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Assessment of Ganabiet-Tersa Drain Wastewater Quality Improvement of by In-stream *Lemna gibba* Naturally Occurring System in Egypt

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ABSTRACT

Ganabiet-Tersa drain comprised a diverse phytoplankton flora represented by 86 species belonging to 30 genera and 5 algal classes namely; Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae and Cryptophyceae. Data revealed remarkable variations in the phytoplankton flora among different seasons. Chlorophyll a concentrations were positively correlated with phytoplankton standing crop. Duckweed (*Lemna gibba*) plant showed a high performance in the removal of nutrients and most other pollutants under natural field conditions. Total dissolved solids, electrical conductivity, total suspended solids, total alkalinity, biological oxygen demand, chemical oxygen demand, orthophosphate, phosphate, ammonia, nitrite, nitrate, calcium, potassium, magnesium, sodium, chloride, sulphate, zinc and aluminum concentrations were decreased between 4.4% - 100%. The effects of duckweed mat on reducing algal abundance and fecal coliform bacterial counts during different seasons were inconsistent.

Key Words: *Lemna gibba*; Phytoplankton; In-stream system

INTRODUCTION

Ganabiet-Tersa drain is a mixed drain from agricultural and sewage wastes and receives water from El-Moheet drain and Tersa Canal. It flows into El-Rahawy drain (mixed agriculture & sewage drain), which is far from El-Kanater (The Barrage) by about 15 km, El-Rahawy drain discharges directly into Rosetta branch of the River Nile. Ganabiet-Tersa drain length is 1.5 km and was stocked with naturally occurring duckweed (*Lemna gibba*) plants covering completely about 500 m of the drain length.

Fecal coliform bacteria may enter the aquatic environment directly from human and animal waste inputs, agricultural and storm runoff, and from wastewater. Many investigations suggest that poultry and cattle are primary sources of fecal coliform bacteria. Fecal coliform concentrations are important for evaluating a water body's compliance with water quality criteria (Sargeant *et al*., 2005).

Use of an integrated UASB (up-flow anaerobic sludge blanket) reactor-duckweed ponds system for domestic wastewater treatment and recycling of nutrients and water in tilapia (*Oreochromis niloticus*) aquaculture was investigated by Abdel-Aziz and El-Shafai (2004). Monitoring of the integrated UASB-duckweed ponds showed that the overall efficiency of the system for organic matter removal was not significantly affected by temperature. The results showed that the UASB-duckweed ponds system is technically appropriate for sewage treatment in small communities and rural areas and provides marketable by-products (duckweed biomass). The potential of duckweed to clean uranium (U) and arsenic (As) contamination from mine surface waters was investigated by Mkandawire *et al*. (2004) in wetlands of two former uranium mines in Eastern Germany and using hydroponic culture. The highest accumulations observed were 896.9 and 1021.7 8 mg U and As kg^{-1} dry biomass, respectively for a 21-days test period in the laboratory experiments. The potential extractions from surface waters with duckweed were estimated to be 662.7 and 751.9 kg U and As ha^{-1} $year^{-1}$. Mkandawire and Dudel (2005) reported that duckweed can be a preliminary bio-indicator for arsenic transfer from substrate to plants and might be used to monitor the transfer of As from lower to higher trophic levels in the abandoned mine sites. The potential of using duckweed for phytoremediation from mine tailing waters exists because of its high accumulation capacity as demonstrated in this study.

Removal efficiencies in pilot scale algae-based ponds and duckweed-based ponds were assessed by Zimmo *et al.* (2005). Overall nitrogen removal rate in the algae system was significantly higher than that in duckweed system. Higher phosphorus removal efficiency was achieved in the duckweed system than in the algal system. Fecal coliforms were better removed during low organic loading in comparison with high organic loading. Duckweed grown on nutrient-rich water has a high concentration of trace minerals, potassium, phosphorus and pigments; particularly carotene and xanthophyll that make duckweed meal a valuable supplement for poultry and other animals and it provides a rich source of vitamins A and B for humans. Fish production can be stimulated by feeding duckweed to the extent that yields can be increased from a few hundred kg ha^{-1} $year^{-1}$ up to 10 tones ha^{-1} $year^{-1}$. Mature poultry can utilize duckweed as a substitute of vegetable protein in cereal grain based diet. Duckweed regarded as a protein and energy source with slightly less efficiency than soybean meal (Leng *et al*., 1995). Duckweed protein has greater amount of the essential amino acids, lysine and methionine, than most plant proteins and more closely resembles animal protein in that respect. In addition, some species of *Wolffia* are a potential source of food for humans because they contain about 40% protein (dry weight) and are equivalent to soybeans in their amino acid content (Rusoff *et al*., 1980).

Ganabiet-Tersa drain was chosen as a case study to evaluate the treatment performance of duckweed natural in-stream system in improving wastewater quality from chemical, biological and bacteriological points of view.

MATERIALS AND METHODS

A field observation and monitoring program was conducted for Ganabiet-Tersa drain for three seasons, beginning from summer 2004 ending in spring 2005. Winter season was excluded because at sampling time a purification practices was carried out for removing duckweed from the drain stream. Chemical, biological and bacteriological analyses were seasonally conducted at the influent and effluent of duckweed natural in-stream system (Fig. 1 & 2a & b). During spring season an overgrowth of duckweed was observed at the effluent sampling location. This overgrowth coincides with the starting work of a fuel station, which was still under construction during summer and autumn seasons, this station discharge its wastes into the drain at the effluent of duckweed in-stream system.

Parameters Measured at Influent and Effluent of Duckweed Natural System

Phytoplankton standing crop determination. Before identification and counting, phytoplankton concentrated samples (10 mL) from the sedimentation process were stained by adding Lugol's iodine solution [10 g pure iodine + 2 gm potassium iodide (KI) + 180 ml distilled water + 20 mL glacial acetic acid, until the samples color changed to faint tea color]. Identification and counting were carried out by using an inverted binocular microscope at 16 X eyepiece and 40 X objective. To identify the algal taxa to the species level, 100 X objectives with oil immersion was used when needed. The drop method was applied for identification and counting of different algal species from different samples (APHA, 1992) and the number of phytoplanktonic organisms present in the samples was calculated as:

$$Y = \frac{\text{Number of organisms counted X Volume of concentrated sample}}{\text{Volume counted X Volume of the original sample}}$$

Where

Y = the number of phytoplankton species counted mL^{-1}.

Chlorophyll-a determination. Samples for this purpose were collected in opaque containers, wrapped with aluminum foil, and 120 mL of each sample was vacuum filtered through a fiberglass filter paper GF/C (4.5 cm diameter). Each filter paper was then transferred to a test tube containing 10 mL of a mixture of 90% aqueous acetone solution and 10% saturated $MgCO_3$ solution (to prevent chlorophyll degradation) for pigment extraction and the tubes were covered with aluminum foil and kept in the freezer overnight. The extract was then clarified by centrifugation for 20 min at 2000 rpm. The absorbance of the extracts was determined with the spectrophotometer and chlorophyll-a determined (APHA, 1992).

Physico-chemical parameters. Standard methods for examination of water (APHA, 1992) were used for the determination of pH (using bench-top pH/ISE meter), EC (using ATC bench electric conductivity meters, HANNA, model HI 8820) and dissolved oxygen (DO) (using profiline dissolved oxygen meter, WTW Oxi 597 with a dissolved oxygen probe cell Ox 325).

Bacteriological parameters. All bacterial counts were made according to APHA (1992). For total and fecal coliform bacterial count, the developed colonies were counted using dark field, LEICA, Quebec Colony Counter. Total coliform density was counted using membrane filter technique on M-Endo Agar LES medium obtained from Difco, USA. After incubation at 35°C for 24 h, colonies showing pink to dark red color with metallic surface sheen were counted as total coliform bacteria. Results were recorded in colony forming unit (CFU) 100^{-1} mL (colony forming unit/100 mL) using the following equation:

Total coliform colonies/100 mL = (Coliform colony counted x 100)/(mL of sample filtered).

Fecal coliform (TC) density was determined using membrane filter technique according to standard method no. 9222 D (APHA, 1992) on M-FC Agar medium obtained from Difco, USA. After incubation at 44.5°C for 24 h, colonies developing various shades of blue were counted as fecal coliform bacteria and recorded in CFU 100^{-1} mL as described in TC calculation.

Hydraulic measurements data. Flow cross-sectional area, wetted perimeter, flow velocity, froude number and flow depth were obtained from the National Water Research Center (NWRC).

Retention time measurement. The retention time below duckweed natural in-stream system to move from the inlet to its outlet, was measured according to French (1985).

RESULTS AND DISCUSSION

Physico-chemial parameters. Influent and effluent temperatures recorded during the three seasons are considered to be within the normal range for duckweed growth (Culley *et al*., 1981). Influent pH values during the

Fig. 1. *L. gibba* natural in-stream system

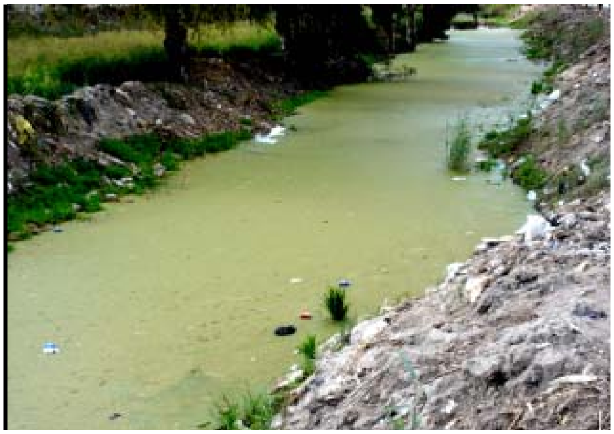

Fig. 2a. Influent sampling location, (b) effluent sampling location

a b

three seasons were higher than effluent values they varied between 8.12 and 8.27 (Table I). This could be explained by phytoplankton photosynthetic activity at surface water, which consumes acidic carbon dioxide in the ponds, resulting in increasing pH values (Abdalla *et al*., 1995). Effluent values ranged between 7.47 and 7.66 (Table I), indicating that duckweed natural treatment system had performed well in reducing pH values and this attributed to the reduction of the light entering the water body due to the duckweed cover, which in turn reduced algal production and lowered pH levels as mentioned by Allinson *et al*. (2000).

The influent dissolved oxygen (DO) values were always higher than the effluent. The influent DO during whole of the investigation period and varied between 6.95 and 4.56 mg O_2 L^{-1}, while effluent values ranged between 0.6 and 1.45 mg O_2 L^{-1} (Table I). These findings were in accordance with those obtained by Parr *et al*. (2002), who observed a reduction in DO levels beneath canopies of duckweed in both field and laboratory experiments. They also found that duckweed mats induced a reduction in oxygen diffusion to the water column and that the oxygen produced by duckweed was not released to the water but released to the atmosphere. In this connection Alaerts *et al*. (1996) found that the water column in a duckweed-covered sewage lagoon system with a low BOD load always remained aerobic, which is in accordance with the present results, where BOD load during this study was not high especially during both summer and autumn seasons.

Duckweed natural treatment system induced a remarkable reduction in both total dissolved solids (TDS) and electrical conductivity (EC) at the effluent along the three seasons the influent TDS and EC values were always higher than the effluent (Table I). Percent reduction in TDS ranged from 30.6% to 57.7% and EC remained from 33% to 57.3%. These findings were in accordance with Dalu and Ndamba (2002) who obtained conductivity reductions of up to 60% in the effluent produced from a duckweed wastewater stabilization pond at Nemanwa, Zimbabwe. According to FAO (1985) average influent TDS and EC values were lying in the high salinity class (which ranged between 1000 - 2000 mg L^{-1} for TDS & 1500 - 3000 umhos cm^{-1} for EC) in which salinity adversely affects most plants. On the other hand, average effluent values for both TDS and EC were lying in the medium salinity class (which ranged between 500 - 1000 mg L^{-1} for TDS & 750 - 1500 umhos cm^{-1} for EC) in which sensitive plants may show salt stress signs and moderate leaching could prevent soil salt accumulation. Thus, it is suggested that effluent quality from duckweed natural treatment system is acceptable for being used in agricultural irrigation purposes.

It was found that duckweed system induced a reduction of 80.5% of total suspended solids (TSS) concentration at the effluent during autumn season, while during both summer and spring seasons it was higher at effluent than at influent (Table I). Reduction in the concentration of TSS determined at the effluent during autumn season could be related to low phytoplankton standing crop recorded at this location. During summer season effluent phytoplankton standing crop was higher than that of the influent the reason, why higher TSS concentration was recorded at the effluent. On the other hand, during spring season an extensive growth of duckweed was observed at the effluent resulting in massive die-off of duckweed plants, which in turn increased the organic load, TSS and algal production. These results agreed with those of Dalu and Ndamba (2002).

Duckweed natural treatment system induced an effluent total alkalinity reduction during both summer and autumn seasons (percent reduction 45.4% & 27%, respectively). On the other hand, effluent total alkalinity value during spring season exceeded that of the influent (633.8 & 550.1 mg L^{-1}, respectively) (Table I). The reduction observed in effluent total alkalinity during summer and autumn seasons could be explained by the interpretation of Filbin and Hough (1985), who reported that the plant may use up to 86% aqueous inorganic carbon and bicarbonate (HCO_3) from water column instead of atmospheric CO_2, which may result in carbon limitation in some submerged species. In spring season an extensive growth of duckweed extended to clog effluent sampling location. This overgrowth was accompanied by the death of a large number of plants and hence microbial decomposition

Table I. Physical, chemical and bacteriological analyses for the influent and effluent of duckweed natural in-stream system of Ganabiet-Tersa drain

Parameters	Summer		Autumn		Spring	
	Influent	effluent	Influent	effluent	Influent	effluent
Physico-chemical parameters						
Temperature (^oC)	34.00	32.00	24.40	24.30	21.80	21.50
pH	8.27	7.66	8.26	7.47	8.12	7.60
DO (mg O_2 L^{-1})	4.56	1.45	6.05	0.60	6.95	0.80
TDS (mg L^{-1})	2003.00	893.00	2137.00	904.00	1719.00	1192.00
EC (umhos m^{-1})	3000.00	1305.00	3310.00	1414.00	2690.00	1800.00
TSS (mg L^{-1})	25.00	28.00	41.00	8.00	5.00	14.00
CO3 (mg L^{-1})	36.60	0.00	0.00	0.00	0.00	0.00
HCO3 (mg L^{-1})	547.90	319.20	498.80	363.90	550.10	633.80
T.alkalinity (mg L^{-1})	584.50	319.20	498.80	363.90	550.10	633.80
BOD (mg O_2 L^{-1})	15.00	12.00	13.00	7.00	6.00	25.00
COD (mg O_2 L^{-1})	94.00	42.00	120.00	27.00	30.00	86.00
Nutrients (mg L^{-1})						
O.phosphate	1.13	0.22	0.56	0.22	0.33	0.95
Phosphorus	0.60	0.08	0.04	0.00	0.22	0.80
Phosphate	1.42	0.20	0.09	0.00	0.53	1.97
Ammonia	2.90	0.31	0.75	0.40	0.15	3.41
Nitrite	4.98	0.64	15.08	9.73	0.79	0.36
Nitrate	7.00	4.00	2.57	0.20	0.97	0.44
Major ions (mg L^{-1})						
Chloride	639.00	247.40	469.95	156.90	510.00	278.60
Sulfate	650.00	228.20	459.16	153.70	425.00	119.78
Calcium	111.00	59.50	120.00	110.00	68.00	65.00
Potassium	40.10	9.84	46.64	11.44	38.20	28.00
Magnesium	56.40	33.30	120.00	110.40	146.40	69.60
Sodium	441.00	170.00	102.85	68.85	141.20	114.00
Calculated sodium adsorption ratio						
SAR	8.3	4.40	1.60	1.16	2.20	2.30
Heavy metals (mg L^{-1})						
Aluminum	0.006	0.000	0.008	0.001	33.680	7.795
Arsenic	0.010	0.005	0.031	0.024	0.020	0.006
Barium	0.076	0.069	0.027	0.024	0.870	0.860
Cadmium	0.005	0.001	0.004	0.000	0.013	0.005
Cobalt	0.003	0.001	0.010	0.002	0.002	0.060
Chromium	0.006	0.004	0.007	0.006	0.090	0.120
Copper	0.002	0.001	0.286	0.097	0.080	0.200
Iron	0.034	0.022	0.729	0.399	3.800	4.440
Manganese	0.213	0.013	0.500	0.350	0.730	0.800
Nickel	0.011	0.005	0.057	0.022	0.170	0.168
Lead	0.007	0.000	0.009	0.000	0.090	0.010
Vanadium	0.005	0.002	0.039	0.027	0.360	0.118
Zinc	0.006	0.001	0.181	0.114	69.830	2.500
Bacteriological parameters (CFU 100^{-1} ml)						
Fecal coliform	2×10^3	2×10^3	3×10^3	25×10^2	1×10^2	14×10^2

of organic matter increased, producing excess CO_2 in water column, leading to increased effluent total alkalinity (Peavy *et al*., 1986).

Duckweed system induced reduction in both biological oxygen demand (BOD) and chemical oxygen demand (COD) at the effluent during summer and autumn seasons. Reduction in BOD was 20% in summer and 46% in autumn; while COD reduction during both summer and autumn seasons were 55.3% and 77.5%, respectively. However, effluent BOD and COD values during spring season were exceeding those of influent (Table I). This was attributed to the extensive growth of duckweed, which was stocked at the effluent sampling location during spring season, and the death of a large number of duckweed plants, which in turn increased organic matter in water. Dalu and Ndamba (2002) also found 30 - 50% reduction in BOD and COD levels of influent and effluent and levels of effluent were higher than those of influent. They related these cases to the under-harvesting of duckweed, which resulted in weed die-off in the ponds that in turn increased organic load. Korner *et al.* (2003) stated that duckweed covered systems can attain BOD and COD removal rates between 50 and 95%. Also duckweed was found to significantly enhance BOD and COD removal in shallow batch systems.

Nutrients. Duckweed system induced reduction in ortho-phosphate, phosphorus and phosphate in the effluent during both summer and autumn seasons, while during spring season the effluent values exceeded the influent ones (Table I). Ortho-phosphate, phosphorus and phosphate percent reduction during both summer and autumn seasons were

80.6% and 61.9%, 87% and 100% and 86% and 100%, respectively. The increase in *O*-phosphate, phosphorus and phosphate observed in the effluent during spring season was related to a massive die-off of duckweed at the effluent and hence activating bacterial decomposition of organic matter. The most important mechanism is the conversion of combined organic phosphate to phosphate, which in turn accelerates the liberation of phosphate into water. In addition phosphorus may be released to water during plant ageing and decaying processes (Klapper, 1991).

Duckweed system reduced ammonia levels at the effluent during both summer and autumn seasons (Table I) with reduction of 89.2% and 46.6%, respectively. Duckweed fat can be used to treat wastewater containing high total ammonia concentrations as long as pH does not exceed a level of about 8 (Korner *et al*., 2003). On the other hand, an elevated ammonia level was recorded at the effluent during spring season as a result of the decomposition of organic matter (Klapper, 1991) produced from the *Lemna* massive die-off. Duckweed natural treatment system performed well in relation to nitrogen uptake, where effluent nitrite and nitrate values were lower than influent values along the three seasons (Table I). Nitrite reduction ranged from 35 to 87.5%, while nitrate ranged from 43 to 92.2%. Similar removal efficiencies of 34 to 99% for nitrogen and 14 to 99% for phosphorus have been reported using duckweed system (Hammouda *et al*., 1995; Vatta *et al*., 1995; Vermaat & Hanif, 1998).

Major ions. Leng *et al*. (1995) reported that the rapidly growing duckweed plants act as a nutrient sink absorbing primarily nitrogen, phosphorus, calcium, potassium, sodium, magnesium, carbon and chloride from wastewater. Their results support our data, which reflected the high potential of duckweed system in reducing calcium, sodium, potassium, magnesium, chloride and sulfate concentrations in the effluent during the three seasons (Table I).

Heavy metals. Members of Lemnaceae have been shown to possess a great ability to accumulate tolerate high concentrations of heavy metals (Landolt & Kandeler, 1987). These characteristics of Lemnaceae suggest a possible application for the efficient removal of metals from wastewater. The present study revealed that duckweed system induced effluent reduction in all heavy metals during both summer and autumn seasons (Table I). The increase in concentrations of some heavy metals in the effluent during spring season might be due to bacterial decomposition of dead duckweed plants, which result in the release of heavy metals in water and soil (Salomons, 1995). Duckweed system induced a remarkable reduction in effluent concentrations of both Al and Zn with a reduction of 76.8and 96.4%, respectively. In this connection, Zayed (1998) proved the efficiency of duckweed in the removal of Cd, Se, and Cu from contaminated wastewater as it can accumulate high concentrations of these elements. Further, the growth rates and harvest potential make duckweed a good species for phytoremediation.

Bacteriological analyses. The present study showed that effluent fecal coliform bacterial counts during the three seasons were inconsistent. It was also found that influent and effluent counts during summer season were 2 x 10^3 CFU 100^{-1} mL, while during autumn season influent density was higher than that of the effluent recording 3 x 10^3 and 2.5 x 10^2 CFU 100^{-1} mL, respectively. However, during spring season effluent density was exceeding that of influent (Table I). The inconsistency of the data may be due to the absence of controlled conditions in the field, as residents and farmers practiced some behaviors (washing their animals in the water, discharging their own wastes & their agricultural runoff into the water). Also the decreased observed in fecal coliform density during spring season at the influent could be attributed to the elevated concentrations of both zinc and aluminum, derived from anthropogenic sources such as agriculture run-off, commercial fertilizers, animal manure and sludge. In this respect, Malik and Ahmad (2002) studied the seasonal variation of bacterial flora of wastewater and soil in the vicinity of industrial area and found that high concentrations of Fe, Zn, Cu, Cr and Ni adversely affected bacterial flora.

Phytoplankton standing crop. Data presented in Table II showed that Ganabiet-Tersa drain comprised a diverse phytoplankton flora represented by 86 species belonging to 30 genera and 5 algal classes namely; Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae and Cryptophyceae. Data revealed remarkable variations among different seasons. Influent phytoplankton standing crop during both summer and spring seasons (11999.5 & 1022.0 individuals x 10^3 L^{-1}, respectively) was lower than effluent standing crop (15377.3 & 8932.9 individuals x 10^3 L^{-1}, respectively), while during autumn season the reverse was true, where influent standing crop was exceeding effluent one (33999.5 & 3611.3 individuals x 10^3 L^{-1}, respectively). Trainor (1984) mentioned that micro-algae have great potential for monitoring and evolving the quality of the water bodies. Clean water would support a great diversity of organisms, whereas polluted water would yield just a few organisms, with one or a few dominant forms. In the present investigation there were two peaks of phytoplankton standing crop; minor recorded at the influent during spring season (1022.0 individuals x 10^3 L^{-1}) and a major one at the influent during autumn season (33999.5 individuals x 10^3 L^{-1}). The minor peak could be related to elevated levels of both zinc and aluminium (69.83 & 33.68 mg L^{-1}, respectively) detected at the influent. A high concentration of aluminum might result in decreased phosphate levels in water by coagulation and precipitation as reported by Klapper (1991), which in turn reduce phosphate availability and hence affecting phytoplankton abundance. This explanation was supported by the reduced concentrations of *O*-phosphate, phosphate and phosphorus recorded at the influent during spring season. On the other hand, the major peak observed during autumn season was attributed to the high concentrations of organic matter (BOD & COD),

Table II. Effect of in-stream duckweed natural system on influent and effluent phytoplankton populations (individuals x 10^3 L^{-1})

Parameters	Summer		Autumn		Spring	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Total individuals	11999.50	15377.30	33999.50	3611.30	1022.00	8932.90
Number of species	34.00	32.00	37.00	14.00	8.00	20.00
Richness	3.50	3.20	3.50	1.60	1.00	2.10
Diversity index	2.40	2.45	2.65	2.14	1.75	1.40
Eveness	0.59	0.61	0.62	0.68	0.71	0.40
Chlorophyll a and Trophic State Index						
Chlorophyll a (mg L^{-1})	52.60	54.30	377.00	14.70	23.70	36.70
Trophic state index	69.40	69.80	88.50	57.00	61.70	65.90

nutrients (nitrite & nitrate) total alkalinity and to the low concentration of ammonia. In this connection, Lai and Lam (1997) found a positive correlation between both nitrite and nitrate and phytoplankton standing crop. These authors (1997) reported that high nitrite concentrations enhance photosynthetic activities of phytoplankton and this in turn not only increased dissolved oxygen but also elevated the pH by consuming the acidic carbon dioxide in the ponds. These conditions are optimal for nitrification process, which increases nitrite and nitrate concentrations. In addition Khan-Nather (1991) found that ammonia concentration was negatively correlated with species richness and diversity, which this is in accordance with the present results.

Chlorophll-a. Chlorophyll a concentration recorded at the influent during both summer and spring seasons (52.6 & 23.7 mg L^{-1}, respectively) was lower than those recorded at the effluent (54.3 & 36.7 mg L^{-1}, respectively). On the other hand, influent chlorophyll a concentration (377.0 mg L^{-1}) during autumn season exceeded effluent concentration (14.7 mg L^{-1}). A positive correlation was found between chlorophyll a concentrations and phytoplankton standing crop during the three seasons of the present investigation at both influent and effluent (Table II), which agreed the findings of Zhang and Prepas (1996) who found that total phytoplankton abundance was correlated with chlorophyll a concentrations in integrated samples from four lakes.

Diversity index, species richness and evenness. Values of diversity index fluctuated between 1.4 as a minimum value recorded at effluent of duckweed system during spring season to 2.65 as a maximum value determined at influent during autumn season (Table II). Ramakrishnan (2003) in water pond study in India found that Shannon-Weiner index ranged between 1.40 and 3.24 for both ponds, minimum values were observed during rainy months and the maximum values were recorded during summer months. These results also confirm the present findings, where maximum values for diversity index were recorded during both summer and autumn seasons. Species richness values ranged from 1 recorded at the influent during spring season, where the least species number was observed and 3.5 at influent of both summer and autumn seasons, where the highest number of species was recorded (Table II). According to Mc-Cormick and Cairns (1997) evenness values were fluctuating in a narrow range, from 0.4 at the effluent during spring season to 0.71 at influent during spring season. These lower values indicated the presence of environmental pollution impacts, where certain species could not tolerate such impacts. Hence the species distribution in the community structure is not equilibrated and only the tolerant species (known as species indicators) appear in the community structure.

Trophic state index. Trophic state index revealed that Ganabiet-Tersa drain during summer season at both influent and effluent is considered to be eutrophic with values 69.4 and 69.8, respectively (Table II). This could be attributed to the high nutrient levels and high organic load, especially at the influent. In contrast, the autumn season was hyper-eutrophic (88.5) at the influent, which resulted from a high nutrient concentrations mainly nitrite and nitrate and high organic load mainly COD. However at the effluent both nutrients and organic load decreased by duckweed system, which shifted the drain trophic state towards meso-eutrophication (57). During spring season both influent and effluent were eutrophic (61.7 & 65.9, respectively). The eutrophication was higher at the effluent as a consequence of higher levels of nutrients mainly phosphate, ammonia and high organic matter produced from the decomposition of dead duckweed plants.

The present findings suggested the importance duckweed plant as an alternative cost effective biological tool for treatment of sewage water and agriculture drainage. Integration of duckweed aquatic systems with conventional treatment systems will be effective in decreasing nutrient levels especially nitrate and phosphate to control algal blooms. Moreover, duckweed can be used to reduce soluble salt concentrations in irrigation water. The use of duckweed as fodder and in fish farms due to high protein content and nutritional value is feasible as there was no health hazards (Islam *et al*., 2004).

REFERENCES

Abdalla, R.R., F.A. Zaghloul, Y.A. Hassan and H.M. Mostafa, 1995. Some water quality characteristics of El-Dekhaila Harbour, Alexandria, Egypt. *Bull. Nat. Inst. Oceanogr. Fish. A.R.E*., 21: 85–102

Abdel-Aziz, S. and A.S.M. El-Shafai, 2004. *Nutrients Valorisation Via Duckweed-based Wastewater Treatment and Aquaculture,* p: 174

Alaerts, G.J., M. Mahbubar-Rahman and P. Kelderman, 1996. Performance analysis of a full-scale duckweed covered lag. *Water Res*., 30: 843–52

Allinson, G., F. Stagnitti, S. Colville, J. Hill and M. Coates, 2000. Growth of floating aquatic macrophytes in alkaline industrial wastewaters. *Environ. Engg*., p: 126

American Public Health Association "APHA", 1992. *Standard Methods for the Examination of Water and Wastewater*, 18th edition. Washington, D.C

Culley, D.D., E. Rejmankova, J. Kvet and J.B. Frey, 1981. Production, chemical quality and use of duckweeds (Lemnaceae) in aquaculture, waste management and animal feeds. *J. World Maric. Soc.,* 12: 27–49

Dalu, J.M. and J. Ndamba, 2002. Duckweed based wastewater stabilization ponds for wastewater treatment; a low cost technology for small urban areas in Zimbabwe. *In:* 3rd *Water Net/Warfsa Symposium 'Water Demand Management for Sustainable Development',* Dar E-Salaam

FAO, 1985. *Water Quality for Agriculture,* p: 174. Irrigation and Drainage 29 Rev. 1. FAO, Rome

Filbin, G.J. and R.A. Hough, 1985. Photosynthesis, photorespiration and productivity in *Lemna minor*. *Limnol. Oceanogr*., 30: 322–34

French, R.H., 1985. *Open Channel Hydraulics*. McGraw-Hill Book Co

Hammouda, O., A. Gaber and M.S. Abdel-Hameed, 1995. Assessment of the effectiveness of treatment of waste water-contaminated aquatic systems with *Lemna gibba*. *Enzy. Microb. Technol*., 17: 317–23

Islam, M.S., M.S. Kabir, S.I. Khan, M. Ekramullah, G.B. Nair, R.B. Sack and D.A. Sack, 2004. Wastewater grown duckweed may be safely used as fish feed. *Canadian J. Microbiol.*, 50: 51–6

Khan-Nather, I.S.A., 1991. Effect of urban and industrial waters on species diversity of the diatoms community in a tropical river, Malaysia. *Hydrob.,* 224: 175–84

Klapper, 1991. *In*: Winkler, M. (ed.), *Control of Eutrophication in Inland Waters,* pp: 37–71. New York, London, Toronto, Sydney, Tokyo and Singapore

Korner, S., E.J. Vermaatand and S. Veenstra, 2003. The capacity of duckweed to treat wastewater. Ecological considerations for a sound design. *J. Environ. Qual.,* 32: 1583–90

Lai, P.C.C. and P.K.S. Lam, 1997. Major pathways for nitrogen removal in wastewater stabilization ponds. *Water Air and Soil Pollut.,* 94: 125–36

Landolt, E. and R. Kandeler, 1987. *The Family of Lemnaceae -A Monographic Study,* 2, *Stiftung Rübel 95*. Veröffentlichungen des Geobotanischen Institutes. der ETH Zürich

Leng, R.A., J.H. Stambolie and R. Bell, 1995. Duckweed - a potential high-protein feed resource for domestic animals and fish. *Livestock Res. Rural Development*, 7

Malik, A. and M. Ahmad, 2002. Seasonal variation in bacterial flora of the wastewater and soil in the vicinity of industrial area. *Environ. Monitor. Assess.*, 73: 263–73

Mc-Cormick, P.V. and J. Jr. Cairns, 1997. Algal indicators of aquatic ecosystem condition and change. *In*: Wang, W., J.W. Gorsuch and J.S. Hughes (eds.), *Plants for Environ. Studies,* pp: 177–207. Lewis publishers, BocaRaton, New York

Mkandawire, M. and E.G. Dudel, 2005. Accumulation of arsenic in *Lemna gibba* L. (duckweed) in tailing waters of two abandoned uranium mining sites in Saxony, Germany. *Sci. Total Environ*., 336: 81–9

Mkandawire, M., B. Taubert and E.G. Dudel, 2004. Capacity of *Lemna gibba* L. (duckweed) for uranium and arsenic phytoremediation in mine tailing waters. *Int. J. Phytoremed.,* 6: 347–62

Parr, L.B., R.G. Perkins and C.F. Mason, 2002. Reduction in photosynthetic efficiency of *Cladophora glomerata,* induced by overlying canopies of *Lemna* spp*. Water Res.*, 36: 1735–42

Peavy, H.S., D.R. Rowe and T. Georgy, 1986*. Environmental Engineering,* McGraw-Hill Book Co., Singapore

Ramakrishnan, N., 2003. Biomonitoring approaches for water quality assessment in two water bodies at Tiruvannamalai, Tamil Nadu India. *In*: Martin, J., V. Bunch, Madha Suresh and T. Vasantha Kumaran (eds.), *Proc. of the Third International Conference on Environment and Health Chennai India*, pp: 374–85. Department of Geography, University of Madras and Faculty of Environmental Studies, York University

Rusoff, L.L., E.W. Blakeney and D.D. Culley, 1980. Duckweeds (Lemnaceae): A Potential Source of Protein and Amino Acids. *J. Agric. Food Chem.*, 28: 848–50

Salomons, W., 1995. Environmental impact of metals derived from mining activities: Processes, predictions, prevention. *J. Geochem. Explor.*, 52: 5–23

Sargeant, D., M. Roberts and B. Carey, 2005. *Nisqually River Basin Fecal Coliform Bacteria and Dissolved Oxygen Total Maximum Daily Load Study*. Environmental Assessment Program, Washington State Department of Ecology, Olympia WA. Publication 05-03-002

Trainor, F.R., 1984. Indicator algal assay laboratory and fields approaches *In:* Shubert (ed.), *Algae as Ecological Indicators,* pp: 3–14. Academic press London, 55

Vatta, G., R. Rota, N. Boniardi and G. Nano, 1995. Dynamic odeling of wastewater treatment plants based on *Lemna gibba*. *Chem. Eng. J. (Lausanne),* 57: 37–48

Vermaat, J.E. and K.M. Hanif, 1998. Performance of common duckweed species (Lemnaceae) and the waterfern *Azolla filiculoides* on different types of wastewater. *Water Res.,* 32: 2569–76

Zayed, A., 1998. Phytoaccumulation of trace elements by wetland plants. I. Duckweed. *J. Enviro. Qual.,* 27: 715–21

Zhang, Y. and E.E. Prepas, 1996. Regulation of the dominance of planktonic diatoms and Cyanobacteria in four eutrophic hard-water lakes by nutrients, water column stability and temperature. *Canadian J. Fish Aquat. Sci.,* 53: 621–33

Zimmo, O.R., N.P. Van Der Steen and H.J. Gijzen, 2005. Effect of organic surface load on process performance of pilot-scale algae and duckweed-based waste stabilization ponds. *J. Environ. Engg.,* 131: 587–94

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