Gravel-bed filtration system for improving Noubaria canal water quality.

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Abstract
The treatment of Noubaria canal water was investigated through a new constructed pilot treatment system as a pretreatment to reduce chemical addition. This system included sedimentation tanks and biological Aerated filter (BAF) under full aeration condition. In the present investigation, gravel (2 – 5mm) was selected as a filtering material for removal of pollutant due to it is local materials, stability and possibility of biofilm formation. During 2 years of operation, the influent flows and quality were changed to determine the optimum operating conditions. This study aimed to evaluate the role of influent quality, operation modes and retention times on the removal efficiency of different pollutants as result of BAF treatment system on canal water. After, ripening period (60 days), the total algal species with gravel bed filter were reduced by 84%, 91% and 93% under flow rates 0.05, 0.025 and 0.017 L/sec, respectively. Also, results showed that, biological aerated filter system and flow rate of 0.05 L/sec could successfully improve water quality as indicated by reduction in concentrations of turbidity, suspended solids, COD and BOD₅. The combination of three treatment stages was almost totally responsible for the overall observed reduction. The effluent water can be safely used in domestic and industrial activities.

Key words: Noubaria canal water, biological aerated filter, algal and microbial indicators

Introduction
Noubaria canal runs for 100 km between starting point and the discharging point at Mediterranean Sea, Alexandria, Egypt. The Canal is connected with many agricultural drains where organic pollutants and drainages influence the nutrient
cycles significantly. Although canal water Canal is affected by drains discharge, all parameters of raw water still comply with Egyptian Standards and WHO guidelines as resources. Also, water scarcity and climate change are all having an impact on technology and investment trends and leading to the implementation of more water treatment.

Currently, Alexandria Water Company (AWCO) employs conventional treatment processes, including prechlorination, coagulation, sedimentation, rapid sand filtration, and disinfection for its water treatment. The conventional treatment processes could not completely remove the metabolites of algae or other microorganisms and chlorination by-products. The disagreeable taste and odor of the treated water are major problems for AWCO. In addition to the taste and odor problem, the high hardness of the water is another complaint of the customers, although the treated water of AWCO meets the current drinking water quality standards in Egypt.

Pre-chlorination process is a conventional and widely applied pre-oxidation technique for algae removal, but chlorination of algal-laden water can produce DBPs (Zhi-gang et al. 2010). Enhanced coagulation is shown to remove organic matter effectively. Hence, trihalomethane formation potential (THMFP) and haloacetic acid formation potential (HAAFP) are reduced (Liang and Singer 2003). But high coagulant dose required in enhanced coagulation process contributes to the high alum or iron content in water distribution system.

As a result of mixing of Noubaria canal water with drainages, the organic compounds load has many forms which play significant roles in the water quality. Besides the literature lacks information on formation of organic chloramines produced from chlorination or chloramination of naturally occurring nitrogenous material and is only
available for a limited range of model nitrogenous organic compounds (e.g., amino acids, heterocyclic N compounds, peptides, proteins) (Gopina, 1994; Lee and Westerhoff, 2009). Chlorination of algal cells has been reported to produce trihalomethanes (THMs) and haloacetic acids (HAAs).

A biologically aerated filter (BAF) with local materials is a novel, flexible and effective bioreactor that provides a small footprint process option at various stages of water treatment (Pujol et al. 1994 and Percival et al. 2000). BAF based on the principle of biofiltration through a submerged granular medium that serves two purposes: biological conversion of organic matter and physical retention of suspended particles by filtration. Fewer odors, modular construction and automated operation could be other advantages for such a process (Pujol et al. 1998). Also, the selection of a suitable BAF media such as gravel is critical in the design and operation of the process, to enable the required effluent standards to be reached.

To decrease prechlorination dosages for water treatment, the pilot plant has been constructed. The aim of this work was to optimize the removal efficiency of physical, chemical microbial and algal species loads by a constructed biological aerated filtration system without addition of any chemicals. Studying the factors affecting treatment though many indictors was investigated. A comparison between different water flow rates, quality and water directions and the effluent quality was run under different operation indicators.

**Materials and Methods**

The pilot plant consisted of three glass chambers (two sedimentation tanks and BAF unit) as show in **Fig.1** and received 140 liters daily. The both sedimentation tanks were 40* 50*50 cm (W*L*H). To control water level and prevent short circuits, the first
sedimentation tank had barrier in the middle but the second had barrier which divided the tank by 2:1. The BAF unit was 40* 40*50 cm (W*L*H) which filled with gravel particles with approximate equivalent diameters of 2-5 mm. The water height in all system was 45 cm and dissolved oxygen of 5 mg/l in the system was maintained.

During operation, water flow rates and its direction were changed in nine test experiment runs to determine the optimum conditions. The ripening period of filter was studied before each mode operations (as first treatment stage) and the effect of water flow on the effluent quality was studied (as second treatment stage). Three different modes of flow rates 0.05, 0.025 and 0.017 L/sec were used as shown in Fig. 1.

![Figure 1](image_url)
2.1. Water samples

The composed samples of surface water were collected from Noubaria canal, Ameria region, Alexandria, Egypt. Firstly, for Noubaria canal water assessment, the samples were obtained monthly through different seasons from March 2008 to Jan 2010. Secondly, for plant treatment performance assessment, the samples were obtained daily from Jan 2010 through December 2011 for using in flow rate control unit as influent for new constructed plant. All physical, chemical, algal and microbial parameters were measured. All experiments were run in three duplicates.

2.2. Physical and chemical analyses of water resource samples

The quality of resource water samples was determined after some measurements such as temperature (°C), pH, electrical conductivity (EC) as (µS/cm), Dissolved oxygen (DO) as mg/l, Turbidity as Nephelometric turbidity units (NTU), Chloride (mg/l), Total alkalinity(mg/l), Total Hardness (mg/l), Silica (mg/l), phosphate(mg/l), Sulfate (mg/l). The pollution indicators such as Chemical Oxygen Demand (COD) as mg/l, Biochemical Oxygen Demand (BOD₃) as mg/l and Total Suspended solids (TSS) as mg/l, and Total dissolved solids (TDS) as mg/l were measured. All the physical and chemical analyses were determined by the procedures recommended in the Standard methods for the examination of Water and Wastewater (APHA, 1998).

2.3. Microbiological analyses of water samples

Nutrient agar was used for the total bacteria count and presented as CFU/ml. Detection of total and fecal coliform groups was based on growth on M-Endo broth and m–FC broth (Difco), respectively and presented as CFU/100ml. Membrane filter technique was used for detection according to standard methods (APHA, 1998).
2.4. Water algae analysis

The 1 L sample in dark brown glass was concentrated by centrifugation at 1000 rpm for 20 minutes. The settled sample concentrate was agitated and the sub-sample was withdrawn with a one ml accurately calibrated pipette. A counting cell (Sedgwick Rafter) was used under microscope supplied with video camera (Sony, Japan). The calculation and classification of sample were according to APHA (1998) as shown in Tab. 1.

Calculation:

\[
\text{No/ml} = \frac{C \times 1000 \text{mm}^3}{A \times D \times F}
\]

Where: \(C\) = number of organisms counted, \(A\) = area of field (Whipple grid image area), \(D\) = depth of a field (Sedgwick-Rafter cell depth), mm., \(F\) = number of fields counted.

Tab.1 Classification of algal species according to its origin (APHA, 1998).

<table>
<thead>
<tr>
<th>Filter clogging algae</th>
<th>Taste and Adour algae</th>
<th>Polluted water algae</th>
<th>Blue-green algae</th>
<th>Waste water algae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melosira</td>
<td>Cyclotella</td>
<td>Oscillatoria</td>
<td>Anabaena</td>
<td>golenknia</td>
</tr>
<tr>
<td>Synedra</td>
<td>Synedra</td>
<td>Anacystis</td>
<td>Anacystis</td>
<td>ankistrodidesmus</td>
</tr>
<tr>
<td>Diatoma</td>
<td>Asterionella</td>
<td>Microcystis</td>
<td>Cylindrospermum</td>
<td>chodatella</td>
</tr>
<tr>
<td>Cyclotella</td>
<td>Pediatrum</td>
<td>Anabaena</td>
<td>Nostoc</td>
<td>cosmarium</td>
</tr>
<tr>
<td>Fraillaria</td>
<td>Anabena</td>
<td>Cylindrospermum</td>
<td>Oscillatoria</td>
<td>Schroederia</td>
</tr>
<tr>
<td>Colstrium</td>
<td>Staurastrum</td>
<td>Nostoc</td>
<td>Microcystis</td>
<td>Scenedesmus</td>
</tr>
<tr>
<td>Anabena</td>
<td>Chamydomonas</td>
<td>Meresrompedia</td>
<td>Meresrompedia</td>
<td></td>
</tr>
<tr>
<td>Oscillatoria</td>
<td>Anacystis</td>
<td>Spirulina</td>
<td>Spirulina</td>
<td></td>
</tr>
<tr>
<td>Asteronella</td>
<td>Gomphosphorea</td>
<td>Geleocapsa</td>
<td>Geleocapsa</td>
<td></td>
</tr>
<tr>
<td>Chorella</td>
<td>Pandorina</td>
<td>Tetradron</td>
<td>Gomphosphaeria</td>
<td></td>
</tr>
<tr>
<td>Navicula</td>
<td>Synura</td>
<td>Nostoc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monoraphidium</td>
<td>Scenedesmus</td>
<td>Nitzchia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staurastrum</td>
<td>Chlomydomonas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pediatrum</td>
<td>Phacus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spirogyra</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Results and Discussion

Noubaria canal is belonging to Alexandria, northern Egypt, being a subtropical area, the canal water temperature varied from summer to winter seasons. At the sampling site of the canal, there was complete mixing with other irrigation drainages with water. The impact of untreated drainage sources from the aquaculture and Industrial activities and long path way for 100 km was investigated. Chlorination of raw surface water is a general practice in conventional water treatment to control bacterial and algal growth. The averages of different water quality parameters during the two years examinations were examined. In general, it could be concluded from these results that the values of all parameters slightly change through studying period.

Tab. Physio-Chemical and pollution indicators analyses of Noubaria canal water through March 2008 to Jan. 2010.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Average</th>
<th>Max</th>
<th>Min</th>
<th>SR*</th>
<th>Parameter</th>
<th>Average</th>
<th>Max</th>
<th>Min</th>
<th>SR*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp</td>
<td>23.81</td>
<td>30.6</td>
<td>19.4</td>
<td>1.78</td>
<td>TDS mg/l</td>
<td>356</td>
<td>566</td>
<td>260</td>
<td>33.7</td>
</tr>
<tr>
<td>EC</td>
<td>605</td>
<td>1110</td>
<td>434</td>
<td>62</td>
<td>TSS mg/l</td>
<td>7.65</td>
<td>18.5</td>
<td>2.6</td>
<td>2.74</td>
</tr>
<tr>
<td>Turbidity</td>
<td>15.7</td>
<td>43.1</td>
<td>7.9</td>
<td>5.3</td>
<td>DO mg/l</td>
<td>5.47</td>
<td>5.8</td>
<td>5.1</td>
<td>0.18</td>
</tr>
<tr>
<td>pH</td>
<td>8.19</td>
<td>8.39</td>
<td>7.96</td>
<td>0.08</td>
<td>BOD₅ mg/l</td>
<td>14.4</td>
<td>22</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>Chloride</td>
<td>59.2</td>
<td>152</td>
<td>35.4</td>
<td>8.8</td>
<td>COD mg/l</td>
<td>37.2</td>
<td>45</td>
<td>15.9</td>
<td>2.6</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>144</td>
<td>186</td>
<td>130</td>
<td>6.4</td>
<td>BOD₅/COD</td>
<td>0.315</td>
<td>0.356</td>
<td>0.252</td>
<td>0.029</td>
</tr>
<tr>
<td>T. Hardness</td>
<td>160</td>
<td>234</td>
<td>133</td>
<td>10.6</td>
<td>Total H. count CFU/ml</td>
<td>4785</td>
<td>65000</td>
<td>580</td>
<td>8413</td>
</tr>
<tr>
<td>Silica</td>
<td>2.83</td>
<td>7.79</td>
<td>0.82</td>
<td>1.14</td>
<td>Total coliform CFU/100ml</td>
<td>2370</td>
<td>12000</td>
<td>400</td>
<td>1813</td>
</tr>
<tr>
<td>Phosphate</td>
<td>0.20</td>
<td>0.54</td>
<td>0.04</td>
<td>0.13</td>
<td>Fecal coliform CFU/100ml</td>
<td>287</td>
<td>1200</td>
<td>40</td>
<td>165</td>
</tr>
<tr>
<td>Sulfate</td>
<td>108</td>
<td>148</td>
<td>87</td>
<td>17.8</td>
<td>Total algae (unit/l)</td>
<td>1382055</td>
<td>3076630</td>
<td>425010</td>
<td>500991</td>
</tr>
</tbody>
</table>

*SR: Standard error

3.1. Water resources assessment

Noubaria canal water characteristics and their variations are summarized in Tables (2) and Fig. 2. These included the monthly average concentrations of temperature, pH, D.O, TSS, COD, BOD₅, three total nitrogen forms (NH₄-N, NO₂-N and NO₃-N) and turbidity during the two years examinations. The canal water temperature varied from summer to
winter seasons, where the temperature of the water was ranged between 30.6 and 24.6 °C (summer), 22.1 and 19.4°C (winter) with an average 23.81°C. The pH levels were quite stable ranging between 7.96 and 8.39. The sulfate of the water was ranged between 94.3 mg/l (summer) and 134.6 mg/l (winter) with an average 108 mg/l. The seasonal averages of T. Hardness and T. alkalinity was ranged between 155, 139 (summer) and 204.5, 166 mg/l (winter), respectively. The phosphate concentration averages ranged between 0.155 (summer) and 0.389 mg/l (winter). The rather limited effect of temperature on trihalomethanes yield attained due to the variation in the nature of organic precursors of algae and bacteria found in raw river water (EL-Dib and Ali, 1995).

The Chemical Oxygen demand (COD) and Biochemical Oxygen demand (BOD₅) in mg/l are an indication of pollution. At sampling site, the COD varied between (15.9 to 36.3 mg/l during summer months with an average 34.3 mg/l while it was higher during the winter seasons (36 – 45 mg/l) with an average 38.7 mg/l. BOD₅ was low in the range of 4 and 20 mg/l but increased to 22 mg/l (May and June 2008). Thus, a Biodegradability ratio (BOD₅/COD) of Noubaria canal water was very poor. As physical pollution indicators, the TSS concentrations were low 2.6 – 6.09 mg/l during the summer period but increased in the range of 10.77 – 18.5 mg/l for the winter seasons (Nov. to March). Also, the TDS was very low and matched with BOD₅ and COD. Also, the other water levels of dissolved salts as chlorides, silica, alkalinity, total Hardness, phosphate and sulfate were determined before the experiments run and represented in Tab. 2. At the end of canal that represented the net mixing of water resources, the change in water quality was insignificant throughout the different sampling time. The impact of drained water was limited because the drains volume was very low compared to the canal water.
In the same period, the ammonia nitrogen concentrations were ranged between 0.39 and 1.55 (summer), 2.25 and 3.84 (winter) mg/l. Canal water D.O levels generally remained at 5.48 mg/l during the summer seasons and decreased to 5.28 mg/l during winter seasons because the water volumes of summer were more than the winter seasons. The nitrite and nitrate nitrogen concentrations were ranged from 0.056 and 1.59 (winter), 0.036 and 1.025 (summer) mg/l respectively as shown in Fig. 2. Bougard et al., (2006) explained the relationships between different nitrogen forms thus the inhibition effect on nitrification may be mitigated on higher free ammonia (FA) concentrations. The FA inhibition by itself, as a sole measure, might not be an effective and sufficient strategy to maintain stable nitrite accumulation in a longer perspective (Rongsayamanont et al., 2010). Therefore, an appropriate combination of several control parameters such as DO and FA concentrations, water flow rates and temperature is needed (Zekker et al., 2011).
Fig. 3 shows the averages of algal species of Noubaria raw water that used in new design pilot plant in unit/L as influent. The most dominant algal species were Cyclotella, Diatoma, Synedra, Melosira, Pediastrum, Scenedesmus, Nitzchia, Oscillatoria, Meresrompedia and Chorella and their represented average percent were 31.2%, 25.7%, 11.3%, 11.2%, 6.2%, 3.9%, 2.0%, 1.6%, 1.3% and 1.0%, respectively. The algal species were classified to five categories as Filter clogging algae, taste and adour algae, polluted water algae, blue-green algae and waste water algae (APHA, 1998). Also, algal blooms cause water quality problems in water supplies including obnoxious taste and odors and the release of algal toxins In addition, algal cells can serve as precursors to form disinfection by-products (DBPs) during chlorination (Niquette, et al., 1998; Knappe, et al., 2004).

3.2. Water treatment without filtration
The decreasing of water flow rate appeared to have a positive effect on suspended solids removal efficiency. It is clearly obvious for water treatment without filtration with decreasing in water flow from 0.05 to 0.017 L/sec that led to better remove of target pollutants. The influent and effluent turbidity and TSS concentration showed significant correlation. For example, average turbidity removal efficiencies with water flow of 0.05,
0.025 and 0.017 L/sec. were determined to be 10.6%, 12.5% and 22.7%, respectively. Also, the results indicated that influent contained all species forms of five algal categories. The concentration of algae in influent varied and the sedimentation process was responsible for removal of total algae by 58.7%, 16.6% and 13.8% at 0.017, 0.025 and 0.05 L/sec flow rates, respectively as shown in Fig. 4. At high flow rate, the resuspension phenomenon of filter clogging and taste and adour algae was noticed.

Fig. 4 removal efficiency percent of different algal categories and total count of algae through treatment system without filter under different flow rates (0.05, 0.025 and 0.017 L/sec).

The fractions that precipitated had a relatively constant concentration and its removal via sedimentation depended on water flow and algal species. The decreasing in water flow was achieved better treatment for all parameters but need more area for treatment. So, the treatment with filtration is the sole solution to reduce area for good water treatment.
Fig. 5 Turbidity removal efficiency% through water treatment system (with and without gravel filter) under flow rates (0.05, 0.025 and 0.017 L/sec).

3.3. Water treatment with filtration system

The results showed that significant removal percent of water turbidity in gravel bed filters compared to treatment without filtration. According to the sedimentation and filtration processes that took place, the maximum and constantly removal efficiencies of turbidity were achieved after 60 days of operations that represented filter ripening period. Zekker et al., (2011) have investigated that the laboratory-scale experiments conducted with reject water of sludge treatment that showed it is possible to ripening the filter biofilm in 37 days by a combination of low flow rate, time controlled intermittent aeration and a low DO concentration and, furthermore, by increased influent nutrient contents. Zhi-gang et al. (2010) reported that sedimentation decreases 13% of the chlorine demand. More organics removal will lead to more chlorine demand reduction.
Fig. 6 removal efficiency percent of different physio-chemical parameters through gravel bed filtration system under different flow rates.

The BAF water treatment system needs to be designed to meet the applicable discharge requirements with a high degree of reliability. So, the selection of a suitable BAF media is critical in the design and operation of the process, to enable the required effluent standards to be reached (Moore et al., 1999). The size of a BAF medium also has a strong influence on process performance. Consequently, different sized media have been recommended for different applications (Mendoza-Espinosa, and Stephenson, 1999).

Fig. 7 removal efficiency percent of different algal categories through gravel bed filtration system under different flow rates.
Vigne et al. (2011) have mentioned that the filtered suspended solids and the excess biomass grown during the treatment phase were removed by backwashing. The accumulation of the protozoan parasites and algae is undesirable because they may cause serious pollution and infection in the case of failure or malfunction of sedimentation and rapid sand filtration processes (Weiying et al. 2010). Acceptable values of NH$_4$-N, NO$_2$-N and NO$_3$-N were recorded throughout the treatment and comply with Egyptian guidelines. Cyrus and Reddy (2010) and El-Masry et al. (1995) have mentioned that at low flow and the Variation in flow rate did not influence the filter desorption process.

**Conclusions**

*Effect of water flow direction*

Through filtration process, two water flow modes were used as down to up and up to down as shown in Fig. 1. In case of down to up direction, the suspended solid and algae were precipitated in front of the filter. So, E.C. levels of effluent increased under flow rate of 0.017L/sec. Increase in THMs yield by rise of temperature was indicated by the present study (Fig. 4) as well as by other investigators (Vymazal, 2006; Gunes and Tuncsiper, 2009; Mousa and El-Rakshy, 2010). The rather limited removal differences of water flow direction on effluent yield attained by this work is most probably due to the variation in the nature of organic content found in raw river water as shown in Figs (6-7).

*Effect of influent quality*

At different influent quality, the frequencies of effluent characteristics show lower values in case of filtration (Fig. 4). However, effluent properties were not directly proportional to the applied influent. Data given in figs 3-4 indicate that the influent contained different five categories of algae with different concentrations. Also, there were variations in turbidity and with very minute dissolved salts. The gavel filtration
had good removal efficiencies for algae, Turbidity and free ammonia. In case of
dissolved salts such as Chloride, Phosphate and sulfate, the removal efficiencies
varied according to its concentrations but still more controllable. In case of microbial
indicators, the removal was a function for water flow rates, influent constituents and
filter media biofilm. Also, these indices represented the microbial load of influent
that could help in biological treatment of pollutants.

**Effect of retention time**
Concentration levels of different pollutant indicators removed through gravel bed
filtration system on raw canal water samples at various contact times are presented in
Figs. 5-7. Removal of Turbidity, algal species and physiochemical concentrations
progressively increased as the flow rate was reduced from 0.05 L/sec to 0.017L/sec.
Increase in removal efficiency, as the flow rate was decreased, has been revealed at
the various turbidity, algal categories and physiochemical properties investigated.
Such a trend confirms that previously with reported by Hamoda *et al.* (2004) and
Rahaman *et al.* (2008). At different flow rates, the gravel bed filtration removal
efficiency increased by 67.45%, 68.44% and 61.7% for 0.017L/sec, 0.025 L/sec and
0.025 L/sec, respectively. The water flows had a positive effect on the removal
efficiency of Total heterotrophic count. In case of total coliforms, both treatment
processes (sedimentation and filtration) had insignificant differences between influent
and effluent.

The assessment of BAF treatment system regarding the removal of total algae,
Turbidity and pollution indicators to the following conclusions:

1- The effect of each process varied from one parameter to another but the
combination of the sedimentation/filtration/ sedimentation system was
responsible for the major part of the observed removal.
2- The results of Noubaria canal water assessment showed that the variation in water quality was limited and the main variable was total algae.

3- The measurement of biodigrability

4- According to the influent flow rate

5- Treatment with new design BAF system reduced total algae that demand chlorine.

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