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Full Length Research Paper

Strategies for Environmental Remediation of Aquaculture Drainage: A Case Study in Fish Farming

[1]Salwa M. Abou ElElla and [2]Hanan A. Abd El-Gawad

[1]Assistant Professor, Channel Maintenance Research Institute (CMRI), National Water Research Center (NWRC), El-Kanater, Qalubiya, P.O. Box 13621/6, Cairo, Egypt.
[2]Assistant Professor, Central Laboratory for Environmental Quality Monitoring (CLEQM), National Water Research Center (NWRC), El-Kanater, Qalubiya, P.O. Box 13621/6, Cairo, Egypt

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The investigation of fish farm discharge effect on drainage network in Kafer El-Sheikh Governorate, three fish farms near by the three drains (near by El-Hax, El-Far and El-Canal drains) with three different production capacities were studied by examining water physicochemical criteria and natural wetland system. Water and plant samples were collected once during summer and winter using a quantitative technique. Results showed a significant increase in oxidizabile organic materials, Total Suspended Solids (TSS) concentrations, a decline in dissolved oxygen (D.O) concentration and pH in the outflow compared to Egyptian Environment Law 9/2009. Rhizofiltration application as one of phytoremediation technology included the emergent plants (Boos - *Phragmites australis*), *Eichhornia crassipes* and *Canna indica* were utilized to extract, sequester, and/or detoxify pollutants as in-stream wetland system at downstream fish farms sites that improved drainage water quality. In conclusion, the results have important consequences for future monitoring strategies of watershed and management of their gradual ecological improvement.

Keywords: Fish farm, Water quality, Technology, Wetland

INTRODUCTION

The water quality of surface waters is threatened by multiple anthropogenic pollutants and the large variety of pollutants challenges the monitoring and assessment of the water quality. Wastewaters draining off a fish farm from open surface drains lead to watercourses pollution and violations of water quality standards for drainage water (WCD, 2009). The most pollutants generated from agricultural operations, domestic and industrial wastewater along drain system include conservative and non-conservative substances. The non-conservative pollutants include most organic, some inorganic matters and many microorganisms which are degradable by the natural purification processes and their concentrations reduce with time. The conservative pollutants include many inorganic substances where their concentrations are reduced by dilution and unaffected by the normal water and wastewater treatment processes. Hence, their presence in a particular water source may limit its use (Abd El-Gawad and El-Kholy, 2008). Moreover, these pollutants such as pesticides and heavy metals are unself-healthy water quality ((Abd El-Gawad and El-Kholy, 2008; El-Kholy, 2006). Recent studies reported wetland ecosystem along fish farming reduced significant negative environmental impacts that confirm increasing human activity within management wetland - vegetation pond (Omondi, 2011).

The current study investigates the environmental purification mechanism of El-Hax drain, El-Canal drain and Far drain with respect to chemical and microbial constituents of drainage water quality. The aim of this study was to use site data of 2011 seasons (summer and winter) and rhizofiltration as one of phytoremediation technology to calculate Biological Concentration Factor (BCF) of metals in *Phragmites australis* (Boos) roots, *Eichhornia crassipes* and *Canna indica* as a phyto-accumulator as a good tool to evaluate the purification effect and understand the main physical, chemical and

*Corresponding Author E-mail:salwaabouelella@yahoo.com

microbial mechanisms of the water quality processes along fish farms of non-conventional water resources.

METHODOLOGY

Description of Study Area

Kafr El-Sheihk governorate is located in the Northern Middle Delta and had many of random fish farms that are first level for fish production (33.7%) of Egypt. The fish farms was designed in many drains and caused many environmental problems for maintains channels because they discharge fish' waste and fish's food. The Middle Delta is divided into a number of main catchment systems, 2nd and 3th drain branches as shown in Figure (1).

Most of these systems have fish farms that drained their wastes through secondary drain. El-Hax drain is considered as the first drainage system which is located at 7 Km from Burullus Lake at Modobus center of drainage network in Kafr El-Sheihk Governorate. El-Far and El-Canal drains are two branches of El-Hax drainage network, is according to the national water quality monitoring program.

In the study area, three farms were selected, that discharged directly in El Far drain (farm 1 and 2) and El Canal drain (farm 3), respectively. There are three types of aquatic plants (*Phragmites australis* (Boos) roots, *Eichhornia crassipes* and *Canna indica*) were surrounded fish ponds and the out fish farm according to field study.

Environmental Sampling

Water quality measurements are monitored and measured from grab samples on seasonally basis representing two reaches (lower reachs) along the El-Hax drain (main reach).

Water sampling for physico-chemical measurements: pH, Dissolved Oxygen (D.O), temperature, turbidity and Electrical conductivity (E.C) were measured in situ using the multi-probe system, model Hydralab-Surveyor according to international standard environment methods of the American Public Health Association (APHA, 2005). On other hand, other environmental parameters: chemical and bacteriology are collected to represent different forms of pollution, analyzed in laboratory according to international standard environment methods of the American Public Health Association (APHA, 2005) and compared with water quality standards.

Plant sampling included enough individual plants (three plants) were collected to overcome the factor of plant variability, analyzed and identified (Chapman and Pratt, 1961; Tackholm, 1974). In the laboratory, the plants were carefully washed with distilled water then divided into roots and shoots, oven dried in a dust-free, forced draft electrical oven at 65^{o}C for about 48 hours to stop enzymatic reactions, removing moisture and to obtain a constant weight, then ground to a fine powder before analysis. The study area is extended for about 49 Km^2 as shown in Figure (2). Codes of sampling locations and their description were represented in Table (1).

Analytical Methods

In addition to the determinations of the field samples, various of chemical measurements were determined in laboratory such as ammonia and total nitrogen (Kjeldahl method) using the Gerhardt Vapodest 20S programmable distillation system, nitrate and nitrite were analyzed using on chromatography (IC) model DX-500 chromatography systems with CD20 Conductivity Detector while organic nitrogen was calculated as the difference between Total Kjeldahl Nitrogen (TKN) and ammonia and Total Suspended Solids (TSS) using Huch DR – 2010 Spectrophotometer U.S.A Anions and cations are checked using water analyses interpretation computer program, version 6.42-07190, through ion balance as well as analytical checks and comparisons were done. Total phosphorus (TP) was measured using the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) with Ultra Sonic Nebulizer (USN).

Heavy metal as toxic pollutants in water samples were filtered through Whatman GF/C filters before trace metals analysis. The concentrations of Copper, Cadmium, Iron, Lead, Manganese and Zinc were determined by using the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) with Ultra Sonic Nebulizer (USN). An amount of 0.5 gram from each powdered plant sample was weighed and treated with a mixture of the digestion reagents ($H_2SO_4/HClO_4$) as reported by (Tackholm, 1974) for destruction of organic matter in plant tissues during which temperature was raised to about 100°C until the digest became clear. After dilution to 25 ml deionized water the digest was filtered through Whatman GF/C filters and analyzed for total Cu, Cd, Fe, Pb, Mn, and Zn using the ICP-OES instrument.

On other hand, many organic measurements are selected to represent organic pollution which are Gross fraction of organic matter include as Chemical Oxygen Demand (COD – colorimetric method) using Huch DR – 2010 Spectrophotometer U.S.A and DL 1 mg/l), Biological Oxygen Demand (BOD) using BOD fast respirometry system model TS 606/2 with a measuring range 0-4000 mg/L at 20 ˚C incubation in a thermostatic incubator chamber model WTW and detection limit 1mg/l. Individual trace organic pollutants are considered to measure: organochlorine using Finnigan Gas Chromatograph model 9001 TM with split-splitless-injector, with ECD detector and column: 30m x 0,25 mm I.D and DL 0.01 µg/l, organophosphorous using Hewlett Packard GC Model 6890 equipped with a flame

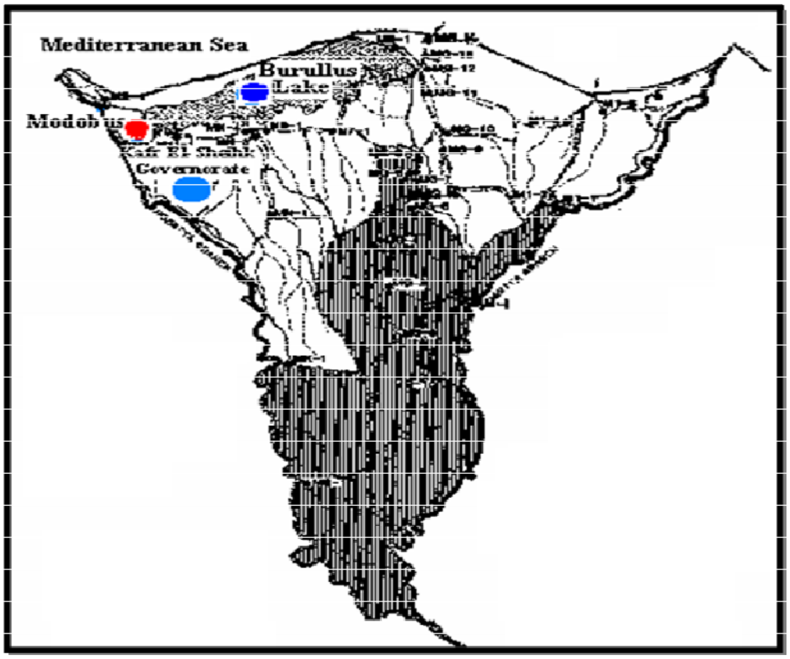

Figure 1. The catchment of Drainage System in Middle Delta

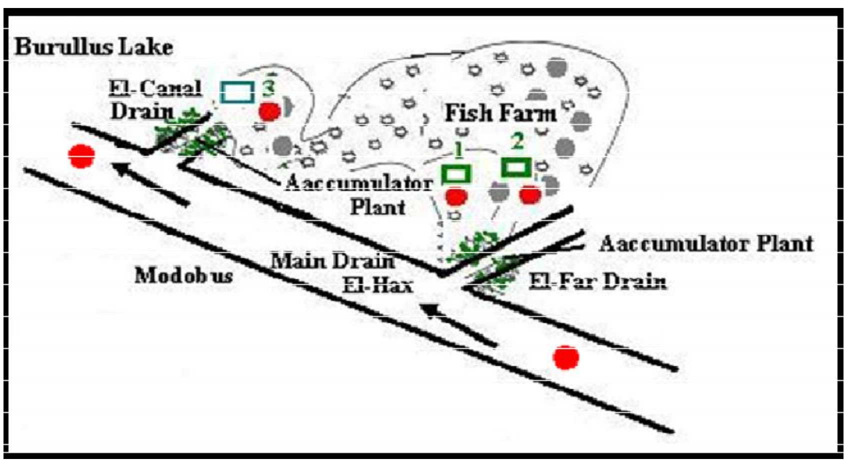

Figure 2. The Catchment of El-Hax Drainage System

Table 1. Codes of Sampling Locations

Code	Description	Type of samples
H-1	El-Hax drain **-** Beginning	Water and plant samples
H-2	El-Hax drain **-** End	Water and plant samples
F-1	Input fish farm (1) at El-Far drain	Water and plant samples
F-2	Feeding pond	Water
F-3	Output fish farm (1) at El-Far drain	Water and plant samples
F-4	Input fish farm (2) at El-Far drain	Water and plant samples
F-5	Feeding pond	Water
F-6	Output fish farm (2) at El-Far drain	Water and plant samples
C-1	Input fish farm (3) at El-Canal drain	Water and plant samples
C-2	Feeding pond	Water
C-3	Output fish farm (3) at El-Canal drain	Water and plant samples

Photometric detector (FPD) with phosphorus filter. A fused silica capillary (PAS-1701), column containing 14% cyanopropilsyloxane as stationary phase (30m length x 0.32 mm internal diameter (i.d) x 0.25um film thickness), pyrethroid using Hewlett Packard GC Model 6890 equipped with an N -electron capture detector, capillary column (30m length x 0.32 mm internal diameter (i.d), x 0.25[tm film thickness), and crbamate using High Performance Liquid Chromatography Agilent I I 00 Series with work station. The U.V Diod - array detector set at 220 nm , and the analytical column Zorbax - C18,5 Um (4.6 x 150 mm). These pesticides were Alfa-BHC, Gamma-BHC, Beta-BHC, Delta-BHC, Endrin Keton, Endrin, Endrin aldhyde, Dieldrin, Aldrin, Alfa chlorodan, Gamma chlorodan, Heptachlor, Heptachlor epoxid, Methoxychlor, Endosulfan I, Endosul fan II, Endosulfan sulfate, 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, P,P-Dicofol, Meothrin, Sumithrin, Tetramethrin, Cyhalothrin, Permithrin, Fenvelerate, Deltamethrin, Cyopermithrin, Dichlorvos, Methamidophos, Ethoprophos, Diazinon, Chlorpyriphos-methyl, Pirimiphos-methyl, Chlorpyriphos, Malathion, Dimethoate, Phenthoate, Prothiophos, Profenophos, Fenamiphos, Ethion, Abamectin, Carbaryl and Methomyl.

For counting total coliforms (T.C) and fecal coliforms (F.C), the membrane filter technique was applied using a filtration system completed with stainless steel autoclavable manifold and oil-free “MILLIPORE” vacuum/pressure pump. Water samples were filtered through sterile, surface girded “SARTORIOUS” membrane of pore size 0.45 µm and diameter 47 mm, according to standard methods No. 9222B and 9222 D on M- Endo Agar LES, M-FC agar, and M-Enterococcus agar medium, respectively. All media used were obtained in a dehydrated form, Difco USA. Results were recorded as Colony Forming Unit (CFU/100 ml). All environmental measurements that include chemical parameters were measured and performed according to the instructions of international examinations in the collected samples (APHA, 2005). The wastewater quality was compared with water quality standards.

Bio-concentration Factor

The bioconcentration factor (BCF) provides an index of the ability of the plant to accumulate the metal with respect to the metal concentration in the substrate. It is calculated as the ratio of the trace element concentration in the plant tissues at harvest to the concentration of the element in the external environment and is dimensionless (Zayed *et al.,* 1998). BCF is given by

$BCF = (P/E)\ i$

Where i denote the heavy metal, P represents the trace element concentration in plant tissues (mg/kg dry wt.) and E represents the trace element concentra-tion in the water (mg/l). A larger ratio implies better bio-accumulation capability.

RESULTS AND DISSCUTION

Reasonable water use and suitable water management are beneficial to water environmental protection, in which one of the ways that utilize fertile water from fish pond is the disposal of the nutrients and others constituents in the drainage water system that are absorbed by plants or adsorbed by sediment (Qixia *et al.,* 2011). An experiment was carried out using three fish farms with a relatively dependent irrigation-drainage system to evaluate the natural purifying fertile water from fish pond under management of natural plants in aquatic environment.

According to this statement, the naturally purification process of El-Hax drain is studied with emphasis on the physical-chemical mechanism of water constituents and its ability to tolerate contaminants induced in the drain catchment from fish farms and drainage wastewater discharges. The purification rate of pollutants concentrations were depending on the environmental conditions, plant capacity in site, season and type of pollutants.

Environmental Purification of Toxic Metal

Average metal concentrations in drainage water are monitored at El-Hax drain for one year in natural wetland. The removal of metals from drainage water occurred through a number of processes: plant uptake, sediment adsorption and precipitation (formation of solid compounds) (Vymazal, 2010).

Figure (3-4) illustrated the distribution of analyzed metals along fish farms which decreased all metal concentrations within permission limits in summer season while in winter season Cu, Mn and Zn were only within safe limits.

Bio-concentration Factor (BCF)

Iron had the highest concentration of analyzed metals which recorded 52%, 45% of total trace metals at beginning and end of El-Hax drain, followed by in and out fish farm (1): 53%, 46%, fish farm (2): 50%, 54%, fish farm (3): 54%, 43%, respectively and Mn, Cu, Zn, Pb concentrations were the same ranked. Similar observation in winter season for all metals concentrations that were higher than in summer season depended on fish’s farm production and the capacity of surrounded bi-accumulator plants.

Figure (5) indicated ambient metal concentration in water; this was the major factor influencing the metal uptake efficiency by surrounding plant accumulators. In

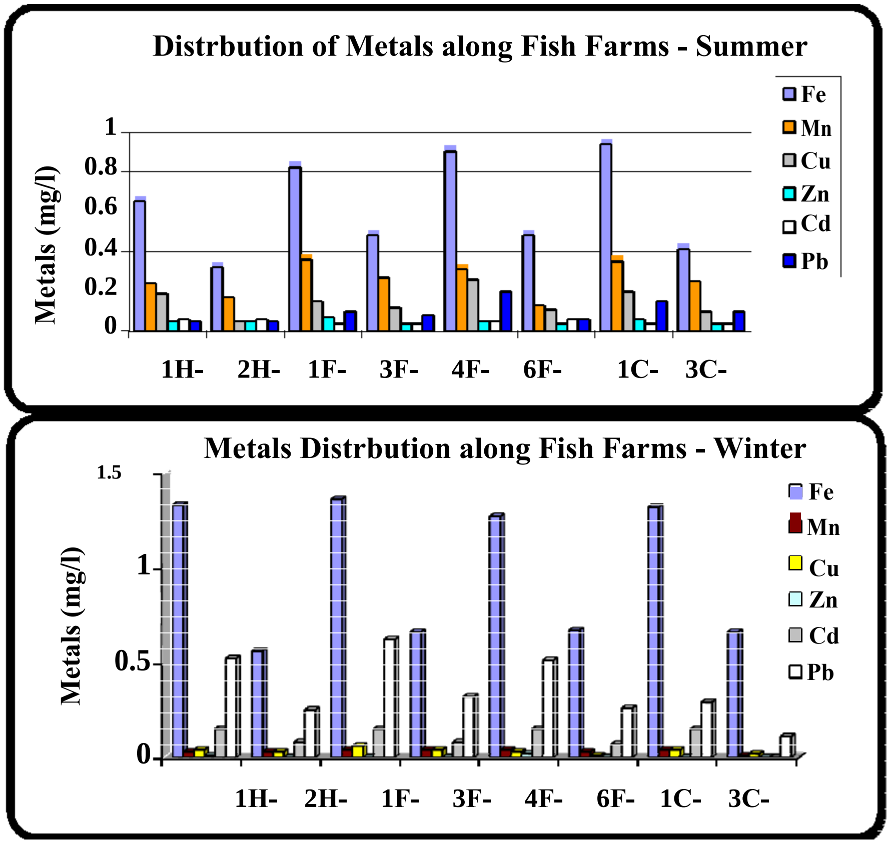

Figure (3-4). Metal concentration in Summer and Winter Seasons

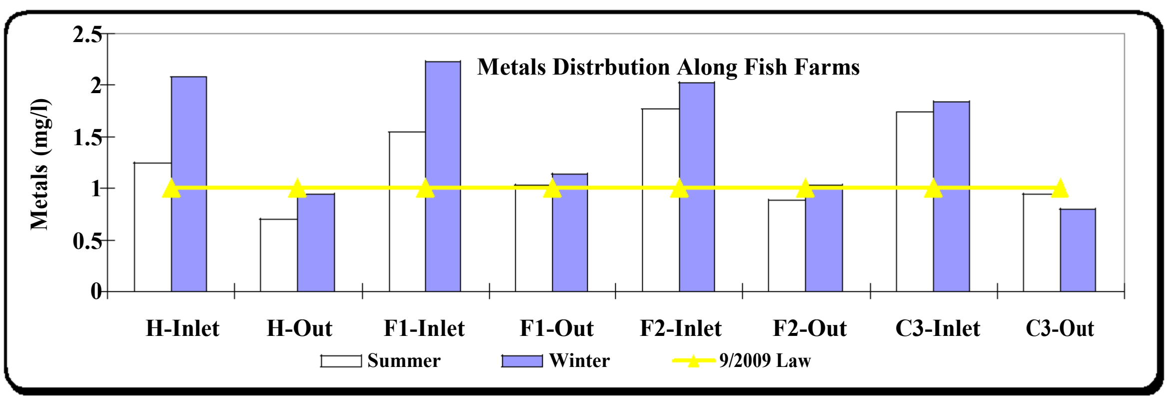

Figure (5). Environmental Purification Along Study Area

general, total metals concentration at outlet of El-Hax drain were within permission limits (1 mg/l – Law 9/2009), while total metals concentration at outlet of other three fish farms were slight above the permission limits.

The management of natural plants according to BCF factor along/or in drains could be used at low cost to reduce negative environmental impacts which is a good solution for drainage water treatment and drain restoration (Abd El-Gawad *et al.,* 2008). In the present study, the most BCF values of Cu, Cd, Fe, Mn, Zn increase when their concentrations in ambient water decreased.

The plant species were selected surrounded three fish farms; inlet and outlet of El-Hax drain manage water in the drain. These species decreased the velocity of wastewater which was useful to remove major contaminants as "in-stream wetland" system. This is indicated by biological accumulation factor (BCF) that reflects the affinity of a plant to a specific pollutant and depends on the metal concentration in the water

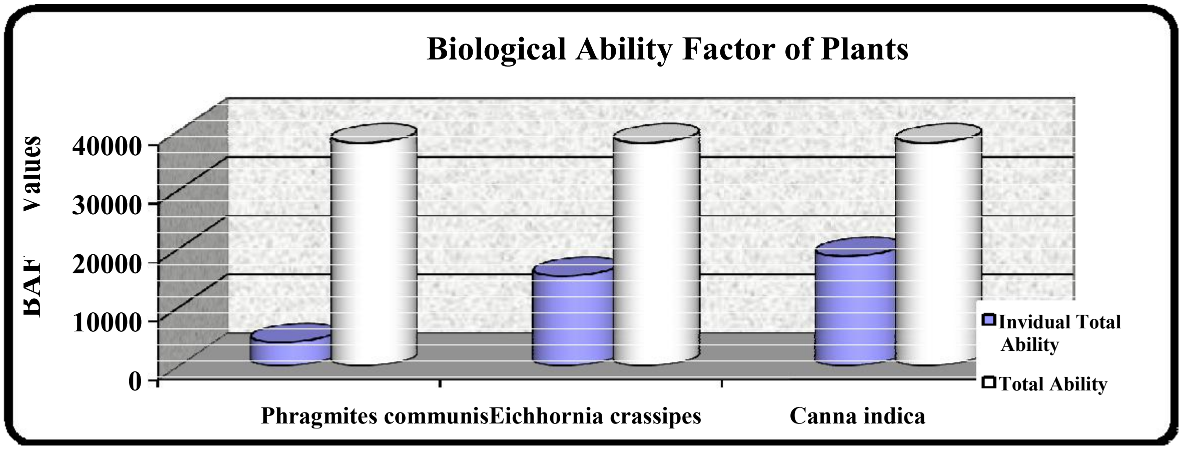

Figure (6). BAF Values for Plant Species

(Doaa, 2011).

Figure (6) showed BCF and the mean concentration of trace element that varied from one plant to another: *Phragmites communis* had high affinity to iron and zinc, *Eichhornia crassipes* had high affinity to iron and manganese and Canna indica high affinity to iron, copper, zinc and manganese. Furthermore, the accumulator species is ranked: *Canna indica* and *Eichhornia crassipes* had high affinity to remove total trace metals than *Phragmites australis* - Boos.

These relations can be used as bio-indicator for water quality restoration to avoid negative environmental impacts along fish farms in drainage catchments system (Qixia *et al.,* 2011).

These factors showed the high tendency of heavy metals accumulation load in all plants that are present in the out of fish farms as shown in Figure (6). Maximum mean ∑BCF values for three plant were Fe: 33173, Zn: 1451, Cu: 1418, Mn: 1315.5, Pb: 468.65 and Cd: 158.6 respectively; while their maximum BCF values for Fe: 17260, Cd: 81.4 in Canna indica, Cu: 617.3, Mn: 482 in *Eichhornia crassipes*, Zn: 649, Pb: 226.5 in *Phragmites Communis*, respectively Table (2).

Environmental Purification

The data in summer and winter seasons through time series analyses (Figure 7-12) showed that there is a strong dependence among the pollutants concentration and their purification rate. Also, when the pollutants concentrations are taken into account, the concentrations during summer season are marginally higher compared to winter season.

Eutrophication and Total Suspended Solids

One of the common parameters used in defining a waste-water is TSS. TSS values in the studied area fluctuate with significant seasonal variations as shown in Figure (7), because of the adsorption/precipitation reactions of phosphorous and nitrogen removal along the different plant species where TSS were effectively decreased via settling and filtration through the dense plants and sedimentation (Kadlec and Wallace, 2008).

Nitrogen is removed primarily through nitrification (in water column) and subsequent de-nitrification (in the litter layer), and ammonia volatilization under higher pH values caused by algal photosynthesis. Phosphorus retention is usually low because of limited contact of water with soil particles which adsorb and/or precipitate phosphorus (Kadlec and Wallace, 2008). According to the analysis findings, about 60% of total nitrogen is in the ammonia form while minor parts are in nitrate, nitrogen forms and the remainder is organic form. This means that mineralization is the predominant process in the water system. Figure (8) showed the purification of total nitrogen (TN) along outflow drains. It is clear that the high values of TN vary along El-Hax drain even though values are very similar for both El-Far and El-Canal drains due to the local conditions of fish farms as morphology, pollutants types and concentrations, light density and dilution effects at site locations.

Oxidizable Organic Material

Dissolved oxygen concentrations are measured directly in wastewater but the potential concentrations of oxygen are measured by oxygen demand and biological activity. So, it is one of the most important biological water quality characteristics in the aquatic environment. It represents the status of the water system at a particular point and time of sampling as shown in Figure (9). The main factor that affected DO is the water velocity that fluctuates along the study period season.

Biochemical Oxygen Demand (BOD) is an index of the

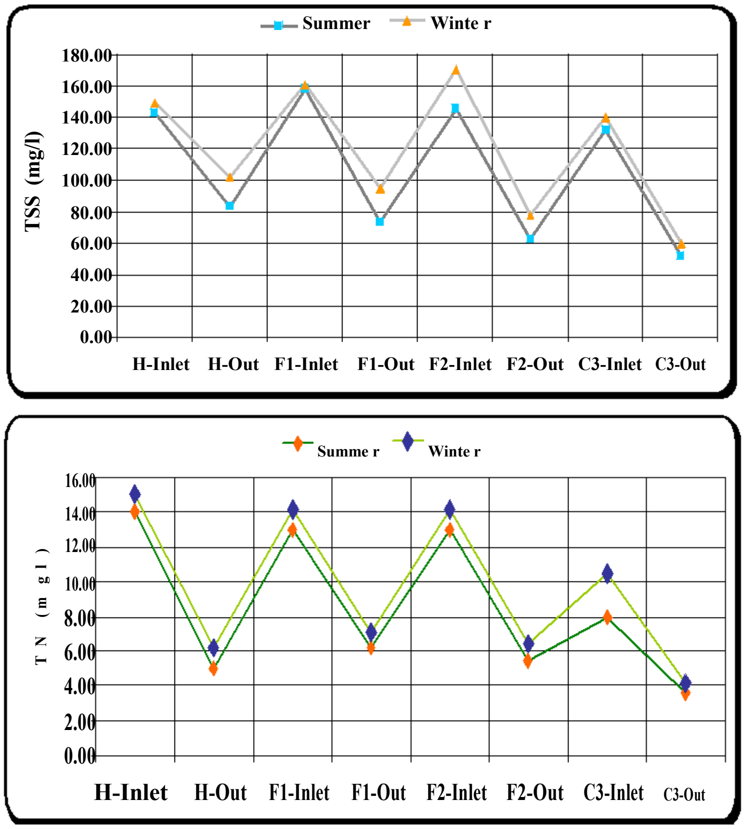

Figure (7-8). Variation of TSS and TN during Study Period

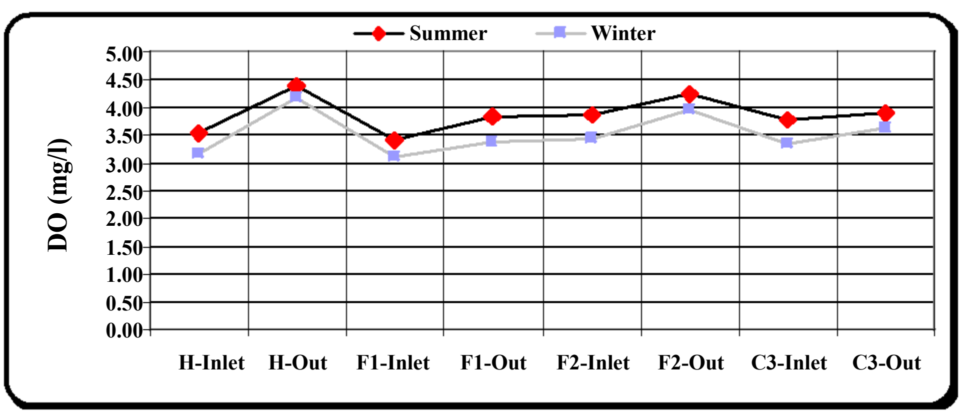

Figure (9). Variation of D.O Concentrations during Study Period

oxygen-demanding properties of the biodegradable material in the drainage water. Also, chemical oxygen demand (COD) is a measure of the pollutant loading in terms of complete chemical oxidation using strong oxidizing agents. The results of BOD and COD vary over a considerably smaller range through investigated sites and follow water patterns.

Figures 10 and 11 show the variations of both BOD and COD according to temperature and time along summer and winter seasons, they indicate higher response of BOD removal more than COD that indicated the wastewater had more non-degradable substances. All the values are closed to national water courses standards (Egyptian Environmental Law 9/2009, BOD: 15 mg/l and COD: 10 mg/l). In the second reach of the El-Far drain, a remarkable decrease is detected (8 and 9 mg/l in summer and winter seasons) in the pollution due to the change in chemical properties (considerable increase in salinity and dominant major ions) and excess of bio-accumulator plants.

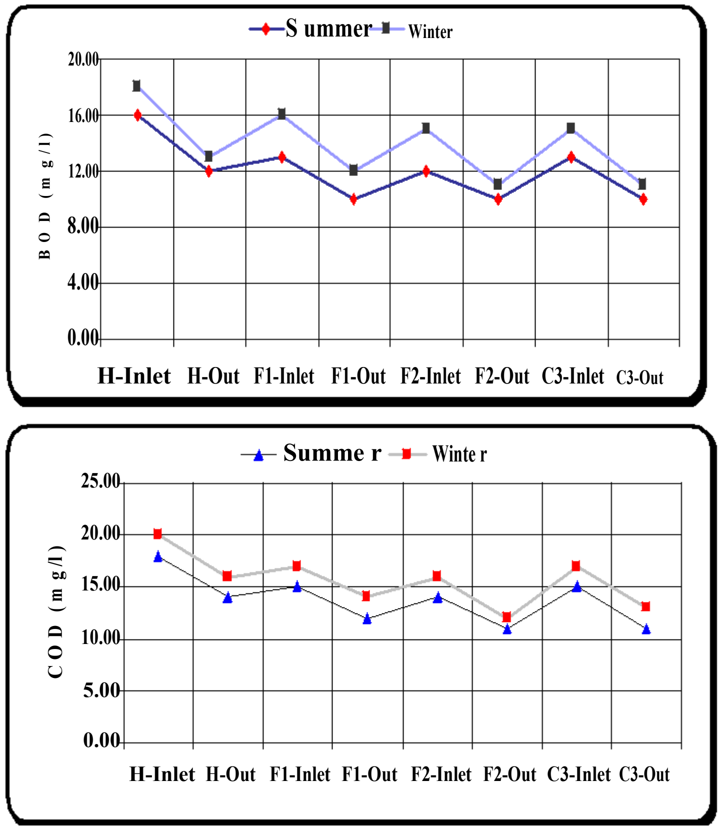

Figure (10-11). Variation of Oxidizable Organic Material (BOD and COD) Concentrations in Summer and Winter Seasons

Therefore, organic compounds are effectively degraded mainly by microbial degradation under anoxic/anaerobic conditions as the concentration of dissolved oxygen in the filtration beds is very limited (Vymazal and Kröpfelová, 2008).

Ecological Organic Uptake

Organic matter contains 45-50% organic carbon which is utilized by a wide array of micro-organisms as a source of energy for growth, so in-stream wetland has high efficiency for the removal of organics (COD and BOD) in general (Vymazal and Kröpfelová, 2008). Figures (10) and (11) showed that the high organic compounds (COD and BOD) uptake is carried out over study duration in El-Far, El-Canal and El-Hax drain. The concentrations of organic compounds are considerable degraded biologically (aerobic and anaerobic) using the high numbers of micro-organisms (T.C and F.C) found at the polluted sites. Interpretation of COD and BOD concentration variations suggests that these micro-organisms consumes oxygen (O_2) (aerobic: O_2-rich) in surface wastewater to breakdown soluble organic carbon to low molecular weight organic acids, carbon dioxide (CO_2) and methane (CH_4), both of them are lost to atmosphere.

Organic matter + O_2 → energy + CO_2 + CH_4 ↑ (1)

Organic matter (Decomposition) → organic carbon + fine particulates matter + dissolved compounds↓ (2)

Therefore, organic matter is stored and recycled (anaerobic: O_2-depleted) copious amounts of organic carbon in plants, and micro-organisms.

Toxic Organic Pollutants

Organic substances that are persistent possess toxic characteristics likely to cause adverse human health or environmental effects. Persistent Organic Pollutants (POPs) is a group of compounds, which are prone to long-range atmospheric transport and deposition (UNEP, 1996). POPs are highly resistant to chemical and biological degradation. The analysis showed that individual traces organic pollutants: organochlorine, organophosphorous, pyrethroid and carbamate concentrations are negligible (< 0.01µg/l) that were within limits for Egyptian environmental Law 9/2009 (all pesticides ≤1mg/l) and ineffective in drainage water for all site locations and seasonally.

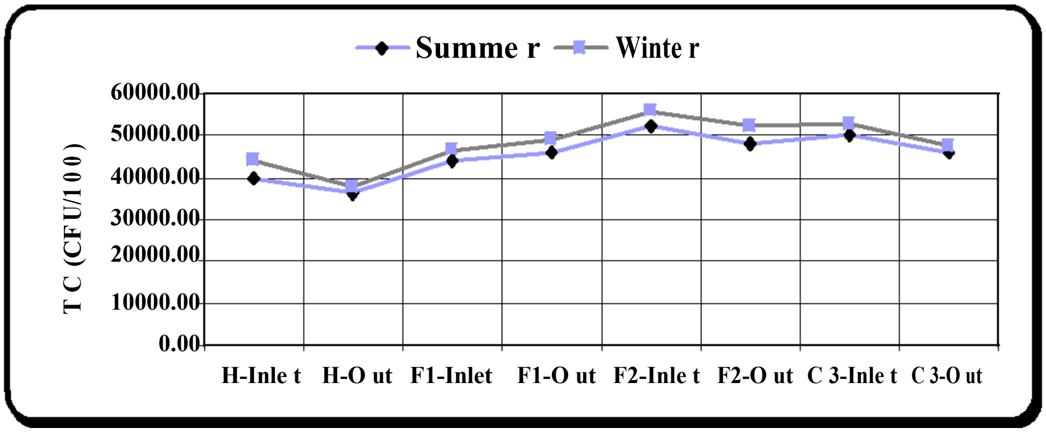

Figure (12). Variation of T.C Count in Summer and Winter

Bacteriological Wastes

High level of pathogenic and other polluting agents raises concern about its consequences for both health and ecology. Therefore, some indicators are used to reflect the presence of pollution such as fecal coliforms (FC) and Total Coliforms (T.C) as the most world-wide accepted bacteriological indicators.

Figure (12) demonstrated the variations of T.C count in summer and winter seasons in investigated study. They indicate higher response of T.C removal in summer season as a result of dilution factor. Moreover, a remarkable decrease is detected (46X103 CFU to 22X103 CFU and 48X103 to 28X103 CFU in summer and winter seasons - El-Far drain) near to the plant communities due to the change in chemical properties with rhizofiltration environmental conditions around *Phragmites australis* (Boos) roots, *Eichhornia crassipes* and *Canna indica* as a hydro-accumulator plant than any other parameter.

Therefore, the most important roles of plants along three fish farms were the provision of roots and rhizomes for the growth of attached bacteria, radial oxygen loss (oxygen diffusion from roots to the rhizosphere), the microbial degradation processes are mostly aerobic (Vymazal, 2010).

CONCLUSIONS

The introduction of contaminants through effluent to different environments can often overcome the self-cleaning capacity of recipient ecosystems and thus resulting in the accumulation of pollutants to problematic or even harmful levels. An awareness of environmental problems caused by fish farms wastewaters has prompted many countries to treat the discharge of fish farms effluents before discharge to drainage network. Drainage water reuse can provide water solution for small scale agricultural irrigation practices in addition to fishery and other activities.

This study investigated self-purification process and the behavior of chemical and bacteriological constituents in water stream and highlights the advantages of the self-cleaning phenomena of polluted water stream using BCF index. The data showed the physicochemical characteristics of fish farms effluents, drainage water quality system, understanding the contributions of fish farms in drainage water quality network and the drain's ability to recover negative environmental impact. The controlling discharges from individual fish farms into drainage network system using rhizofiltration application can be done for safe sustainable environment and development.

RECOMMENDATIONS

The following studies are recommended for future investigation:

1- Study the self-purification process to reuse drainage water for many proposes to determ-ine the ability of a stream to assimilate waste discharges.

2- A broad view of In-Stream wetland is an effective, cheap, and simple treatment alternative for future environmental and economical management options for reuse drainage water as broad-spectrum treatment

3- Utilize QC/QA programs to determine the most effective variables for water quality variants, especially toxic wastes for aquatic organisms.

4- Initiate a special program for biodegradable and non-degradable organic pollutants such as volatile organic contaminants in industrial wastes induced to the drainage system and the suitable treatment technique to reduce them.

5- Initiate a special program for fish pollutants such as bacteriology, toxic organics to check safe use for consumer.

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