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Effect of different media in constructed wetland on the removal of some heavy metals from wastewater

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Abstract: Constructed wetlands are natural treatment systems based on using plants, soils, and micro-organisms to improve treated wastewater quality. When compared with other conventional treatment technologies, these systems are efficient and eco-friendly treatment methods for wastewater. A constructed wetland unit was designed in Samaha wastewater treatment station, in Al-Dakahliya governorate, Egypt, in which domestic wastewater was treated. This pilot scale contains three units; each one contains different kind of media, i.e. plastic, gravel and rubber which used to test the removal efficiency of different metal ions. The average removal efficiencywas (59%, 46.1% and 36.9%) for Mn (II), (56%, 49.1% and 42.7%) for Pb (II), (62.3%, 51.4% and 42%) for Fe (III), (67.3%, 58.6% and 51.7%) for Zn (II) and (40.5%, 33.6% and 26.7%) for Cd (II), when using plastic, gravel and rubber media respectively. The removal efficiencies of metal ions were remarkably enhanced after mixing polystyrene foam media with plastic, gravel and rubber, solely. The removal efficiency values became (70.2%, 57.8% and 48.2%) for Mn (II), (64.1%, 56.6% and 50.9%) for Pb (II), (71.3%, 56.9% and 49.3%) for Fe (III), (72.2%, 61.1% and 53.6%) for Zn (II) and (41.1%, 35.5% and 29.2%) for Cd (II), using plastic/polystyrene, gravel/polystyrene and rubber/polystyrene mixtures respectively. This improvement of removal efficiency was explained taking into consideration the aeration effect of polystyrene foam **.**

keywords: wetlands; Polystyrene; Wastewater

1.Introduction

Dischargingindustrial, agricultural and domestic wastewater without adequate treatment, shares in raising the level of pollution in water streams and estuarine ecosystems. By time massive amounts of organic compounds and nutrients will accumulatein receiving streams and estuaries, and consequently this will lead to fish death as a result of oxygen depletion and the spread of algal blooms in estuaries. Domestic wastewater contains wastes coming from bathrooms, kitchens and laundries, in addition tosome other wastes that people may intentionally or accidentally pour it into drains **[1, 2]**. Industrial wastes commonly include; heavy metals toxic chemicals, organic wastes and sediment. Heavy metal contamination has become a global environmental problem due to increasing metal refining and mining, industrial fabrication, and waste disposal **[3]**. Heavy metals are released into the environment from several natural and anthropogenic sources. **[4]**. The concentration of heavy metals incoming to wastewater treatment plants (WWTPs) is high and wastewater secondary treatment systems cannot get rid of all heavy metals to reach the concentrations within the permissible limits. The amount of wastewater incoming to treatment wetland systemsin Dakahliya Governorate onlyis about 548200 m^3 per day **[5]** and the environmental laws do not allow the use of wastewater in productive agriculture **[6]**. The conventional methods of treatment of wastewater are widely used and not environmentally safe because of the use of specific chemicals and reagents, therefore heavy metals still pose threat to environment even after the treatment process. The regular release of wastewater treated by simple treatment methods such as chemical precipitation into large water bodies possibly will lead to the deactivation of self-purification process and subsequently to gradual poisoning of water and aquatic organisms **[7]**. Constructed wetland systems (CWs) are biologically varied and productive natural ecosystems. Although not all CWs are natural ones, it is sensible to design wetland systems that increase water quality and improve wildlife habitat. CWs are designed to decrease the amount of pollutants, such as metals, nutrients or organic materials and biochemical oxygen demand existing in diverse types of wastewaters and improve water quality **[8, 9]**. CWs are cost-effective and feasible approach for treating wastewater **[10]**. They are often less expensive than other traditional wastewater treatment alternatives because of their low operating and maintenance expenses and esthetically pleasing and can decrease bad odors of wastewater **[11]**.

In CWs there are many chemical, physical, and biological processes involved in decreasing the fate of contaminants, such as (1) chemical precipitation then filtration; (2) settling of suspended matters; (3) adsorption through contact between water, sediment, and plants; (4) using micro-organisms for breaking down and transformation of contaminants; (5) predation of pathogens; and (6) uptake of nutrients by plants and other organisms. The treatment effectiveness of different CW systems is variabledue to the complicated biogeochemical mechanisms and different wetland types **[8].** Heavy metals are removed in CW systems by four main processes (i.e. chemical, physical, biochemical and biological). These processes happen in the four main parts of wetland units, i.e. (i) water (ii) biota (iii) substratum and (iv) suspended solids. The removal of heavy metal ions is carried out by sedimentation, co-precipitation, adsorption, complexation, cation exchange, microbial activity and plant uptake. However, it is difficult to explainthe actual mechanism of heavy metal removal in the CWs; it is very complicated because the processes are dependent on each other **[4]**. The effect of different media on the removal efficiency of heavy metals was studied; the presence of these different media is an important factor for the removal of heavy metals from wastewater using CWs **[12]**. According to the study carried out by Windom et al. **[13]** in rivers on the east coast of the USA, about 40%, 62%, 80% and 92%, of Cu, Cd, Zn and Pb concentrations were achieved by suspended solids. Also, Mulligan et al. **[14]** reported that the combination between heavy metal ions and the suspended solids increased the removal of heavy metal to reach about 98.9%. Hares and Ward **[15]** applied a study in 39-month study and they found that the removal of heavy metal ions increased by precipitation, filtration and bioaccumulation processes in plants of constructed wetlands. Thus removal of heavy metal ions from wastewater by constructed wetlands is a probable approach for environmental management and affordable contamination treatment method **[16]**. The main purpose of the present study is to provide some information on the concentration of some heavy metal ions in wastewater environment and their probable effective removal mechanisms using constructed wetlands receiving collected domestic wastewater from the village, based on the previous literatures and practical working experiences. It's extremely important to study the effect of different media (i.e. plastic, gravel, rubber and polystyrene foam) in wetlands to realize the basic mechanisms that control the metals removal by wetlands. This knowledge will increase the possibility of succession the treatment of wastewater using constructed wetland systems. The aim of this workis to study the effect of varying the media on the removal efficiency of heavy metal ion s.

1. xperimental

i. Studied area

The present study was applied by designing a special basin in Samaha wastewater treatment station located in a small village (1000 acres) in Aga city, Dakahliya governorate, Egypt. This station received 1000 m^3 wastewater daily from the surrounding area servicing a population of approximately 7000 residents at Samaha village. The experiments were elaborated during May 2016 to April 2017.

ii. Sample collection

96 wastewater samples were collected from the inlet and outlet points of the basin two times per week over 12 months. All samples were

kept in polyethylene plastic bottles and analyzed after collectionin the wastewater central laboratory of Dakahliya Company for water and wastewater. Samples were maintained at 4 ºC until the detection of studied metal ions following the standard methods **[17]**.

The removal efficiency was calculated using the following equation:

$$\text{Removal \%} = \frac{Ci - Co}{Ci} X100$$

Where C_i and C_o are the concentration of metal ions present in the inflow and outflow respectively.

Characteristic features of wastewater before and after treatment for the parameters pH, Conductivity, total dissolved solids (TDS), Zn, Cd, Fe, Pb and Mnare concluded in table (1) and table (2).

Table (1), Average inlet and outlet concentrations of each monitored parameters for sole media.

parameter	Inlet	Outlet		
		Gravel	Rubber	Plastic
pH	7.23	6.84	7.11	7.21
Conductivity(µs)	1289	1240	1255	1168
TDS (mg/L)	820	787	797	742
Zn (II) (ppm)	1.601	0.664	0.774	0.525
Cd (II) (ppm)	0.0025	0.0016	0.0018	0.0015
Fe (III) (ppm)	0.811	0.394	0.470	0.305
Pb (II) (ppm)	0.047	0.024	0.027	0.021
Mn (II) (ppm)	0.260	0.140	0.164	0.106

Table (2), Average inlet and outlet concentrations of each monitored parameters for media mixtures.

parameter	Inlet	Outlet		
		Gravel-Foam	Rubber-Foam	Plastic-Foam
pH	7.15	7.08	7.06	7.32
Conductivity(µs)	1427	1142	1159	1122
TDS(mg/L)	906	725	736	712
Zn (II)(ppm)	1.795	0.695	0.830	0.498
Cd (II)(ppm)	0.0029	0.0018	0.0020	0.0017
Fe (III) (ppm)	0.818	0.350	0.413	0.235
Pb (II) (ppm)	0.052	0.022	0.025	0.019
Mn (II) (ppm)	0.251	0.106	0.130	0.075

iii. The design of wetland's basin

Samaha wastewater treatment station consists of a number of basins having rectangular shape with dimensions (width 7m× length 10m and 0.5m depth), each basin was planted with papyrus plants in three layers of gravel with different shapes and sizes, as shown in **(Fig. 1).**The wastewater was collected from this village in small tanks for primary treatment by filtrating the suspended matters from wastewater then interring the basins.

Fig. (1): The whole basin before split.

For comparative studies, onebasin was unloaded from its contents then divided to three small separated basins; each basin had dimensions of (2m width, 10m length and 0.5m depth) as shown in **(Fig. 2)**. These three small basins contained various media (gravel, rubber and plastic) to study their effect on the removal of heavy metal ions presents in wastewater. These basins were applied on a pilot scale (horizontal subsurface flow) system (HSSF) to avoid the clogging problems happen occasionally **[18]**. The inlet and the outlet points were constructed from bricks and cement to avoid the leakage. Plastic pipes (20cm diameter and 5 m length) were used to introduce the wastewater into the basins. The water kept in the basins for 8 hours.

Fig. (2) The basin after split.

Three layers of gravel mediaofdiverse sizes were used, soft gravel (<20 mm diameter) was at the top, then gravel with 20:40 mm diameter was at the middle and the last layer was made up of gravel with 40:60 mm diameter **(Fig. 3)**.Torn tires were used as rubber media were cut into small pieces (30:50 mm width 40:50 mm length and 5:15 mm thickness). The plastic media were hollow plastic pipes in a form of zigzag shape (length 40 mm and diameter 19 mm). All basins were covered by a plastic screen to prevent floating of foam pieces **(Fig. 4).**This plastic screen didn't hinder the growth of plant. After the examination of the three sole media, equal pieces of polystyrene foam were added to each basin, to improve the aerobic conditions.

Fig. (3) Graded gravel media

Fig. (4) Covering plasticmediawith plastic screens.

Heavy metal ions Determination

The effects of metal ions in water and wastewater are alternated from useful through worrying to dangerously toxic. Some metal ions are important to animal and plant growth while others may have dangerouseffects on water consumers and receiving waters. Theconcentrations of metal ion in water is the key factor in determining the benefits versus toxicity of these metals **[8]**.

The concentration of all studied metal ions in wastewater samples was determined using an atomic absorption spectrometer (AAS Vario 6) made in Germany by Analytic Jena company.

The following table (3) shows the wavelengths with flame C_2H_2/Air for detected metals.

Table (3) wavelengths and flame of metals

Metal ion	Wavelength (nm)	Operating Parameters(L/h)
Zn (II)	213.9	50
Cd (II)	228.8	50
Fe (III)	248.3	65
Pb (II)	283.3	65
Mn (II)	279.5	60

iv. Statistical analysis:

The SPSS package version 20 was used for obtained results statistical analysis; firstly quantile-quantile plot (Q-Q plot) diagram was used to detect outlier results. Secondly standard deviation and variance were calculated.

2. Results and discussion:

I. The proposed mechanisms of removing heavy metal ions in constructed wetland systems

When the wastewaters coming from urban cities pass through constructed wetlands, several pollutants can be eliminated by various physical, chemical, and biologic methods. Recently, constructed wetland systems proved to have a great deal for water-quality improvement treatment of different kinds of wastewaters **[19-22].** Understanding the basic methods by which these pollutants are eliminated; extremely helpful for determining the potential applications, knowingboth benefits and limitations of constructed wetland treatment systems to improve the water quality.

a. Physical removal method

In both natural and constructed wetland systems, the removal of heavy metal ions from wastewater include many processes, starting withfiltration followed by adsorption or plant uptake and chemical transformation depending on the type of media used **[19]**. Nevertheless, precipitation of suspended solid particles has been always known as the primestep in the removal of heavy metal ions from wastewater.Practically, wetland systems have been used widely for the purification of urban wastewater **[23, 24]**. This purification depends on reducing suspended solid particles, nutrients and heavy metal ions. Once wastewater contaminated with heavy metal ions enter into a constructed or natural wetland unit, many removal processes happen **[25]**. Heavy metal ions tend to combine with the fine suspended particles, thentransport from wastewater to the biota or sediment or vice versa, so it can be easily filtered off and collected in wetland systems **[19]**. In wetland systems, the rate of sedimentation depends on the water flow rate, as both plant roots and floating mediaslow down the speed of surface water flow through wetlands.Plants contribute in purification of wastewater by sedimentation using its roots and stalks through different physical, chemical and biochemical processes **[26]**. Solid suspended particles are heavier than water, and sedimentation happens after flock formation **[27]**. Sedimentation or precipitation rate is directly proportional to the water residence time in wetlands and particle settling speed **[28]**. The process of forming flock includes alsothe combination of suspended particles with heavy metals so it can be removed from wastewater.In ecosystems of constructed wetlands; pH affects the flocculation in addition to ionic strength and concentration of suspended particles, besides the concentration of microorganism **[29-31].** Sedimentation is a simple physical process and some other chemical processes must occur first such as sorption, precipitation and co-precipitation, and then sedimentation happensafter theaggregation of heavy metals with suspended particles into solid particulates large enough to sink **[19]**. By this way heavy metal ions are removed from wastewater flow and gettrapped into the wetland sediments, consequently protecting the receiving surface and groundwater bodies.

b. Biological removal method

The biological mechanism is another removal method andit is one of the most important processes for pollutant removal in constructed wetland systems.Plant uptake is the most widely known biologicalmethod for removing pollutant from wastewater in wetlands **[28]**. In the meantime, the plants absorb some ofthe contaminantsdirectly fromwastewater in addition to supplying oxygen to the microorganismsattached around the rhizospherein the constructed wetlands.

i. Metal ions motilities in the rhizosphere

Rhizosphereis an essential interface of plant and soil and plays a significant role in the constructed wetland systems.Under reducing conditions, many metal ions associate with sulfides and carbonates in the sediments.Wetland plants supply the soil with oxygen necessary to oxidize the sediments in the rhizosphere **[32, 33]**. This oxidation process can resolve the metal ions in the sediment of wetlands and increase their concentration in wastewater again **[34, 35]**. But the oxidation of the rhizosphere allows the plants torise the amount of iron oxy-hydroxides in the sediments and preserve the metal ions in the wetland media **[36]**. Plants have an effect on the biogeochemical dynamics of constructed wetland sediments through evapotranspiration-induced transfer, through which the loading of dissolved metal ion pollutants increases into the rhizosphere **[37]**. In constructed wetland sediments, there is combination between the microbial activity and the oxygen released by plant roots. This combinationproduces both aerobic and anaerobic zones, where both oxidative and reductive reactions occur simultaneously in the interface of plant and soil**[38]**. Mostly, these methods are composed of Mn and Fe hydroxides, beside other co-precipitated metal ions, and are known as "iron plaque." Sometimes, other metal ions are released from the anoxic sediments into wastewater and then accumulate in the oxidized rhizosphereand their concentrations become 5–10 times higher than that present in the surrounding sediments **[39, 40]**. Additionally, the roots of some plants in constructed wetland systems have metal ions-rich rhizo concretions **[35]**. Sometimes the remobilization of heavy metal ionsoccur by the excretion of some plant exudates **[41]**. For example, under heavy metal ions stress, types and amounts of root exudates significantly change **[42].**Root exudates have the ability to stimulate heavy metal ions in soil, and improve their bioavailability via dissolving **[41]**. The presence of microbial symbioses in constructed wetland systems such as mycorrhizae affect the accumulation of metal ions because mycorrhizae offer an interface between the soil and root of plants and thenincrease the absorptive surface area of root hairs **[35, 43]**.

ii. Metal ions uptake by plants

Wetlands systems are very productive and offer a suitable habitation for large biodiversity of microorganisms. It was reported byMacFarlane et al. **[44]** and Weis and Weis **[35],** that metal accumulation in plants depends on the type of bothplants and elements. Also, the level of accumulation in leaves depends on the type of metal ions, for example, Zn can accumulate in leaves but lead levels differ in leaves and prefer to accumulate in roots and shoots.The concentrations of metal ions in leaves are relevant to their concentrations in soil around the plant roots. Deng et al. **[45]** inspected that the Zn, Pb, Cu and Cd ions can accumulate by many perennial plants in constructed wetlands. This accumulation differ among plant tissues of and the most accumulation occur in root tissues, and then in their shoots. Various factors have an impact on the metal accumulation in constructed wetland plants including metal ion concentrations, temperature, pHand nutrient concentrations in the surroundings soil.Generally, heavy metal ions accumulation into plants is classified into two kinds, Zn, Ni, Cu, and Mn which are necessary micronutrients, and Cd, As, Hg and Pb which are toxic heavy metal ions **[46, 47]**. Although necessary micronutrients are main components of plants, but the high content of it is potentially toxic.On the other hand, if plants absorb the toxic heavy metal ions via the transportion system, it will affect badly on plant growth and also minimize the uptake of vital micronutrients **[46, 47]**. The ability of metal ions to transfer from roots to upper partsdepends on the type of plant species, types of metal ions, and present physical conditions, such asredox potential, pH and temperature**[35, 48]**. In addition, the organic compounds content in soil, nutrients, microbial biomass, and the concentration of other ions can also affectthe metal uptake by wetland plants **[42, 48]**.

c. Chemical removal methods

Moreover, there are some chemical processes participate in the removal of heavy metal ions in constructed wetland systems.

i. Precipitation and co-precipitation

There are the different treatment proceduresused to eliminate heavy metal ions in wastewater and precipitation is the most common method. For example, heavy metal ions can be removed by adjusting the pH in wastewater to the minimum solubility of heavy metal ions **[49]**. Then, theprecipitated salts can be removed by filtration **[49].** The removal of some toxic metal ions such as Zn, Pb, Cu, Cd, and As, can be done via co-precipitation **[50]**. Furthermore, zinc precipitate as insoluble carbonate and sulfide compounds, and can also co-precipitate with Mn and Fe oxides, on plaques and/or adsorbed on the surface of plant roots **[36, 51]**.

ii. Sorption

Sorption is the most significant chemical removal method in constructed wetland systems, through which many pollutants can be removed by short-term retention.In the sorption methodions transfer from wastewater (liquid phase) to soil (the solid phase). Heavy metal ions in soil are adsorbed on the solid particles by either physical adsorption or cation exchange, as clays have high cation exchange capacity and large surface areathat remove pollutants from aqueous solutions.Adsorption process has stronger binding forces than cation exchange process. Adsorption of metal ionson specific and non-specific sorbents depends on the media used in wetlands, as these media affect the solubility of metal ions in solution, along with the binding sites for metal ions onto media surfaces **[28, 52, and 53].** As previously reported by St-Cyr and Campbell **[54]**, Zn metal ions can combine with Fe ionsby absorption and co-precipitation, therefore, if these Zn mobilized metal ions come close to the iron compounds onto the plant roots, they get adsorbed on the root surface. In wetland systems, more than 50% of the present heavy metal ions in wastewater can be adsorbed onto sediment and particulate matter **[27]**.

II. Removal of some heavy metal ions from wastewater:

Removal of pollutants from wastewater by wetland systemsis useful for environmental management andlow cost pollution treatment approach. Constructed wetland systems holding different types of media were used for treatment of wastewater from Zn, Pb, Fe, Mn and Cd ions.

a. Removal of Zinc ions:

The removal efficiency of Zn (II) is shown in **(Fig. 5),** where plastic presents the higher removal efficiency (67.3 %) than gravel (58.6 %) and rubber (51.7 %). After addition of polystyrene foam, the removal efficiencies increased to 72.2%, 61.1% and 53.6% for plastic/polystyrene, gravel/polystyrene and rubber/polystyrene respectively, as shown in **(Fig. 6).**

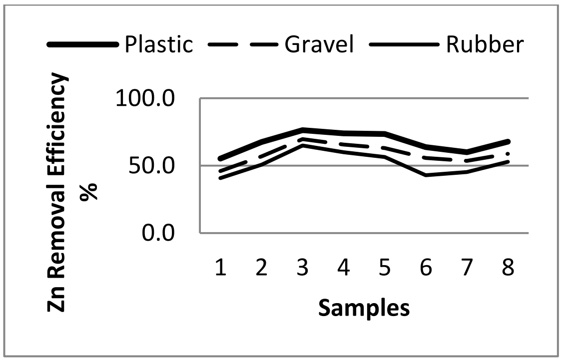

Fig. (5) Removal Efficiency of Zn(II) before mixing the media with polystyrene

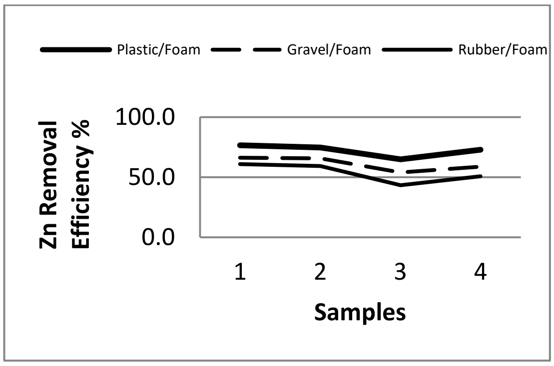

Fig. (6) Removal Efficiency of Zn(II) after mixing the media with polystyrene

Lead ions:

The removal efficiency of Pb ions was high at the outlet of the cell contains plastic media, but the removal efficiency dropped in case of using rubber and gravel beds. Pb (II) removal efficiency in plastic cell varied between (45.9% - 66.7%), while gravel bed produced removals efficiencies lie in range of (32.4% - 60.8%) and (27% - 56%) in case of rubber as shown in **(Fig. 7)**.The removal efficiencies became 64.1%, 56.6% and 50.9% for plastic-polystyrene mixture, gravel-polystyrene mixture and rubber-polystyrene mixture respectively, as clear from **(Fig. 8)**.

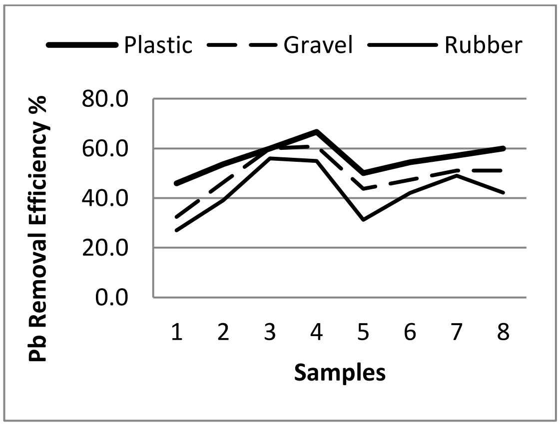

Fig. (7) Removal Efficiency of Pb(II) before mixing the media with polystyrene.

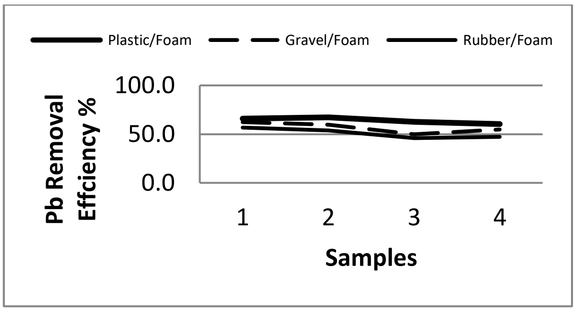

Fig. (8) Removal Efficiency of Pb (II) aftermixing the media with polystyrene

Manganese ions:

(Fig. 9) present the removal efficiencies for Mn (II) as it were fluctuated between the three media used in the experiment. The removal efficiencies varied between (50% - 69.2%) for plastic, and (38.5% - 61.5%) for gravel, while for the rubber media the values of removal efficiency were in between (28% - 50%).After the addition of polystyrene foam media, the removal efficiencies increased to (66.3% - 72.7%) for plastic/polystyrene blend, (48.8% - 61.5%) for gravel/polystyrene blend, and (42.5% - 53.5%) for rubber/polystyrene blend, as shown in **(Fig. 10)**.

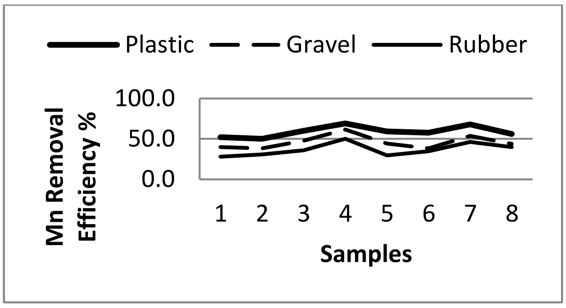

Fig. (9) Removal Efficiency of Mn(II) beforemixing the media with polystyrene

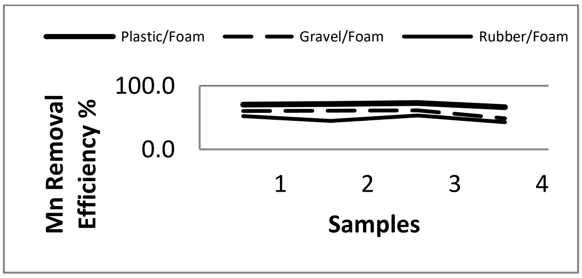

Fig. (10) Removal Efficiency of Mn(II) after mixing the media with polystyrene

Iron ions:

Fe (III) removal efficiency was measured in the different constructed wetland cells containing variable media. The removal values varied from (54.1% - 70.2%) in case of plastic media, (41.9% - 60.7%) in case of gravel media and (30.2% - 51.3%) in case of rubber media as reported in **(Fig. 11).** The removal efficiency increased after mixing the media with polystyrene foam media as concluded in **(Fig. 12)**, were the removal efficiencies varies form (67.5 – 74.1) for plastic-polystyrene mix, (50.7% - 63.5%) for gravel-polystyrene mix and(43.7% - 55.3%) for rubber-polystyrene mix.

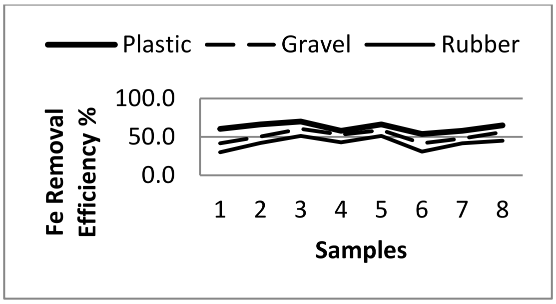

Fig. (11) Removal Efficiency of Fe(III) beforemixing the media with polystyrene

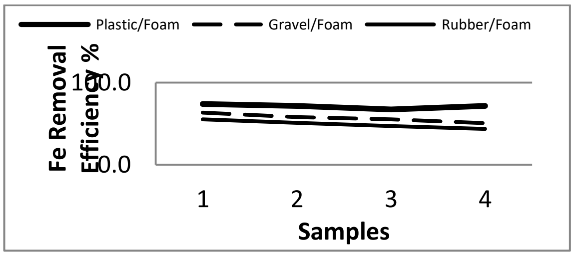

Fig. (12) Removal Efficiency of Fe(III) aftermixing the media with polystyrene.

b. Cadmium ions:

Plastic media showed the highest removal efficiency for Cd (II) which varied between (30.8% - 55.4%) than gravel and rubber media where the removal efficiencies were (23.8% - 50.8%) for gravel media, and (18.8% - 41%) for rubber media. After mixing the media of polystyrene foam, the removal efficiencies raised and became (37.5% - 45.4%), (29.9% - 42.4%) and (23.7% - 35.1%) for plastic/polystyrene, gravel/polystyrene and rubber/polystyrene respectively, as shown in **figures (13, 14)**.

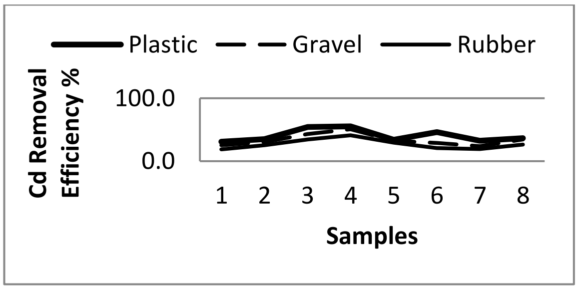

Fig. (13) Removal Efficiency of Cd(Ibeforemixing the media with polystyrene.

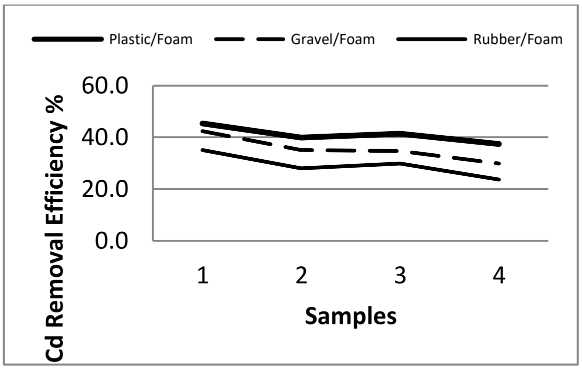

Fig. (14) Removal Efficiency of Cd(II) after mixing the media with polystyrene.

The explanation for the obtained results can be that, heavy metal ions present in wastewater combined with suspended solid particles then transported from wastewater to the sediment or plants, where it can be easily filtered and accumulated in constructed wetlands **[12].**

The high removal efficiency achieved due to using plastic media may be attributed to the high surface area of plastic which allow to formation of a wide biofilm of bacteria which is responsible for the removal of metals from wastewater. Furthermore Zn, Mn, Pb and Cd ions accumulate into plant roots and leaves.

Also, the addition of polystyrene increased the removal efficiency of heavy metal ions because the air present in polystyrene foam improved the aeration conditions to each cell and increased the oxygen necessary for the oxidation of the rhizosphere which in turn increased the amount of iron oxy-hydroxides in the sediments and preserved the target heavy metal ions in the wetland media.

Moreover, as stated previously, Zn, Pb and Cd ions might co-precipitate with Fe and Mn oxides in iron plaques.

Furthermore; in the sorption process, the studied heavy metal ions transfered from wastewater to soil by either physical adsorption or cation exchange, because clays have the advantages of both high cation exchange capacity and large surface area.

3. Statistical analysis:

The Q-Q plot is a graphical tool or a scatterplot made by plotting two groups of quantiles against one another. The number of quantiles is selected to match the size of sample data **[55, 56].**The removal efficiencies for the results were evaluated, then ordered from smallest to largest so as to plotting Q-Q plot which identify the outliers. Figure (15) shows the Q-Q plot graphical representation for the removal efficiencies of zinc metal ions in case of plastic media, this figure also clarifies the extravagant results which are far from the curve. While figure (16) elucidate the same but in case of plastic/foam mixture media, it is clear that the existence of foam adjust the obtained results

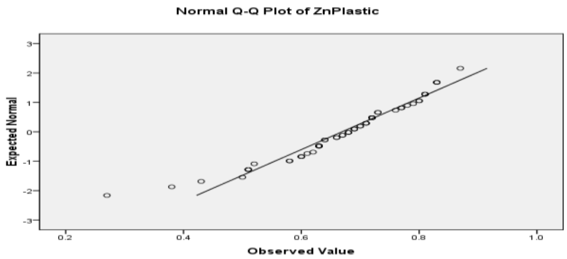

Fig. (15). Q-Q plot for removal efficiency of Zn in case of **plastic** media

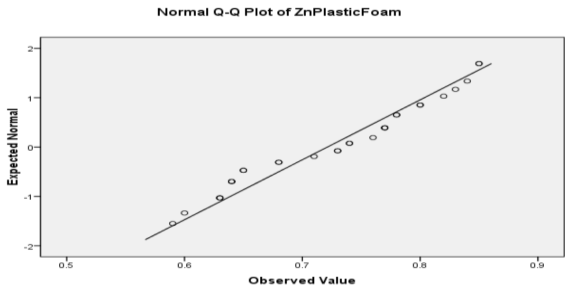

Fig. (16). Q-Q plot for removal efficiency of Zn in case of **plastic/Foam** media

After removing the outliers and regulation of results,standard deviation was evaluated;the standard deviation is used as a measure to quantify the amount of variationof a set of data values**[57]**.Table (4) shows the standard deviation and variance for all metal ions in cases of studied media.

Table (4) Standard deviation and variance for metal ions.

	Standard deviation						**Variance**		
	Plastic	Gravel	Rubber	Plastic/ Foam	Gravel/ Foam	Rubber/ Foam	Plastic and Plastic/Foam	Plastic and Plastic/Foam	Plastic and Plastic/Foam
Zn (II)	0.091	0.095	0.102	0.823	0.098	0.097	0.802	1.070	0.889
Fe (III)	0.127	0.141	0.141	0.075	0.094	0.113	0.348	0.446	0.651
Mn (II)	0.153	0.182	0.179	0.088	0.136	0.149	0.332	0.559	0.697
Pb (II)	0.082	0.123	0.142	0.077	0.092	0.122	0.874	0.568	0.740
Cd (II)	0.145	0.151	0.126	0.132	0.141	0.137	0.835	0.873	1.175

Conclusion:

In comparison between different materials (plastic, gravel and rubber) and by the mixing them with polystyrene foam to these three media solely in horizontal subsurface flow constructed wetland, it was noticed a high performance for the removal of different metals where these are easily found and locally available for operation. The constructed wetland systems offer an economic benefit for wastewater treatment since there is no or less energy required for the operating system. The present results indicated that the removal

efficiency for Zn (II), Fe (III), Mn (II), Pb (II) and Cd (II) when plastic is used as media is higher than gravel and rubber. An addition of polystyrene foam to the three target media, plastic-polystyrene mixture gave the highest removal efficiency. Hence, the constructed wetland systems using this media would be preferable compared to the high cost conventional wastewater treatment tools. We are looking to resolve the problem of heavy metal ions on the plant and media and how to safely dispose of them in further future studies.

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