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Adopting flow and pollutants loads of subsurface flow constructed wetlands to cope Egyptian water reuse standards

Sally Mostafa[1], Rashed, A. A.[2] and Mohsen Ezzeldin.[3]

[1]Executive Engineer Egyptian Public Authority for Drainage Projects, Cairo, Egypt
[2]Professor, and Director Research Institute of Ground Water, National Water Research Center, Cairo, Egypt
[3]Professor, Faculty of Engineering Mansoura University, Egypt
Sally.mostafa62@yahoo.com

Abstract: Wastewater treatment using subsurface flow, (SSF) constructed wetland, (CW) has been increasingly applied throughout the world, as it is an efficient technique for the removal of pollutants and presents low construction and operational costs. However, a major operational problem of these systems is the treatment capacity to keep the flow completely subsurface as designed. The over design treatment capacity in addition to clogging of the porous medium may reduce its performance producing water that may contain pollutants above the vital target. In this paper a practical field operation program of an old pilot scale SSF CW was employed to adopt its treatment performance according to both predicted media porosity and the water quality standards of the Egyptian drainage water production and reuse. Three CW cells in Aga city, Dakahlia, Egypt, with gravel, pieces of plastic pipes, and shredded tire rubber chips as treatment media were tested with wide range of flow rates (0.7 – 9.0 m3/d) followed by a water quality evaluation to select the optimum rate compatible with the treated water standards. The limiting effluent treated pollutants for drainage water reuse were BOD, COD, DO, NH4, PO_4, TSS and FC, of which COD was the governing pollutant in the cells operation since the safe limit realized/obtained from the smallest (governing) discharges that were 1.3, 2.00 and 1.00 m3/d for gravel, plastic and rubber respectively.
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1. Introduction

Constructed wetlands (CWs) are increasingly being used globally over the last 40 years for the pollutants treatment of several wastewaters types, including municipal, industrial, agricultural and hazards wastes, (Gikas et al., 2017). They are treatment units, which mimic conventional treatment systems, with mechanisms to remove pollutants via combinations of medium-plant-microorganisms system. The CWs are classified into surface water flow, either vertically or horizontally subsurface water flow, and a combination of the two types (Kadlec and Wallace, 2009).

As a green technology, it has many advantages compared with conventional treatment systems, such as flexibility against shock loads, low maintenance and operational costs, and minimal power consumption. Horizontal SSF represents one of the dominant types of CWs through which wastewater flows beneath the surface of the porous media in a fully saturated flow pattern (Kadlec and Wallace, 2009). With continuous operation, the treatment media faces gradual decreasing in its porosity due to accumulation of organic/non-organic matter as well as the expansion of roots and rhizomes of CW's aquatic plants. Increasing this accumulation may cause flow overtopping, media clogging resulting in producing treated water that did not realize the designed targets.

Previous studies showed that horizontal SSF CW was much tolerant against media clogging than the vertical SSF CW due to its advanced continuous or intermittent loading regime, substrate material, and influent water feeding position (above media or through its cross section) (Kadlec and Wallace 2009 and Wu et al. 2015). Pedescoll et al. (2011) and Paoli and von Sperling (2013), found that the planted SSF CWs had better hydraulic conductivity than the unplanted CWs.

Wastewater treatment is classified by the contaminants concentration and the planned purpose of reuse (David et. Al, 2017). According to treatment levels, such reuse may be at landscape, fire protection, concrete mixing, car washing, toilet flushing, machinery coolant, industrial process water, agriculture, and bathing [Haering, et al., 2009]. Agricultural wastewater reuse is usually guided by restricted standard guidelines including the United States Environmental Protection Agency (USEPA) guideline for reuse for irrigation [US EPA, 2004], Food and Agriculture Organization (FAO) guidelines [FAO, 2016], and the World Health Organization (WHO) guidelines [WHO, 2006]. Considering these guidelines is a must to prevent the spread of diseases and the attendant risk to public health. Egypt has its treated wastewater regulation for dumping at agriculture drains to be mixed with its drainage water or for either direct reuse or via mixing drain water with the fresh canal water (MWRI, (2013).

The SSF CWs can produce an advanced treated wastewater after passing through a primary treatment facility such as sedimentation tanks. Coping reuse standards, such treated water can be directly used in non-edible crops cultivation or edible crops production after its mixing with fresh water in a certain mixing ratio. However, effluent discharges from existing overloading wastewater treatment plants such as CWs can contain toxic pollutants. Samaha municipal wastewater treatment plant contained SSF CW units was a sample of such overloading plants. Changing wetland media material to increase its porosity and treatment efficiency was a solution to overcome this overloading problem. Reducing/adopting its effluent discharge may be a short term solution.

The main objective of this study is to find the maximum discharges that can be treated through 3 type's media Samaha wetland cells to produce the permissible limits of BOD-COD-TSS-DO-FC-NH_4-PO_4 pollutants measured in the effluent water. These values might be suitable for such wetlands that may face water overtopping due to overloading, overdesigning or media partial clogging. These adaptations can offer new water sources that can be mixed with canal fresh water saving equivalent better quality water amounts for much precious uses.

2. Methodology

Field and experimental work

The only and oldest municipal wastewater treatment plant (WWTP) had a SSF CW is Samaha WWTP located in Dakahlia governorate, Nile Delta, Egypt (30° 52' 09.81" N and 31°16' 55.28" E) (Company of drinking water and wastewater).

A series of sedimentation tanks followed by 8 SSF CW cells and a polishing sand filter representing primary, secondary and tertiary treatment of a 5000 capita village was built in 1995. Due to the overloading situation of the plant, a pilot SSF CW was built in 2012 using higher porosity materials media (hollow plastic pipes and shredded tiers chips) in order to decrease the treatment footprint of the plant to accommodate additional discharge due to the increase in village population.

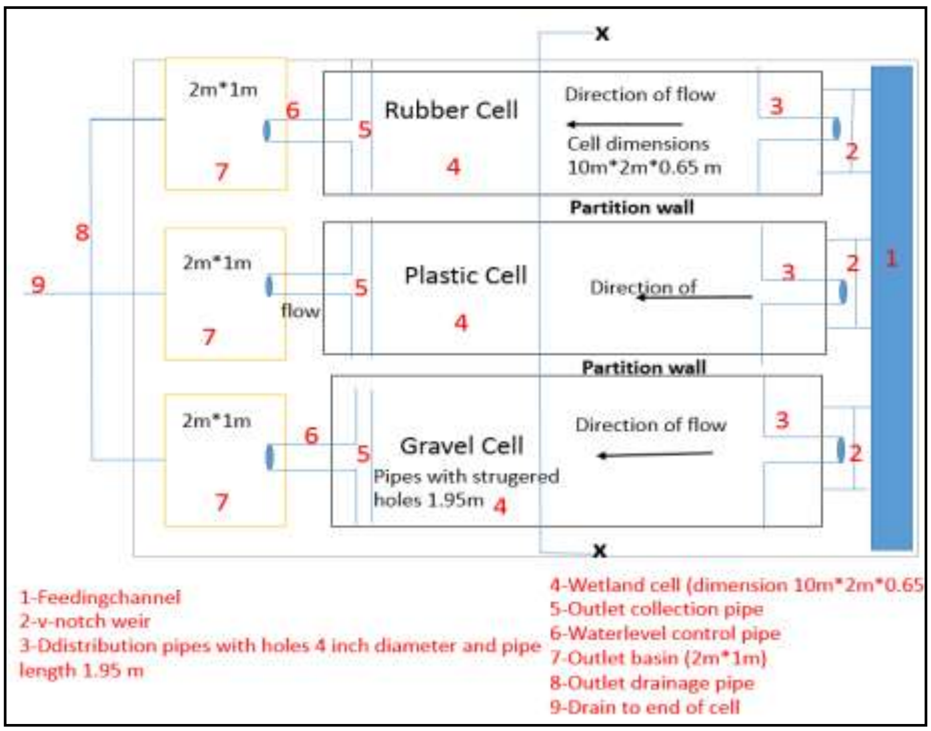

Figure (1) Components of media cells

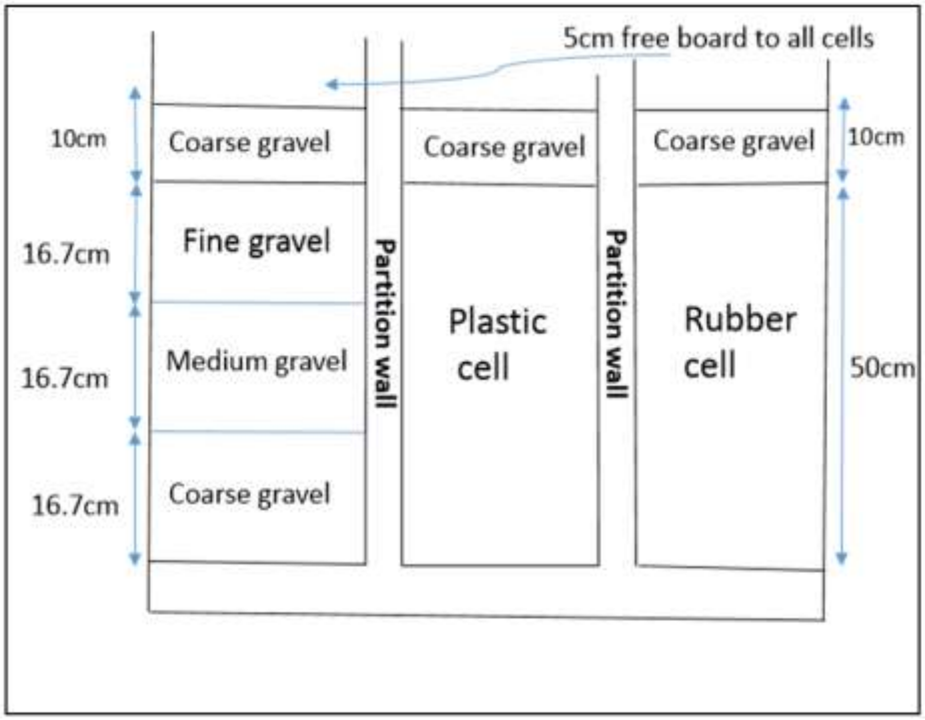

Figure (2) cross section x-x show layers of each media cell

Three parallel micro SSF CW cells (10 m long, 2 m wide, and 0.65 m deep each), formed the pilot plant. The 1^{st} cell contained rubber media made from shredded tires (each peace had dimensions of 30–60 * 25–55 * 5–15 mm), the 2^{nd} was filled with hollow pieces of plastic pipes 50 mm length and 19 mm diameter and the 3^{rd} cell was similar to the originally built gravel cells placed in 3 layers (40-60 mm, 20-40 mm and 15-20 mm at bottom, middle, and top respectively). A plastic screen covered by 10 cm fine gravel layer was placed on top of each cell, to prevent floating of plastic media, (figure 1,2).

Loading rate and water sampling practices

To identify the suitable SSF CW cells loading rate that can produce treated water, according to the Egyptian standards, 16 discharges were applied in the range from the lowest (0.788 m^3/d or 0.039 $m^3/m^2/d$) to the highest (9.712 m^3/d or 0.486 $m^3/m^2/d$). Calibrated V-notched weirs fixed at cells outlet were used to adopt the influent discharges. Each discharge was applied for 10 days through cells to reach the media treatment stability, and both its biofilm and plants adaptation. Just before flow rate changing, water samples will be collected from each cell's inlet and outlet of 3 cells for analysis followed by adjusting the 3 inlet weirs for the next assigned discharge. Water samples will be stored in ice tanks, sent to laboratory and analyzed for BOD, COD, TSS, DO, NH_4, PO_4 and FC.

Estimation of media porosity

Abdel-Hady, 2014, introduced an innovating method to measure the field media porosity using a porosity measuring apparatus. Portable media buckets were placed and periodically removed from the treatment cells and the void ratio and porosity were measured in a calibrated tank via water displacement procedure during the 1^{st} 240 days of cells operation (Abdelhady, 2014). In this study, the pervious porosity of three media types and the entrance coarse gravel were plotted against time during the 218 days pervious study and by using data extrapolation, porosity values will be predicted for additional 2250 days. As this study was carried out after 1830 days of the 1st day of pervious study operations and due to multiple reasons plant stops such as cells maintenance and power failure. Porosity values will be taken corresponding to the extrapolation of only 1000 days actual cells operation.

Performance evaluation of treatment cells

Cells actual water volume and retention time are required to calculate the treatment efficiency of each treatment cell to know the performance of each cell to each pollutant and also the time that water spends in each one to evaluate the efficiency of the system as shown in figures (3 to 15). Cells water volume was calculated by equation (1) which can proof by taking section in total length (10m) as shown in figure (3):

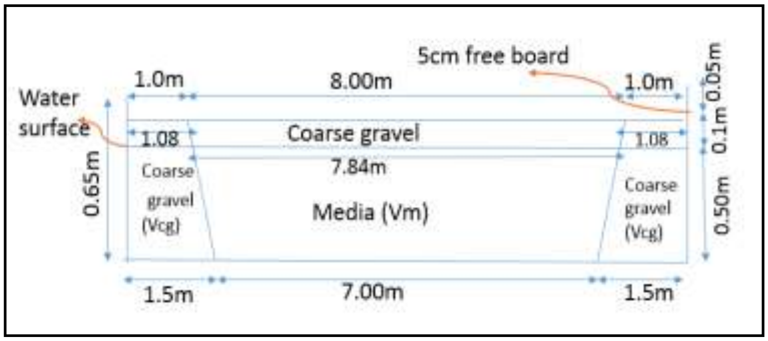

Figure (3) longitudinal section in wetland cell media

V_{total} = ncg V_{cg}+nm Vm (volume at total cell in submerged cell area)
V_{cg} total = 2*V_{cg}
=2(1.5+1.08/2)*0.50*2
=1.29*2=2.58 m^3
V_m = (7+7.84/2)*0.5*2.00 =7.42m^3
$V_w = 2.58 \times n_{cg} + 7.42 \times n_m$, ($m^3$) (1)
V_w = water volume in the wetland cell, (m^3)
n_{cg} = porosity of coarse gravel
n_m = porosity of used media
2.58 & 7.42 = length of cell entrance and cell media, respectively, (m)
The hydraulic retention time, T_r was obtained from equation (2)
$T_r=V_w/Q$ (2)
Where Q = treated discharge (m^3/d)

The removal efficiency of studied pollutants were calculated according to equations (3), (Kadlec and Wallace, 2009), where: RE = removal efficiency, %, C_o = effluent concentration, mg/l, and C_i = influent concentration, mg/l.
$RE=1-(C_o/C_i)*100$ (3)

Article 52/2013, (subject 64) of the modifications of the Law 48/1982 (Ministry of Water Resources and Irrigation) MWRI, will be used as a reference to obtain the suitable cells flow discharges that its effluent water quality is fitting these laws (MWRI, 2013). For example, BOD reference value of the effluent municipal wastewater draining at non-fresh water (drains) is 60 mg/l as represented in the law. The suitable cell discharge should produce a BOD effluent concentration less than or equal this 60 mg/l reference limit and this discharge may be called an optimum flow rate.

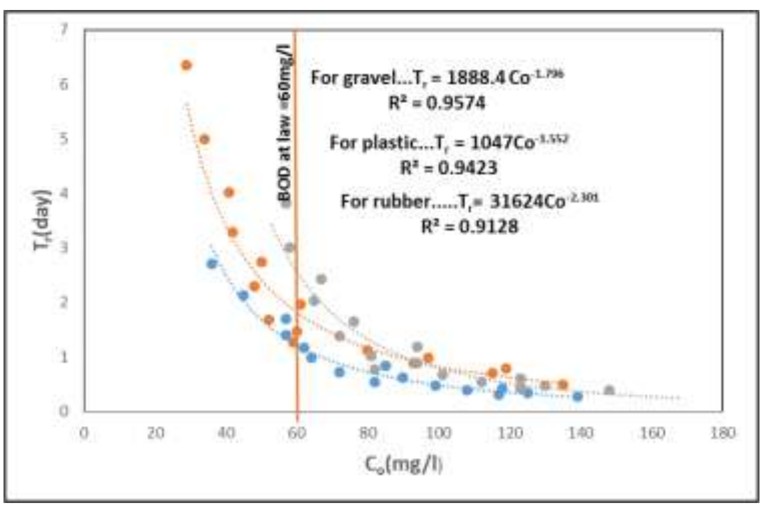

Figure (4) BOD effluent concentration comparing with its retention time for the 3 cells

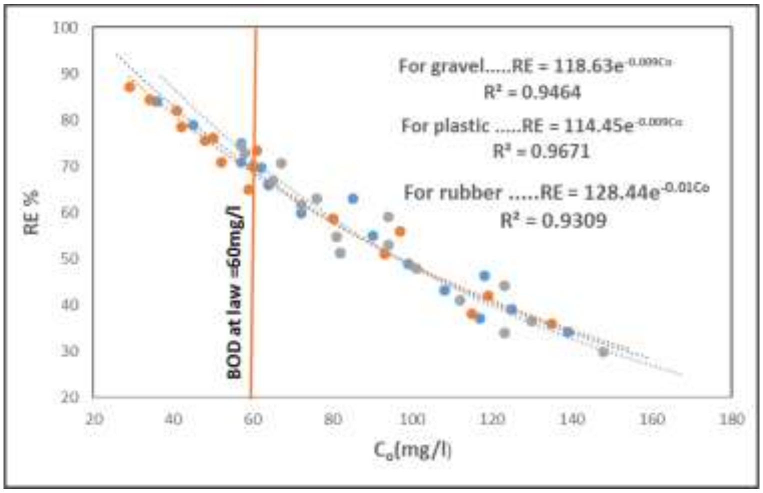

Figure (5) BOD effluent concentration comparing with its removal efficiency for the 3 cells

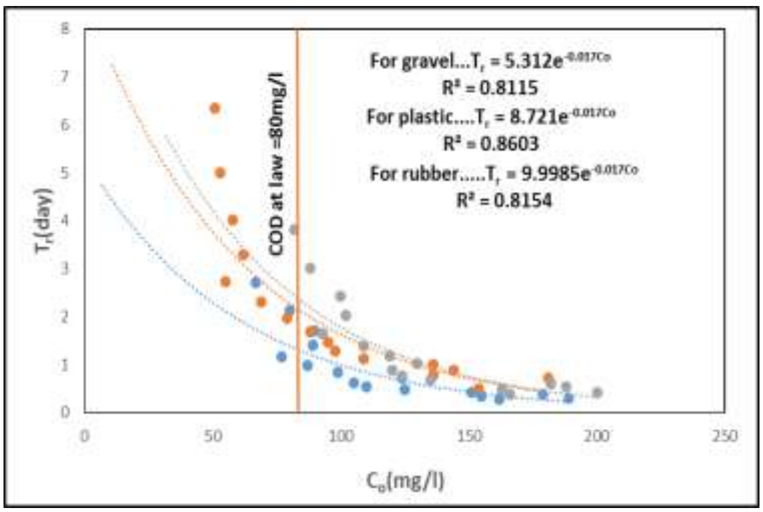

Figure (6) COD effluent concentration comparing with its retention time for the 3 cells

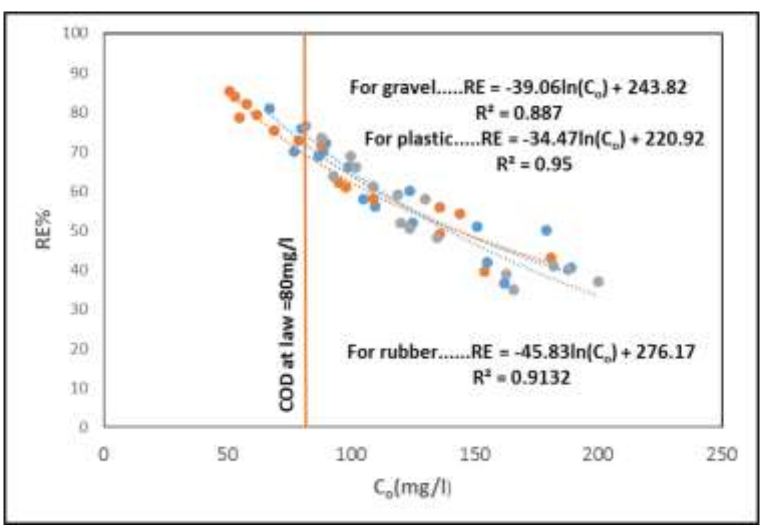

Figure (7) COD effluent concentration comparing with its removal efficiency for the 3 cells

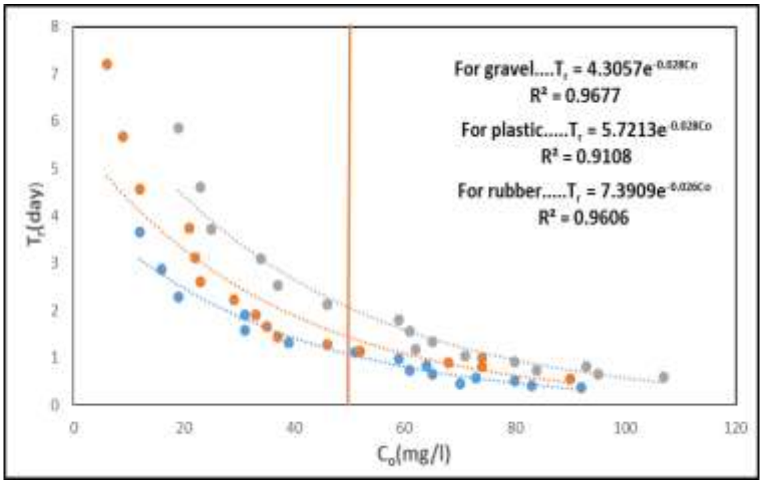

Figure (8) TSS effluent concentration comparing with its retention time for the 3 cells

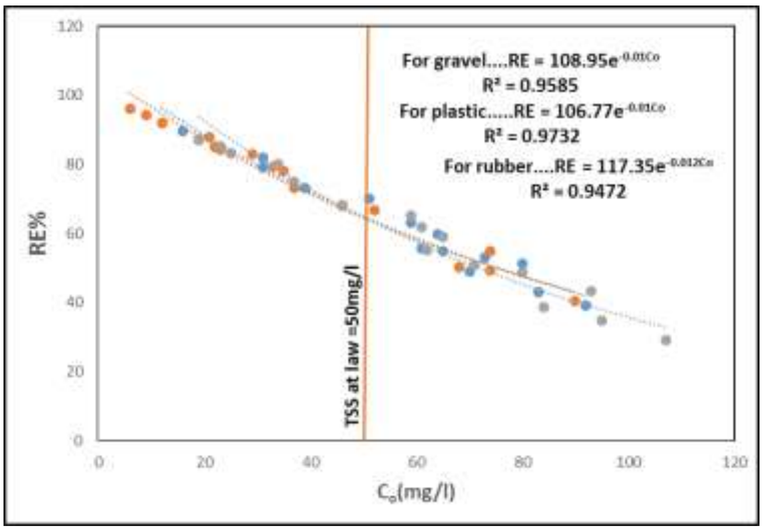

Figure (9) TSS effluent concentration comparing with its removal efficiency for the 3 cells

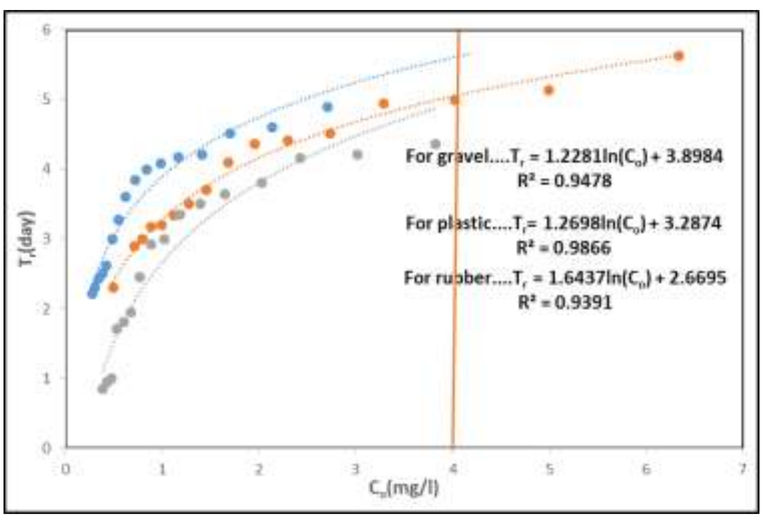

Figure (10) DO effluent concentration comparing with its retention time for the 3 cells

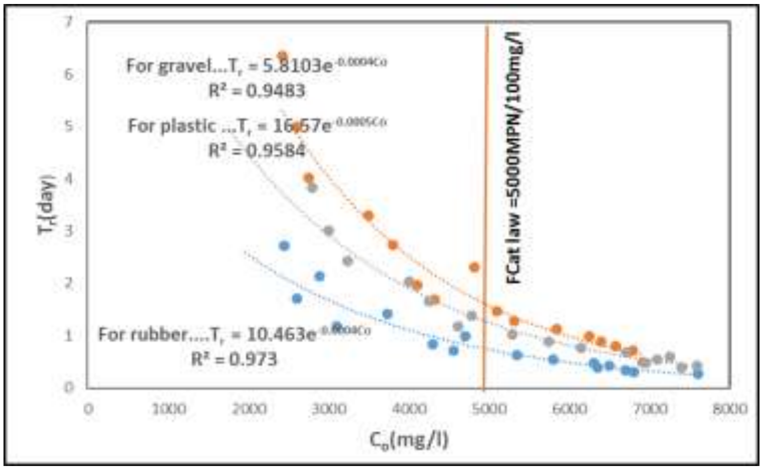

Figure (11) FC effluent concentration comparing with its retention time for the 3 cells

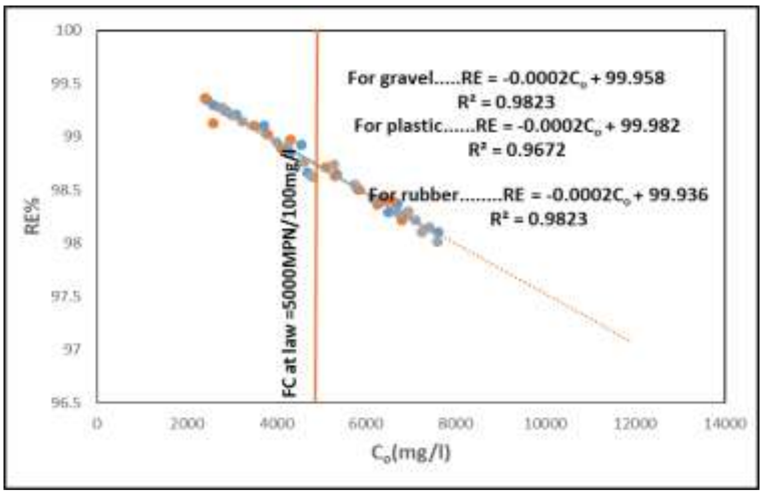

Figure (12) FC effluent concentration comparing with its removal efficiency for the 3 cells

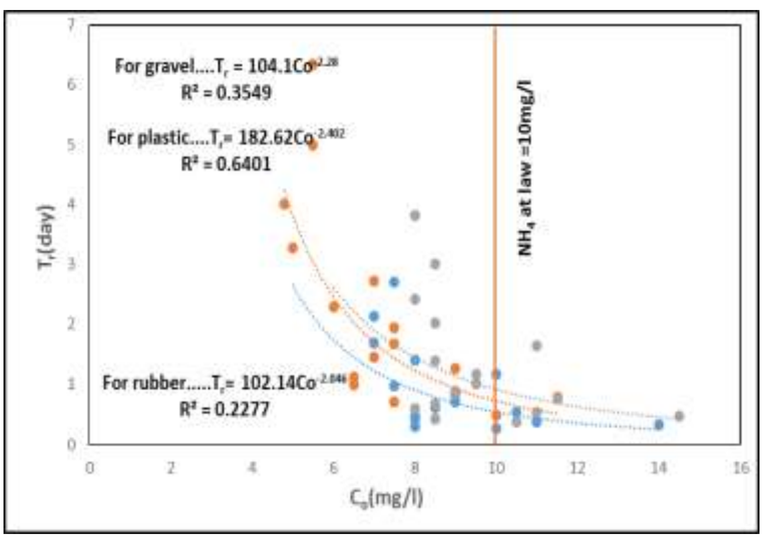

Figure (13) NH_4 effluent concentration comparing with its retention time for the 3 cells

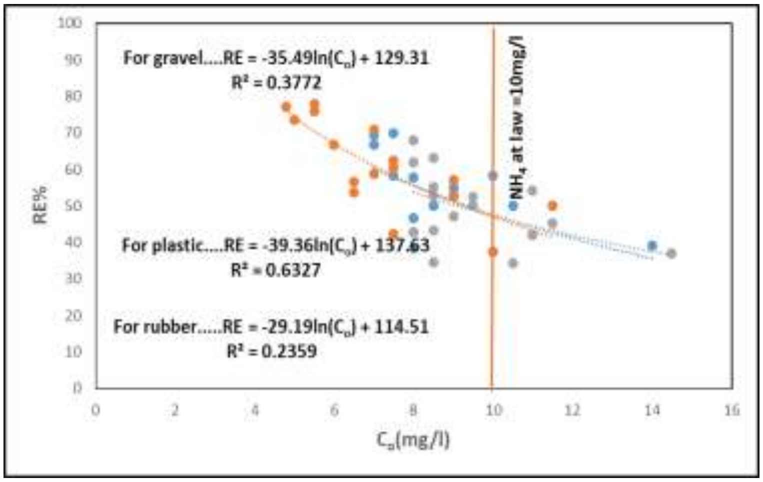

Figure (14) NH_4 effluent concentration comparing with its removal efficiency for the 3 cells

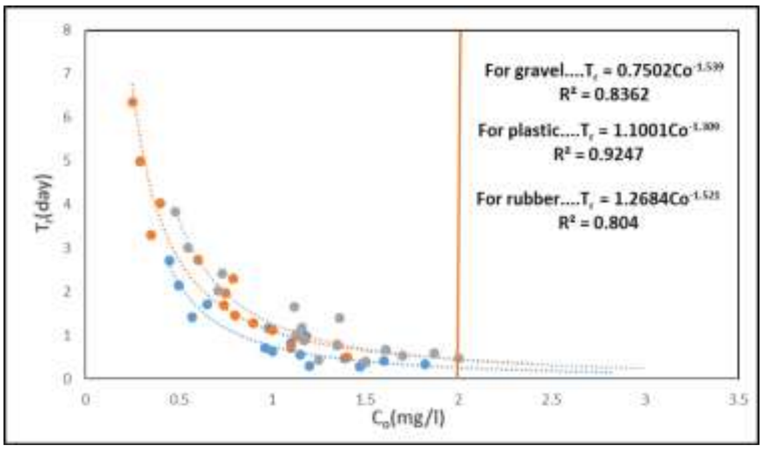

Figure (15) PO_4 effluent concentration comparing with its retention time for the 3 cells

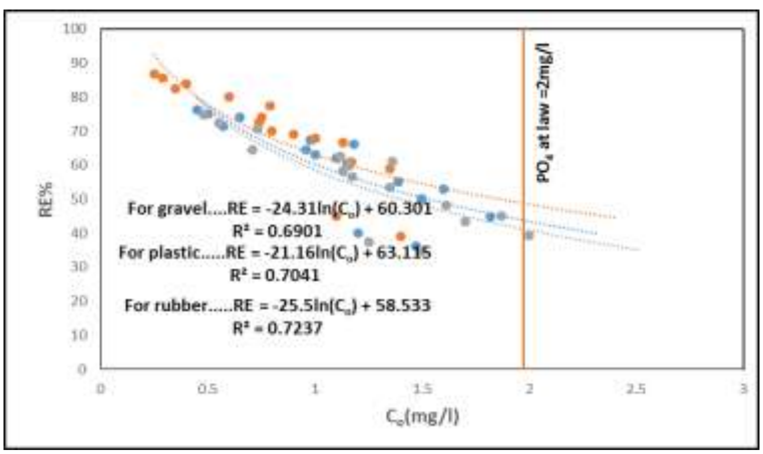

Figure (16) PO_4 effluent concentration comparing with its removal efficiency for the 3 cells

The relationship between the effluent concentrations of BOD and retention time for the three cells media to a power function (figure 4) obtaining the following relationships:

Gravel: $T_r = 1888.40\, C_o^{-1.796}$ R^2=0.957

Plastic: $T_r = 1047\, C_o^{-1.552}$ R^2=0.942

Rubber: $T_r = 31624\, C_o^{-2.301}$ R^2=0.9128

Where:

C_o= BOD outlet concentration, mg/l
T_r= retention time (day)

The relationship between the effluent concentrations of BOD and removal efficiency for the three cells media to exponential function figure (5) obtaining the following relationships:

Gravel: $RE = 118.63\, e^{-0.009 C_o}$ R^2=0.946
Plastic: $RE = 114.45\, e^{-0.009 C_o}$ R^2=0.9671
Rubber: $RE = 128.44\, e^{-0.01 C_o}$ R^2=0.9309

Where:
C_o= BOD outlet concentration, mg/l
RE= removal efficiency (%)

The relationship between the effluent concentrations of COD and retention time for the three cells media to an exponential function (figure 6) obtaining the following relationships:

Gravel: $T_r = 5.312\, e^{-0.017 C_o}$ R^2=0.8115
Plastic: $T_r = 8.721\, e^{-0.017 C_o}$ R^2=0.8603
Rubber: $T_r = 9.9985\, e^{-0.017 C_o}$ R^2=0.8154

Where:
C_o= COD outlet concentration, mg/l
Tr= retention time (day)

The relationship between the effluent concentrations of COD and removal efficiency for the three cells media to logarithmic function figure (7) obtaining the following relationships:

Gravel: $RE = -39.06 \ln C_o + 243.92$ R^2=0.887
Plastic: $RE = -34.47 \ln C_o + 220.92$ R^2=0.950
Rubber: $RE = -45.83 \ln C_o + 276.17$ R^2=0.9132

Where:
C_o= COD outlet concentration, mg/l
RE= removal efficiency (%)

The relationship between the effluent concentrations of TSS and retention time for the three cells media an exponential function (figure 8) obtaining the following relationships:

Gravel: $T_r = 4.3057\, e^{-0.028 C_o}$ R^2=0.9676
Plastic: $T_r = 5.7213 e^{-0.028 C_o}$ R^2=0.9109
Rubber: $T_r = 7.3909\, e^{-0.026 C_o}$ R^2=0.9606

Where:
Co= TSS outlet concentration, mg/l
T_r= retention time (day)

The relationship between the effluent concentrations of TSS and removal efficiency for the three cells media to exponential function figure (9) obtaining the following relationships:

Gravel: $RE = 108.95\, e^{-0.01 C_o}$ R^2=0.9585
Plastic: $RE = 106.77\, e^{-0.01 C_o}$ R^2=0.9732
Rubber: $RE = 117.35\, e^{-0.012 C_o}$ R^2=0.9472

Where:
C_o= TSS outlet concentration, mg/l
RE= removal efficiency (%)

The relationship between the effluent concentrations of DO and retention time for the three cells media is logarithmic functions (figure 10) obtaining the following relationships:

Gravel: $T_r = 1.228\, lnC_o + 3.8984$ R^2=0.9478
Plastic: $T_r = 1.2698\, lnC_o + 3.2874$ R^2=0.9866
Rubber: $T_r = 1.6437\, lnC_o + 2.6695$ R^2=0.9391

Where:
C_o= DO outlet concentration, mg/l
T_r =retention time (day)

The relationship between the effluent concentrations of FC and retention time for the three cells media to an exponential function (figure 11) obtaining the following relationships:

Gravel: $T_r = 5.8103\, e^{-.0004 C_o}$ R^2=0.9483
Plastic: $T_r = 16.57\, e^{-.00004 C_o}$ R^2=0.9584
Rubber: $T_r = 10.463\, e^{-.0004 C_o}$ R_2=0.973

Where:

C_o= FC outlet concentration, MPN/100ml

T_r = retention time (day)

The relationship between the effluent concentrations of FC and removal efficiency for the three cells media to linear function figure (12) obtaining the following relationships:

Gravel: $RE = -0.0002C_o + 99.958$ R^2=0.9823

Plastic: $RE = -0.0002C_o + 99.982$ R^2=0.9672

Rubber: $RE = -0.0002C_o + 99.936$ R^2=0.9823

Where:

C_o= FC outlet concentration, MPN/100ml

RE= removal efficiency (%)

The relationship between the effluent concentrations of NH_4 and retention time for the three cells media to a power function (figure 13) obtaining the following relationships:

Gravel: $T_r = 104.10\, C_o^{-2.28}$ R^2=0.3549

Plastic: $T_r = 182.62\, C_o^{-2.402}$ R^2=0.6401

Rubber: $T_r = 102.14\, C_o^{-2.046}$ R^2=0.2277

Where:

C_o= NH_4 outlet concentration, mg/l

T_r = retention time (day)

The relationship between the effluent concentrations of NH_4 and removal efficiency for the three cells media to logarithmic function figure (14) obtaining the following relationships:

Gravel: $RE = -35.94 \ln C_o + 129.31$ R^2=0.3772

Plastic: $RE = -29.19 \ln C_o + 114.51$ R^2=0.2359

Rubber: $RE = -39.36 \ln C_o + 137.63$ R^2=0.6327

Where:

C_o= NH_4 outlet concentration, mg/l

RE= removal efficiency (%)

The relationship between the effluent concentrations of PO_4 and retention time for the three cells media to a power function (figure 15) obtaining the following relationships:

Gravel: $T_r = 0.7502C_o^{-1.539}$ R^2=0.8362

Plastic: $T_r = 1.1001C_o^{-1.309}$ R^2=0.9247

Rubber: $T_r = 1.2684C_o^{-1.521}$ R^2=0.8040

Where:

C_o= PO_4 outlet concentration, mg/l

T_r = retention time (day)

The relationship between the effluent concentrations of PO4 and (RE removal efficiency) for the three cells media logarithmic function figure (16) obtaining the following relationships:

Gravel: RE= $-24.3 \ln C_o + 60.301$ R^2=0.6901

Plastic: $RE = -21.16 \ln C_o + 63.115$ R^2=0.7041

Rubber: $RE = -25.5 \ln C_o + 58.533$ R^2=0.7237

Where:

C_o= PO_4 outlet concentration, mg/l

RE =removal efficiency

Figures (4) to (16) presented the effluent pollutant concentrations C_o against the removal efficiency and retention time for BOD, COD, TSS, DO, FC, NH_4 and PO_4 respectively. Figure (4) presents BOD C_o-T_r relationship for the 3 cells and the reference BOD value (60 mg/l). There is indirect relationship between Co and T_r as the C_o increases with the decrease of T_r. The safe C_o value are shown against the T_r values were 0.26 for rubber, 1.20day for gravel while there are a wide range for plastic media as the 60 mg/l BOD exists at a discharge of 1.80 day. The performance of plastic media cell was much better than the 2 other cells and water still in plastic cell more than any other cell.

Figure (5) presents BOD C_o-RE relationship for the 3 cells and the reference BOD value (60 mg/l). There is indirect relationship between Co and RE as the Co increases with the decrease of RE. The safe Co value are shown against the RE values were 67% for rubber, 69%for gravel while plastic media was 70%. The performance of plastic media cell was much better than the 2 other cells while the gravel cell showed better performance than the rubber cell and the efficiency of treated water is the best in plastic cell.

Figure (11) presents the FC C_o-T_r relationship for the 3 cells compared with the article 52/2013 modified of law 48/1982 reference FC value (5000 MPN/100 ml). The safe C_o values are shown against the T_r were 1.00day for gravel, 1.20day for rubber and 2.00day for plastic. The performance of plastic media cell was much better than the 2 other.

Figure (12) presents FC Co-RE relationship for the 3 cells compared with the article 52/2013 modified of law 48/1982 reference FC value (5000 MPN/100 ml). There is indirect relationship between C_o and RE as the C_o increases with the decrease of RE. The safe Co value are shown against the RE values were 99% for rubber, 99%for gravel while plastic media was 99%. The performance of plastic is similar to plastic and rubber so, the efficiency of treated water is equal in 3 cells for FC pollutant.

3. Results and Discussions

Hydraulic performance and media porosity

Table (1) The values of porosity used in calculation retention time and drawing the curve of porosity.

T_o (day)	n_{cg}	n_g	n_p	n_r
0	0.453	0.431	0.866	0.576
15	0.431	0.404	0.842	0.558
31	0.411	0.393	0.827	0.544
40	0.398	0.381	0.819	0.533
77	0.387	0.374	0.812	0.527
107	0.376	0.365	0.799	0.516
155	0.371	0.362	0.795	0.512
218	0.365	0.358	0.788	0.505

Porosity reductions were observed during the first 218 days of wetlands initial operation in 2012 due to accumulation of degradable fine particles and suspended solids, growing of plants (reeds) roots and attached bacterial biofilm on media surface. Porosity reduction was worth in gravel media followed by rubber, then plastic. The pervious porosity of the three media types and the entrance coarse gravel that presented in table (1) will be plotted against time and with data extrapolation the expected the porosity values will be calculated. This study is carried out after 1830days of the 1st day of pervious study operations. Due to multiple purposes plant stops of maintenance and other reasons the actual operation period of this study may be approximated to be only 1000days.

Measuring media porosity was stopped after 218 days, reaching values of 0.788, 0.505 and 0.358 for plastic, rubber and gravel respectively. The 218 days porosity results of Abdel-Hady, 2014 study were plotted and extrapolated up to 2500 days porosity and presented in Fig. (17).

The actual cells 1000 actual operational days of all media porosity were also shown. Exponential relationships between porosity (n) and operation time (T_o) were obtained for each media as presented in Equations 4 to 7:

Gravel: $n_g=0.406\ e^{(-7\ E\text{-}04\ To)}$ (4)

Plastic: $n_p=0.843\ e^{(-4\ E\text{-}04\ To)}$ (5)

Rubber: $n_r=0.557\ e^{(-5\ E\text{-}04\ To)}$ (6)

Entrance coarse gravel: $n_{cg}=0.428e^{(-9\ E\text{-}04\ To)}$ (7)

The 1000 days porosity values were listed in table (1). The course gravel porosity of 0.195 was considered at each wetland cell entrance. Comparing the 3 cells media porosity, the largest value of porosity (0.576) was for hollow plastic media followed by 0.345 for chipped tires rubber, and then 0.220 for gravel media. Calculated volume of treated water (V_w) followed the same trend and equaled 4.778, 3.063, and 2.136 m^3 of water at plastic, rubber and gravel media cells respectively. Similarly maximum and minimum discharges followed the same sequence as the plastic cell treated a discharge of 0.753 m^3/d at inlet weir water head of 0.02 cm and 9.721 m^3/d at water head of 0.05 cm, while the gravel cell treated a discharge of 0.788 m^3/d at water head of 0.02 cm and 7.788 m^3/d at water head of 0.05 cm. The hydraulic retention time T_r followed an opposite trend with maximum values corresponding to minimum discharges and vice versa. The maximum and minimum T_r at plastic cells 6.34 and 0.4 days, while it was 3.82 and 0.39 days for rubber cell and 2.71 and 0.27 days at gravel cell. The actual media porosity values were the governing factor for calculating the hydraulic parameters of the SSF wetland cells. A misleading error might happen to obtain these parameters from the initial porosity values which were 50 – 100% higher than the actual 1000 days media age porosity. The overloading and under designed treatment results in SSF CW project may be attributed to ignoring the cells media maintenance to tickle its porosity reduction with time.

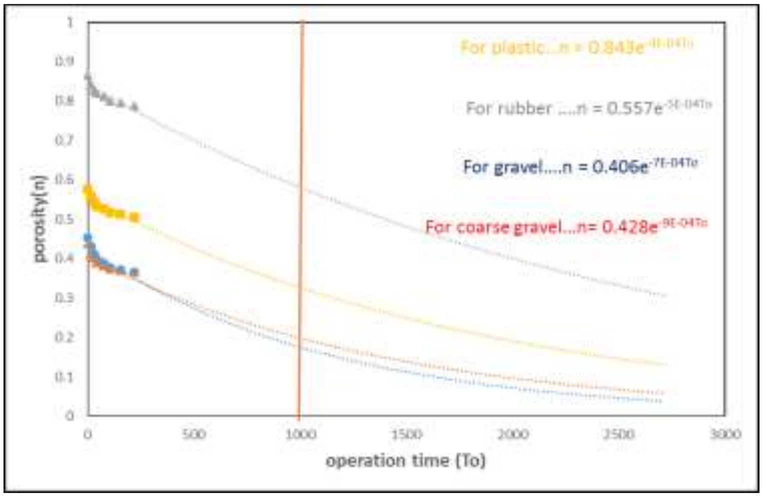

Fig. (17) Predicted cells media porosity after1000 operation day

Treatment performance and flow discharges

Results of pollutants concentrations (BOD, COD, TSS, DO, FC, NH_4 and PO_4) in effluent treated water against flow discharge are presented in Figures 18 to 24. Pollutants reference values represented in Law48/1982 of the effluent municipal wastewater draining at non-fresh water (drains) were plotted and used as a datum for selecting the optimum discharge producing accepted effluent water quality

Table (2) Porosity, water volume and both maximum and minimum applied discharges at each wetland cell and its corresponding detention times.

Type of Media	**Day 1 Porosity**	**Day 1000 Porosity**	**V_w (m^3)**	**$Q_{min.}$ (m^3/d)**	**$T_{r\ min.}$ (day)**	**$Q_{max.}$ (m^3/d)**	**$T_{r\ max.}$ (day)**
Plastic (n_p)	0.866	0.576	4.778	0.753	6.34	9.721	0.49
Rubber (n_r)	0.576	0.345	3.063	0.801	3.82	7.914	0.39
Gravel (n_g)	0.431	0.220	2.136	0.788	2.71	7.788	0.27

$Q_{min.}$ at water head = 0.02 m. $Q_{max.}$ at water head = 0.05 m. Cells entrance Coarse Gravel porosity after Days 1000 = 0.195

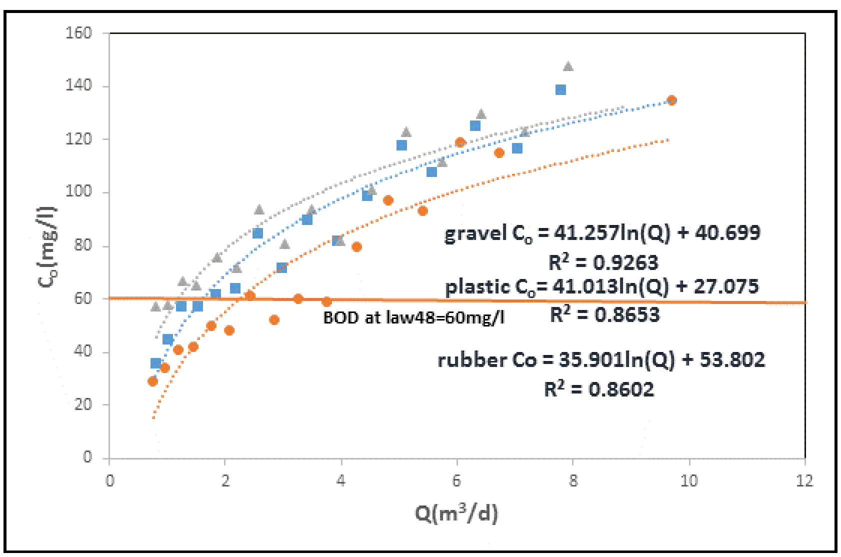

Fig. (18) BOD effluent concentration comparing with its applied discharge for the 3 cells

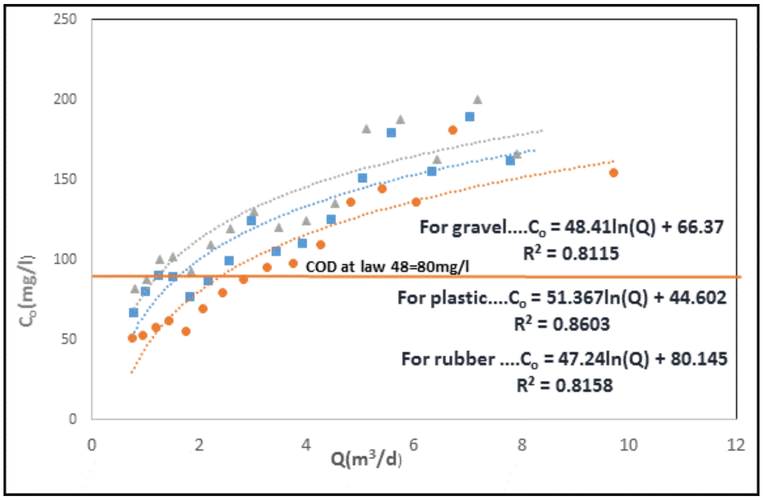

Fig. (19) COD effluent concentration comparing with its applied discharge for the 3 cell

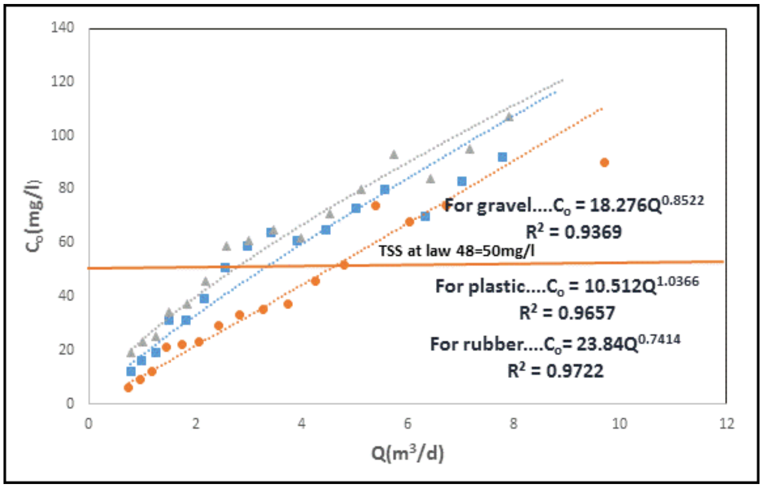

Fig. (20) TSS effluent concentration comparing with its applied discharge for the 3 cell

The relationship between the effluent concentrations of BOD and Q (discharge) for the three cells media, a logarithmic function (figure 18) obtaining the following relationships:

Gravel: $C_o = 41.257\ lnQ + 40.699$ R^2=0.9263

Plastic: $C_o = 41.013\ lnQ + 27.075$ R^2=0.8653

Rubber: $C_o = 35.901\ lnQ + 53.802$ R^2=0.8602

Where:

C_o = BOD outlet concentration, mg/l

Q = discharge (m^3/day)

The relationship between the effluent concentrations of COD and (Q discharge) for the three cells media a logarithmic function (figure 19) obtaining the following relationships:

Gravel: $C_o = 48.41 \ln Q + 66.37$ R^2=0.8115

Plastic: $C_o = 51.367 \ln Q + 44.602$ R^2=0.8603

Rubber: $C_o = 47.24 \ln Q + 80.145$ R^2=0.8158

Where:

C_o = COD outlet concentration, mg/l

Q = discharge (m^3/day)

The relationship between the effluent concentrations of TSS and (Q Discharge) for the three cells media a power function (figure 20) obtaining the following relationships:

Gravel: $C_o = 18.276\ Q^{0.8522}$ R^2=0.9369

Plastic: $C_o = 10.512\ Q^{1.0366}$ R^2=0.9657

Rubber: $C_o = 23.84\, Q^{0.7414}$ R^2=0.9722

Where:
C_o = TSS outlet concentration, mg/l

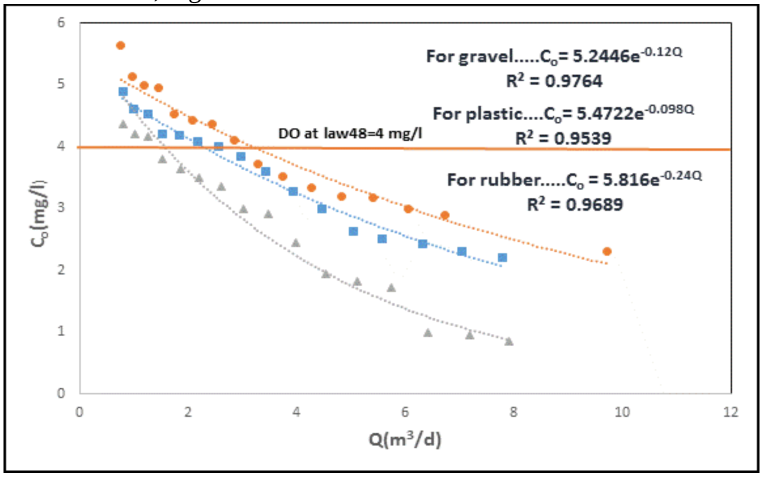

Fig. (21) DO effluent concentration comparing with its applied discharge for the 3 cell

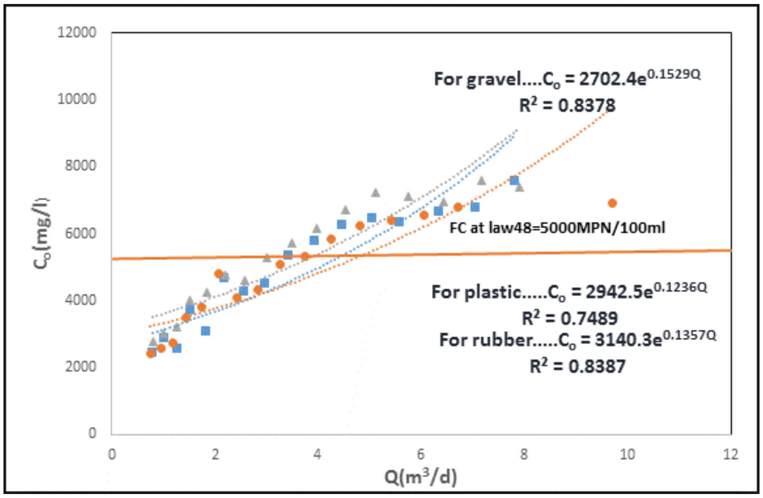

Fig. (22) FC effluent concentration comparing with its applied discharge for the 3 cell

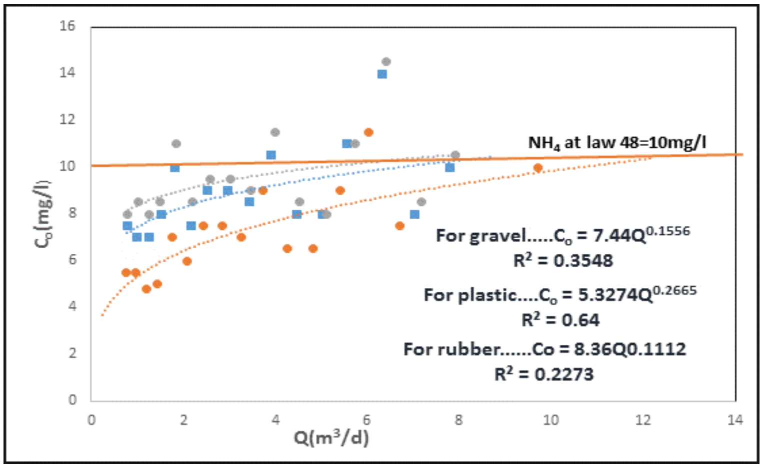

Fig. (23) NH_4 effluent concentration comparing with its applied discharge for the 3 cell

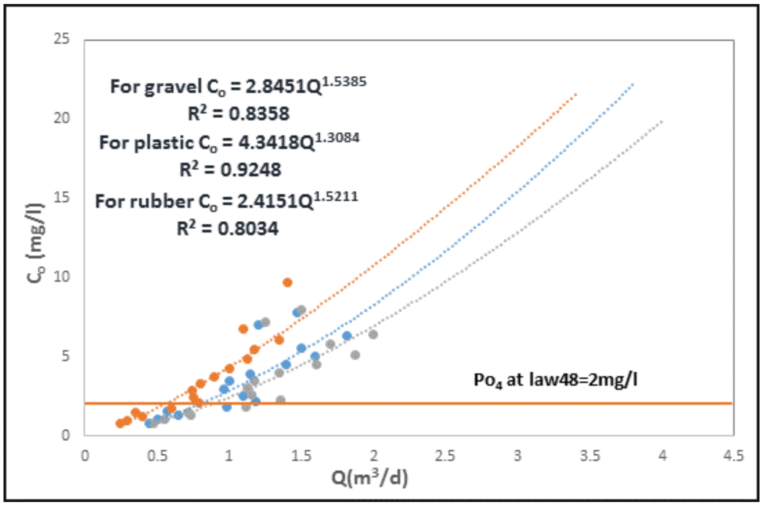

Fig. (24) PO_4 effluent concentration comparing with its applied discharge for the 3 cell

The relationship between the effluent concentrations of DO and Q discharge for the three cells media exponential functions (figure 21) obtaining the following relationships:

Gravel: $C_o = 5.2446\, e^{-0.12Q}$ R^2=0.9764

Plastic: $C_o = 5.4722\, e^{-0.098Q}$ R^2=0.9539

Rubber: $C_o = 5.816\, e^{-0.24Q}$ R^2=0.9689

Where:

C_o = DO outlet concentration, mg/l

Q = discharge (m^3/d (

The relationship between the effluent concentrations of FC and (Q discharge) for the three cells media an exponential function (figure 22) obtaining the following relationships:

Gravel: $C_o = 2702.4\, e^{-0.1529Q}$ R^2=0.8378

Plastic: $C_o = 2942.5\, e^{-0.1236Q}$ R^2=0.7489

Rubber: $C_o = 3140.3\, e^{-0.1357Q}$ R^2=0.8387

Where:

C_o = FC outlet concentration, MPN/100ml

Q = discharge (m^3/day)

The relationship between the effluent concentrations of NH_4 and (Q discharge) for the three cells media power function (figure 23) obtaining the following relationships:

Gravel: $C_o = 7.44Q^{0.1556}$ R^2=0.3548

Plastic: $C_o = 5.3274Q^{0.2665}$ R^2=0.640

Rubber: $C_o = 8.36Q^{0.1112}$ R^2=0.2273

Where:

C_o = NH_4 outlet concentration, mg/l

Q = discharge (m^3/day)

The relationship between the effluent concentrations of PO_4 and (Q discharge) for the three cells media a power (figure 24) obtaining the following relationships:

Gravel: $C_o = 2.8451Q^{1.5385}$ R^2=0.8358

Plastic: $C_o = 4.3418Q^{1.3084}$ R^2=0.9248

Rubber: $C_o = 2.4151Q^{1.5211}$ R^2=0.8034

Where:

C_o = PO_4 outlet concentration, mg/l

Q = discharge (m^3/day)

Figures (18) to (24) presented the effluent pollutant concentrations C_o against the applied discharges Q for BOD, COD, TSS, DO and FC respectively. Figure (2) presents BOD C_o-Q relationship for the 3 cells and the reference BOD value (60 mg/l). There is a direct relationship between C_o and Q as the C_o increases with the Q increase indicating treatment efficiency reduction. The safe C_o

value are shown against the Q values less than 1.20 m^3/d for rubber, less than 1.60 m^3/d for gravel while there are a wide range for plastic media as the 60 mg/l BOD exists at a discharge of 2.30m^3/d or less. The performance of plastic media cell was much better than the 2 other cells while the gravel cell showed better performance than the rubber cell. The optimum effluent BOD, C_o (60 mg/l) is achieved at these ranges while below these ranges a safe operation treatment states could be achieved. The exact Q values for gravel, plastic and rubber cells obtained from logarithmic equations shown in Fig. 2 are 1.60, 2.30, and 1.20 m^3/d, respectively.

Figure (20) presents the FC C_o-Q relationship for the 3 cells compared with the article 52/2013 modified of law 48/1982 reference FC value (5000 MPN/100 ml). The safe C_o values are shown against the Q less than 3.00 m^3/d for rubber, less than 2.00 m^3/d for gravel, and less than 4.50 m^3/d for plastic. The performance of plastic media cell was much better than the 2 other cells while the gravel cell showed better performance than the rubber cell. The optimum effluent FC, C_o is achieved at these ranges while below these ranges a safe operation treatment states could be achieved. The exact Q values for gravel, plastic and rubber cells obtained from logarithmic equations shown in Fig. 6 are 4.00, 4.30, and 3.40 m^3/d, respectively.

Table (3) summarizes the 3 wetland cells hydraulic parameters and the optimum pollutant values compatible with law 48/1982 and its modifications including flow rates, as well as pollutants load, retention time and treatment efficiency. The COD was the governing pollutant in the cells operation since the safe limit realized/obtained from the smallest discharges that was 1.3, 2.00 and 1.00 m^3/d for gravel, plastic and rubber respectively. As a result, the recommendation of such SSF CWs hydraulic operational parameters, the Q, q, and T_r values should not exceed 1.3 m^3/d, 6.6 m/d and 1.4 days for rubber media cells. The corresponding values for plastic and rubber wetland cells mustn't exceed 2.0 m^3/d, 9.9 m/d and 2.2 days and 1.0 m^3/d, 5.0 m/d and 2.6 days respectively. These values were suitable for such wetlands that may face water overtopping due to overloading, overdesigning or media partial clogging.

Pollutants load, retention time and treatment efficiency. The COD was the governing pollutant in the cells operation since the safe limit realized/obtained from the smallest discharges that was 1.3, 2.00 and 1.00 m^3/d for gravel, plastic and rubber respectively. As a result, the recommendation of such SSF CWs hydraulic operational parameters, the Q, q, and T_r values should not exceed 1.3 m^3/d, 6.6 m/d and 1.4 days for rubber media cells. The corresponding values for plastic and rubber wetland cells mustn't exceed 2.0 m^3/d, 9.9 m/d and 2.2 days and 1.0 m^3/d, 5.0 m/d and 2.6 days respectively. These values were suitable for such wetlands that may face water overtopping due to overloading, overdesigning or media partial clogging.

Table (3) Hydraulic parameters for the 3 cells to produce optimum pollutant values compatible with law 48/1982.

Parameter	Limits*	Gravel				Plastic				Rubber			
		q	Q	T_r	RE	q	Q	T_r	RE	q	Q	Tr	RE
		m/d	m^3/d	d	%	m/d	m^3/d	d	%	m/d	m^3/d	d	%
BOD	60	**7.6**	1.6	1.2	**69**	11.2	2.3	1.8	70	**5.9**	1.2	0.26	67
COD	80	**6.6**	1.3	1.4	**73**	9.9	2.0	2.2	70	5.0	1.0	2.6	75
TSS	50	15.9	3.3	0.8	**67**	22.5	4.5	1.2	**67**	13.6	2.7	1.3	67
DO	4	11.3	2.3	5.6	---	15.5	3.2	5.1	---	7.8	1.6	5.0	----
FC	5000	14.7	4.0	1.0	99	15.3	4.3	2.0	99	12.2	3.4	1.2	99
NH_4	10	33.4	6.7	0.6	47	53.1	10.6	0.7	48	25.0	5.0	0.9	47
PO_4	2	12.1	0.9	0.3	43	13.9	0.6	0.4	48	11.1	1.0	0.4	40

***** article 52/2013 modified of law 48/1982 (All units are in mg/l except FC in MPN/ 100 ml)

4. Conclusions and Recommendations

Effluent discharges from existing overloading WWTPs such as CWs can contain pollutants that are toxic to specific species of plants and animals. Up to increasing these plants treatment capacity, one way to manage these pollutants is to adopt the treatment loading rate in order to cope the effluent water with the permissible limits of the water quality and water use laws. The actual media porosity values were the governing factor for calculating the hydraulic parameters of the SSF wetland cells (discharge, loading rate, detention time). The optimum treatment discharge in Samaha WWTP CW plastic media cell was 2 and 1.3 folds that of the gravel and rubber media cells respectively. After studying treatment results of water quality parameters, minimum cells discharge that produced COD concentrations realizing the laws standards was the safe operational discharges of the 3 media subsurface constructed wetland. A misleading error would be to obtain hydraulic parameters from the initial media porosity values since they were greater than the actual 1000 days' age media porosity by 50 – 100%. The overloading and under designed treatment results in some SSF CW projects may be attributed to ignoring the dynamic media porosity reduction with time.

Maintenance of SSF CWs media porosity should be practiced regularly to keep treatment performance as designed and prevent effluent water deterioration. An economic evaluation for the different treatment media (gravel, plastic and rubber) should be carried out in order to help the decision makers in selecting the suitable and better performance media that decrease water treatment expenses.

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