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Reuse of Wastewater Treated Effluent by Lagoon for Agriculture and Aquaculture Purposes

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Abstract: Municipal wastewater treatment via biological techniques was the subject of this study. An integrated treatment scheme under investigation, includes two basins, the first one was aeration tank followed by classical sedimentation tank to reduce the organic load and to remove the suspended solids. The post treatment is the use of algal pond to oxidize ammonia to nitrate. The pilot plant was designed to treat 0.144 m^3/ day. The results obtained showed that, overall removals were very good and gave high quality effluents amenable for disposal into surface water or to reuse for agricultural and aquaculture purposes. Average residual of COD, BOD_5 and suspended solids concentrations were 70 mgO_2/L and 38 mgO_2/L and 25 mg/L, respectively. However, the overall percentage removal values were 91.1, 90.1 and 94.6%, respectively. Also, complete nitrification was took place. Significant improvements in the micro-biological quality of the effluent were obtained. Faecal coliform density has been declined by 10 logs. The final effluent of the series complied with the recommended F.C. count of less than 1000 per 100 ml for unrestricted irrigation. Toxicity to fish was completely eliminated.

Key words: Domestic wastewater treatment, Algal pond, Effluent quality, Reuse, Phosphate uptake, Fish culture, Irrigation.

INTRODUCTION

Wastewater is widely recognized as a significant, growing and reliable water source. Wastewater production is the only potential water source which will increase as the population grows and the demand on fresh water increases. Therefore, intensive and safe wastewater treatment and reuse schemes should be practice on a large scale in the Mediterranean region and especially in the Middle East. Use of treated wastewater in agriculture and Landscaping purposes is common in many countries such as Tunisia, Egypt, Jordan, and Syria. Water resources management strategies in these countries consider wastewater as part of the water budget (World Bank, 1996).

During the last two decades, the reuse of treated wastewater for agricultural irrigation has expanded, especially in arid and semi-arid regions, helping to relieve water scarcity and improving the means for local food production (Blumenthal *et al*., 2000). The use of domestic wastewater for irrigation is advantageous for many reasons including water conservation, ease of disposal, nutrient utilization, and avoidance of surface water pollution. Nevertheless, it must be borne in mind that although the soil is an excellent adsorbent for most soluble pollutants, domestic wastewater must be treated before it can be used for crop irrigation to prevent the risk to both public and the environment (Mohammed, 2006). Stabilization ponds, high-rate algal ponds and macrophytes are three low-cost treatment systems to be applied. Waste stabilization ponds have been widely studied and there is a great deal of information concerning the removal of BOD_5, nutrients, as well as pathogenic bacteria (Mara, *et al*, 1992). Algal pond is considered an efficient treatment system for controlling wastewater pollution by reducing the organic matter, the inorganic nutrients and parasitical load (Ouazzani *et al*, 1995). The removal of phosphates is of great importance in relation to eutrophication. Most of the treatment plants in the East Mediterranean use activated sludge process. These sophisticated technologies were developed to reduce the suspended solids load and oxygen demand of the discharged water, but these are not efficient for the removal of pathogens. Balluz *et al*, (1977) studied the performance of activated sludge plant for removing suspended solids, viruses and other pathogens. The main objective of this study is the development and evaluation of an appropriate technique for municipal wastewater purification to reduce an effluent suitable for different reuses.

MATERIAL AND METHODS

Location of the Study:

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The treatment units are located at a site in the National Research Center in Cairo, within a residential area where a connection to the sewerage system was available.

Biological Systems:

Tow prototype biological treatments were designed and manufactured for this purpose (Figures 1, 2). The first unit was a compact one based on a completely mixed activated sludge which contains approximately 0.042 m^3 of municipal wastewater followed by a classical sedimentation tank. The system was fed continuously with raw sewage at a constant hydraulic load of $2.2m^3/m^2$/day. The post treatment was an algal pond. It consists of a mixing chamber coupled with a sedimentation part. The system is equipped with diffused aeration system which provides necessary oxygen and required mixing. The process was started by seeding the pond with phytoplankton collected from the River Nile water after, being concentrated via phytoplankton net. The unit was fed continuously with the biologically treated effluent from the activated sludge system at a constant hydraulic and BOD_5 loads of 0.08 m^3/m^2/d and 0.044kg/m^3/d, respectively. The retention time was three days.

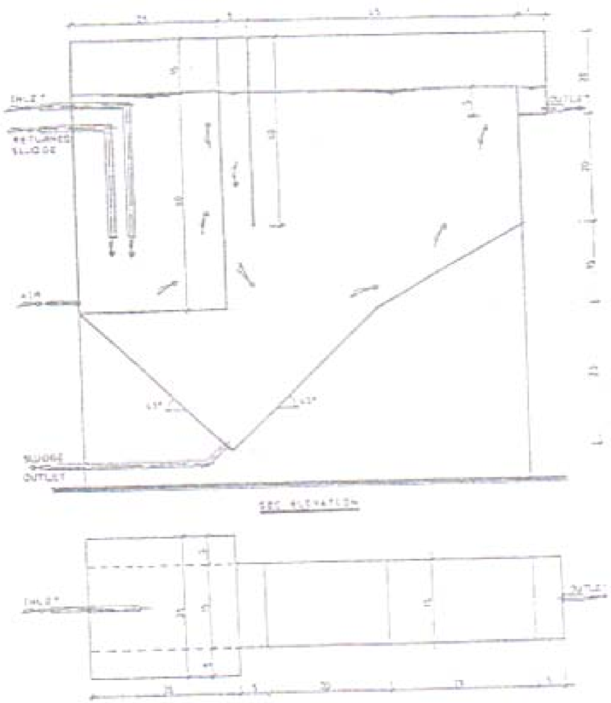

Fig. 1: Activated Sludge Unit with P. Settler.

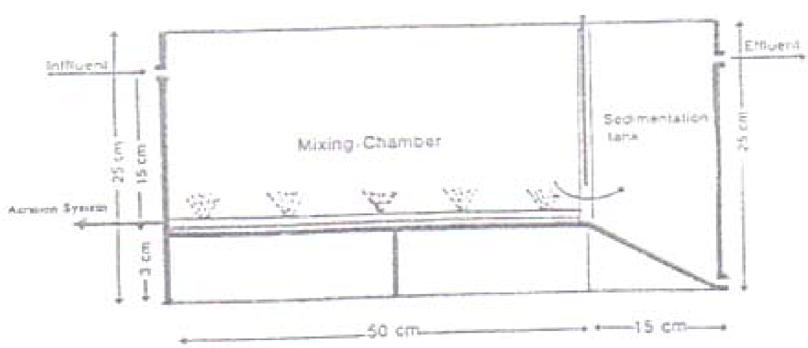

Fig. 2: Schematic Diagram of the Continuous Tank.

Analysis:

The performance of the system was evaluated by monitoring the quality of the raw wastewater and effluents of treatment units. Analyses were performed on composite samples. All physic-chemical and micro-biological examinations were carried out in accordance with the Standard Methods (2005). Bio-mass production was monitored daily by determination of chlolophylls (a, b, c) contents from the mixing chamber using spectrophotometric method according to APHA (2005) and the changes in the community structure according to the key of the fresh water algae (Streble and Krauter 1978). Total protein content was measured according to Chapman and Pratt (1978). Total carbohydrate content was estimated as glucose using the spectrophotometric method described by Dubois *et al*, (1956).

Statistical Analysis:

Statistical analysis was established applying regression coefficient according to Ezakel and Fox (1957).

Fish bio-assay:

Static bio-assay tests were conducted on raw and biologically treated effluents using the Nile Fish *Oreochromis Niloticus*. The fish were held in glass containers filled with aerated Nile water. They were maintained under these conditions for at least two weeks without mortality before toxicity tests were carried out. The median tolerance limits (TL_{50}) were derived from the graphic interpolation of mortality percentage against concentration. The bio-assay method adopted in the present investigation was described by El-Gohary *et al*, 1989.

RESULTS AND DISCUSSION

1-Physico-Chemical Characteristics of Raw Wastewater:

The results obtained from the analysis of twenty nine composite samples are presented in Table (1). It has been found that the raw wastewater COD, BOD_5, solids, total nitrogen and phosphorous contents were relatively high. Available data indicated that suspended solids ranged from 260 to 780 mg/L and it involved 39% of the total solids content. The BOD_5 values of wastewater was around 383 $mg0_2$/L. corresponding average COD values was 791$mg0_2$/L (Figs. 3, 4). Around 71% of COD and 64% of the BOD_5 were in a particulate form. Mean total phosphorus concentration was 9.9 mg p/L. The concentration of oil and grease was also high. It ranged from 60 to 210 mg/L with an average value of 104 mg/L. Geometric mean of Total coliform and Faecal coliform were5.4 × 10^{13} and 8.4 ×10^{12}, respectively.

Table 1: Efficiency of Biological Treatment Unit.

Parameter	Unit	Raw Municipal Wastewater		Treated Effluent for Activated Sludge		Treated Effluents For Algal-Pond		Overall removal
		Range	**Average	Range	**Average	Range	**Average	
PH Value	-	6.9-7.8	-	7.2-7.5	-	7.5-9.3	-	
COD	mg O_2 /L	593-1305	791	202-288	205	50-83	70	91.1
COD Soluble	mg O_2 /L	222-350	226	68-124	85	40-77	55	75.6
BOD_5	mg O_2 /L	220-690	383	89-165	111	14-68	38	90.1
BOD_5 Soluble	mg O_2 /L	57-190	136	26-85	53	6-36	20	85.3
Ammonia nitrogen	mg N /L	17-27	22	11-19	11.5	0.0-0.0	0.0	100
T.K.N	mg N /L	22-35	30	16-26	20.7	10-21	16	46.6
Total Phosphate	mg P /L	5.6-17.5	9.9	4-6.6	5.5	2.8-4.6	3.4	65.6
Soluble Phosphate	mg P /L	2.6-9.2	6.2	2.6-5.4	3.9	2-4.4	2.8	54.8
T.S.S at 105°	mg /L	260-780	461	55-96	76	10-43	25	94.6
T.R at 105°	mg/L	750-1059	866	406-501	445	360-407	410	52.6
Oil & grease*	mg/L	60-210	104	***N.D	***N.D	***N.D	***N.D	100
Total Coliform	MNP-index/ 100ml	(1.7-1.1)x10^{14}	5.4 x 10^{13}	9x10^4-1.1x10^{11}		8.4x10^3-8x10^5		
Faecal Coliform	MNP-index/ 100ml	1.7 x10^{12}-1.1x10^{13}	8.4x10^{12}	2.1x10^4-4x10^{10}		2.1x10^3-4x10^5		

*Oil & grease and all extractable matter by chloroform. **Average results of twenty nine runs. *** Not detected

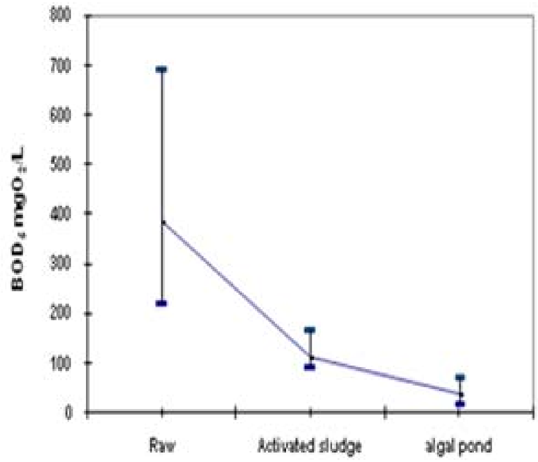

Fig. 3: Variation of BOD_5 Values along the treatment plant.

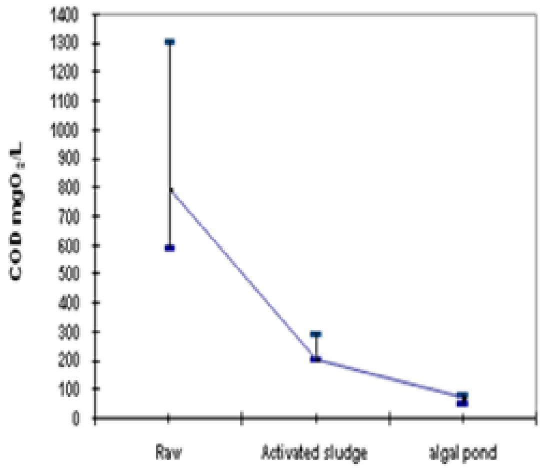

Fig. 4: Variation of COD Values along the treatment plant.

In general, the wastewater can be classified as above medium strength for physico-chemical characteristics, but as strong in terms of bacteriological parameters.

2-Efficiency of the Biological Treatment Units:

Physico-Chemical Analysis of Activated Sludge Effluent:

Available data indicates that the use of activated sludge system can achieve better results (Table 1). $BOD_{5\ tot}$, COD_{tot}, and suspended solids removal values averaged 69%, 70% and 68%, respectively. An improvement in $BOD_{5\ sol.}$ and COD_{sol}. of 67% and 61% has been recorded. Although considerable reduction in both COD and BOD_5 values were achieved, average residual ammonia and phosphorus was still high. They were 11.5 and 5.5 mg/L, respectively (Figs. 3-6). No nitrification has been recorded. Microbiological examination revealed a reduction in Total and Faecal Coliform counts ranging from 5.4×10^{13} to 9×10^4 and from 8.4×10^{12} to 2×10^4, respectively.

However, residual values of COD, BOD_5 and the bacterial indicators of pollution were exceeding permissible limits. To comply with the laws regulating discharge or reuse of wastewater, the effluent produced from the activated sludge process was subjected to algal pond.

Physico-Chemical Analysis of Algal Pond Effluent:

After almost two weeks, a steady state has been reached. The results obtained are recorded in Table (1). COD and BOD_5 removal values ranged from 84% to 95% and from 79% to 94%, respectively. Corresponding residual average values of 70mgO2/L and 38mgO2/L, respectively (Figs 3, 4). The mean value of suspended solids was 25 mg/L (Fig 5). Available data indicated complete nitrification of ammonia. Residual ammonia in the final effluent was almost not detected (Fig 6).

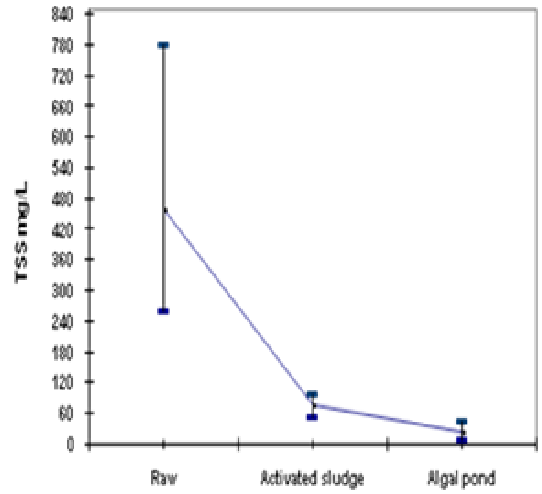

Fig. 5: Variation of TSS values along the treatment plant.

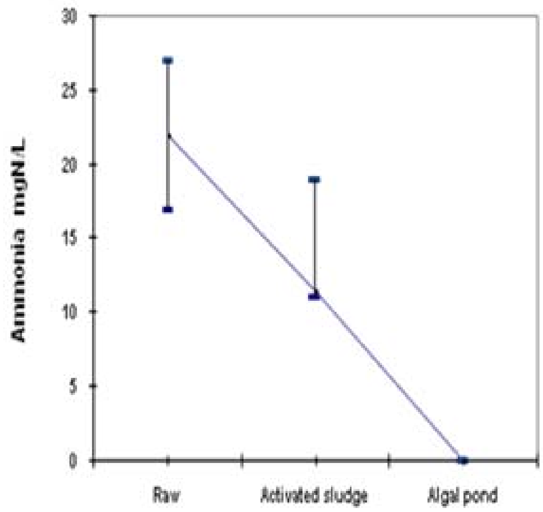

Fig. 6: Variation of Aminonia values along the treatment plant.

Residual phosphorus in pond effluent ranged from 2.8 to 4.6 mg/L. Nutrient removal through the algal pond is principally a function of assimilation into algal- bacterial biomass. The amount of nitrogen and phosphorus which may be removed from effluent by algal assimilation mechanism is dependent upon the intra-cellular contents of algal biomass and the amount of biomass which may be extracted as daily productivity or yield (Hensman 1986). Bacteriological examination revealed a reduction in the bacterial indices of pollution e.g. Faecal coliform was reduced by 10 log.

Algal Growth & Population:

Phytoplankton biomass determined as chlorophyll (a, b &c) is shown in Fig. (7). The produced biomass contained about 58.8% chlorophyll “a”, 16.6% chlorophyll ”b” and 24.8% chlorophyll “c” corresponding to 2.4:0.66:1 ratio. Changes in chl. “a”/ chl.”b”/ chl. ”c” ratio were detected throughout the experimental run. However, the chlorophylls ratio serves as a simple sensitive semi-quantitative of algal diversity. These can be correlated with the distribution pattern of algal population. On the other hand, positive correlation between protein, carbohydrate and chlorophyll “a” content of algal biomass took place (Fig.8). However, the maximum bio-mass (chl.”a” 2.9 mg/L) was equivalent to 38.5& 11.9 mg/gm of protein and carbohydrate of dry weight, respectively.

Community structure of algae in algal pond throughout the investigation period is demonstrated in Table (2). From the results obtained it may be shown that various algal species belong to four algal groups namely, *Chlorophylla*, *Euglenophyta* ,*Cyanophyta* and *Bacillariophyta*. The recorded four algal groups included 36 species, 15 species of *Chlorophyta*, one species of *Euglinophyta* 4 species of

Table 2: Changes in Community Structure in Algal Pond.

Algal Taxa \ days	Initial flora	5	10	20	30	35
Chlorophyta						
Actinastrum hantzschii	++	+++	++++	++++	+++	+++
Ankistrodesmus acicularis	+	+	+	++	++	++
Closterium poronum	±	±	±	+	++	++
Coelastrum microporum	±	±	±	+	+	+
Dictyosphaerium pulchellum	±	±	±	+	+	+
Eudorina elegans	±	±	+	+	+	+
Micractium pusilium	±	+	++	+++	++++	++++
Oocystis parva	+	+	+	+	+	+
Pandorina morum	±	±	±	±	±	±
Pediastrum duplex	±	±	±	+	+	+
Pediastrum simplex	+	+	+	+	+	+
Scenedesmus obliquus	±	±	±	±	+	+
Scenedesmus quadricauda	++	++	++	++	++	++
Selenastrum gracile	±	±	±	±	+	+
Spirogyra communis	+	±	±			
Euglenophyta						
Euglena viridis	+	+	+	+	+	+
Cyanophyta						
Cylindrospermum stagnale	++					
Oscillatoria mougeotti	++	++	++	+	±	±
Oscillatoria chlorina	+	+	+	±	±	±
Oscillatoria limnetica	+	±	±			±
Bacillariophyta						
Asterionella gracillina	±	±				
Cyclotella comta	++++	+++	++	++	+	+
Cyclotella glomerata	+	+	±			±
Diatoma elongatum	+++	+++	++	++	++	+
Fragilaria construens	±	±	±	+	+	+
Fragilaria capucina	±	±				
Gomphospheria olivaceum	±	±				
Melosira granulata	++	++	++	++	++	+
Melosira varians	+	+	+	+	+	+
Navicula cryptoccephata	±	±	±	±	±	±
Navicula gastrum	±	±				
Nitzschia linearis	++	++	+++	++++	++++	++++
Nitzschia filiforms	±	±	±	±		
Stauroneis anceps	±					
Surirella ovalis	±	±	±	±		
Synedra ulna	++	++	+	+	+	+

++++ Dominant +++Plenty ++ Many + Detectable ± Rare

Cyanophyla and 16 species of *Bacillariophyta* (Table 2 and Fig. 9). Shanthala *et al*, (2009) show that, total numbers of algae identified were 71 species belonging to *Cyanophyta, Chlorophyta, Euglenophyta, Bacillariophta and Desmidaceae*.

Bacillariophyta represented the most dominant groups in the initial flora. The most dominant species were *Cyclotella comta* and *Diatoma elongatum*. High species diversity was detected in *Chlorophyta*. The lowest diversity was associated with *Euglenophyta.*

During the experimental run no clear changes in diversity of *Chlorophyta* took place, *Actinastrum hanlzschu*, *Microactinum pusillum* and *Scenedesmus spp.* were the most dominant species. Shanthala *et al*, (2009) found that, the genera *Chlorella* and *Scenedesmus* were the dominant forms among the algal genera throughout the study period, where *Ankistrodesmus* and *Euglenoids* were found to be subdominant forms.

Succession of *Cyanophyta* appears to be evident only during the first days of operation, but gradually disappeared during the experiment. Also, *Bacillarophyta* were fairly common at the

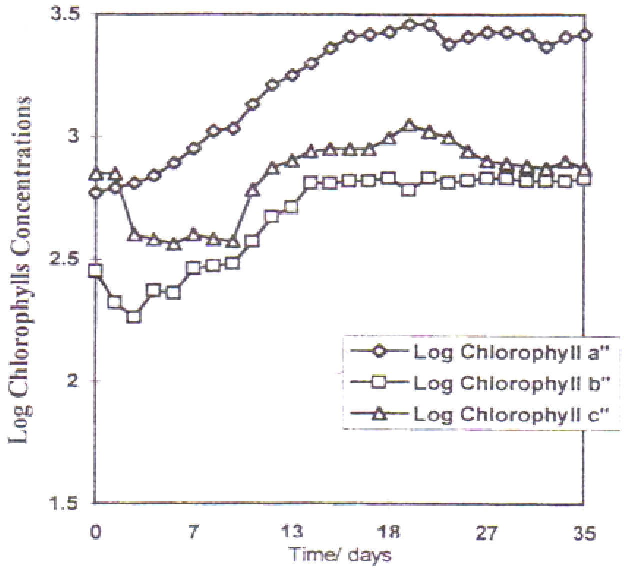

Fig. 7: Relationship Between Chlorophylls Concentrations.

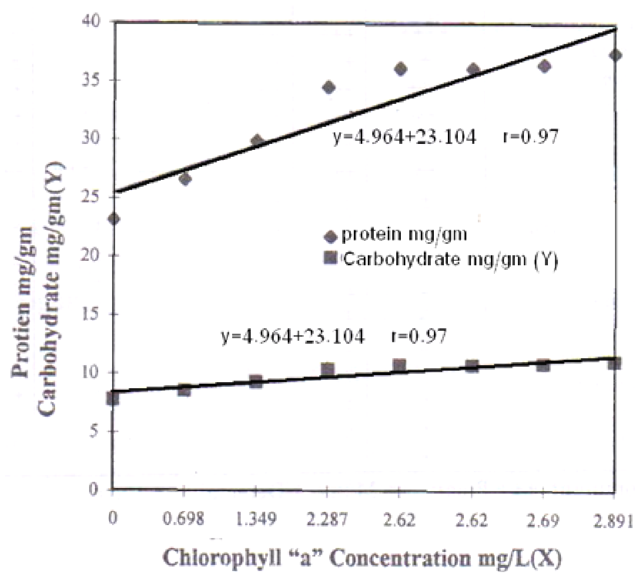

Fig. 8: Relationship Between Chlorophyll "a" Concentration, Protein and Carbohydrate.

beginning of the experiment and disappeared during the experiment and only *Nitzschia Linearis* was present in good number. Silva (1982) found that, the increase of the organic load led to the disappearance of some algal species while some species are not affected.

3-Fish Bio-Assay:

To evaluate the effluents of the different treatment units for fish production, a series of static bio-assay tests have been conducted for the inflow and outflow of each treatment step. Figure (10) shows the average TL_{50} values of raw and treated wastewater after 24, 48 and 96 h. These results clearly indicate the harmful effect of using untreated wastewater for fish culture. Also, they obviously manifest the damage which may occur if untreated wastewater is discharged to surface water. The negative impact may be attributed to the high concentrations of organic contaminants, which consume the dissolved oxygen for their bio-degradation and/or the high values of un-ionized ammonia (NH_3-N) as referred by many investigators (Baird *et al*., 1979 and El-Gohary *et al*., 1989).

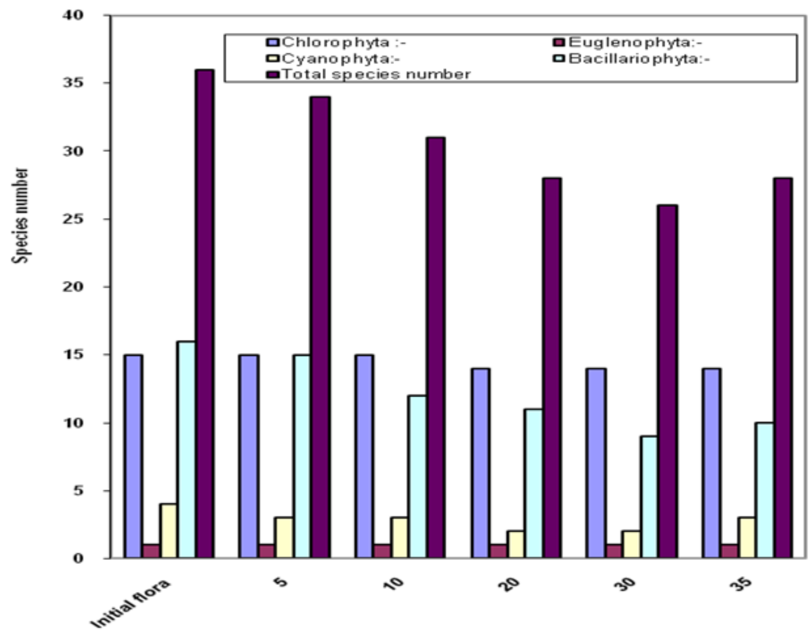

Fig. 9: Change in Algal species number in algal pond.

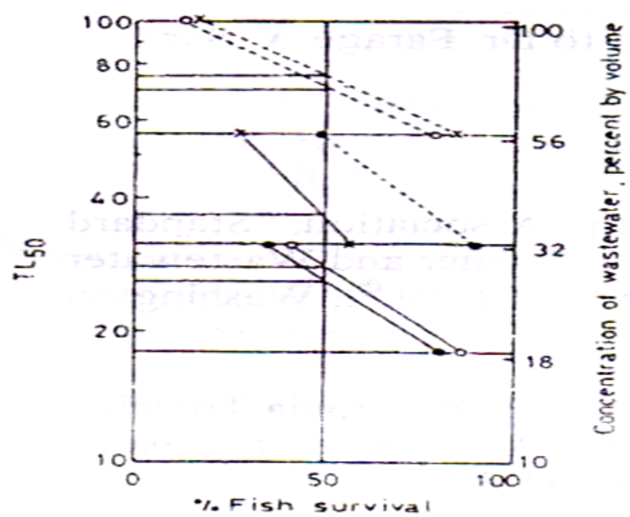

Fig. 10: TL50 for Raw and Biologically Treated Effluent.

Bio-assay tests for the outflow of the activated sludge unit showed an improvement in TL_{50} by 39% compared to the raw wastewater. However, this effluent cannot be discharged to any water body unless it is diluted to at least 4 times its volume with fresh water due to its high toxicity, arising from the high residual of (NH_3-N).

Biological treatment, via algal pond produced high quality effluent as the toxicity effect was completely eliminated. All fish survived over a period of 96 hours. From the previous data, it can be concluded that biologically treated wastewater can be used for fish culture without any dilution.

Conclusion:

From the results obtained, it may be concluded that:

- In general, the raw municipal wastewater can be classified as above-medium strength for physico-chemical characteristics, but as strong in terms of bacteriological parameters.
- Before the reuse of wastewater, treatment of sewage is necessary.
- Biological treatment via activated sludge produced a quality of effluent suitable for restricted irrigation in arid climate such as in Egypt. The residual ammonia and phosphorus serve as nutrients.

- Further biological treatment via algal pond proved to be a satisfactory technique for the removal of both organic and inorganic pollutants. Complete removal of ammonia was achieved and toxicity to fish is completely eliminated. The algal-pond effluent is suitable for unrestricted irrigation and/or fish culture.
- Harvested algae provide valuable protein source for animal fodder.
- Production of algae protein can contribute markedly to the livestock economy.

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