear, independent of its beginning and ending. In this study the ROUT model is applied on El-Batss drain. The drain is divided to dynamic segments, two events are defined the modeled water quality parameters concentrations and eutrophication ratio (TN/TP). The modeling output is captured, stored in the geo-database and linked back to the geographically referenced drain. Estimating the percentage of the WWTP’s flow to the drain flow is ranged from 6.0% to 10.0 % and TN/TP is ranged from 8.0 to 11.0 % that mean the limiting nutrient at this reach of the drain.
CONCLUSIONS

- GIS has been utilized in the storage and retrieval of attribute data such as water quality parameters (pollution loads), population density and fertilizer consumption over the spatial database (map) of El-Batts drain catchment. This geo-database is useful in monitoring the trend of pollution load and population growth in the entire drainage catchment.
- The suggested framework for the spatial modeling approach is fairly better in terms of pollution control.
- Applying linear referencing technique enables displayed, queried, edited and analyzed without affecting the drain geometry.
- The Ratio of TN/TP is ranged between 8.5 to 11.0 over the three monitoring stations. The TN/TP ratio at FB09 is less than 10 due to the highly dumping flow from OLD and New Fayoum.

REFERENCES

5- UNDP 2003, Fayoum Human Development Report, Cairo, Egypt.