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Phytoremediation of Wastewater Using Some of Aquatic Macrophytes as Biological Purifiers for Irrigation Purposes

Removal Efficiency and Heavy Metals Fe, Mn, Zn and Cu

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Abstract**—**An attempt was made for availability of wastewater reuse/reclamation for irrigation purposes using phytoremediation "the low cost and less technology", using six local aquatic macrophytes "e.g. ***T. angustifolia***, ***B. maritimus, Ph. australis***, ***A. donax, A. plantago-aquatic****a* and ***M. longifolia*** (Linn)" as biological waste purifiers. Outdoor experiments/designs were conducted from May 03, 2007 till October 15, 2008, close to one of the main sewage channels of Sulaimani City/Iraq*. All processes were mainly based on conventional wastewater treatment processes, besides two further modifications were tested, the first was sand filtration pots, implanted by individual species of experimental macrophytes and the second was constructed wetlands implanted by experimental macrophytes all together. Untreated and treated wastewater samples were analyzed for their key physico-chemical properties (only heavy metals Fe, Mn, Zn and Cu with particular reference to removal efficiency by experimental macrophytes are highlighted in this paper). On the other hand, vertical contents of heavy metals were also evaluated from both pots and the cells of constructed wetland. After 135 days, macrophytes were harvested and heavy metals were analyzed in their biomass (roots/shoots) for removal efficiency assessment (i.e. uptake/ bioaccumulation rate). Results showed that; removal efficiency of all studied heavy metals was much higher in ***T. angustifolia*** followed by ***Ph. Australis***, ***B. maritimus*** and ***A. donax*** in triple experiment sand pots. Constructed wetland experiments have revealed that; the more replicated constructed wetland cells the highest heavy metal removal efficiency was indicated.

Keywords**—**Aquatic Macrophytes, Heavy Metals (Fe, Mn, Zn and Cu), Phytoremediation and Removal Efficiency.

I. INTRODUCTION

LARGE volume of water is being consumed in agriculture, industry, domestic and municipal use which imposes a further demand on this resource. Agriculture is the single largest user of fresh water in the world, accounting for nearly 70% present of all extractions of fresh water worldwide [1].

During the last two decades, the reuse of treated wastewater for agricultural irrigation has expanded, especially in arid and semi-arid regions, helping to relieve water scarcity and improving the means for local food production [2]. In recent years, the amount of wastewater produced from several activities has increased as a result of the rapid improvement of living standards [3]. Although some communities treat their wastewater in a suitable way, others lack convenient treatment systems, thus discharging untreated wastewater into the natural environment. Pollutants (e.g. heavy metals) enter aquatic systems via numerous pathways, including effluent discharge, urban and agricultural run-off. Contaminants present in sewage commonly include a wide range of metallic and organic compounds [4].

Wastewater treatment technology needs to be appropriate and sustainable. It also needs to be less costly, easy to operate and maintain, and very efficient in removing both organic matter and heavy metals. In developing countries natural treatment systems, are more suitable. Natural treatment systems are considered one of the best treatment options, particularly in warm climates [5].

Constructed wetlands are one of the many types of natural systems that can be used for treatment and pollution control. According to [3], a constructed wetland is defined as "a wetland specifically constructed for the purpose of pollution control and waste management, at a location other than existing natural wetlands". Constructed wetlands have many unique benefits as a wastewater treatment process, including the ability to operate on ambient solar energy, self-organize and increase treatment capacity over time, create wildlife habitat, produce oxygen and consume carbon dioxide, and achieve high levels of treatment with minimal maintenance [6]. Since 1950s, constructed wetlands have been used effectively to treat different wastewaters with different configurations, scales and designs throughout the world. This may be related to their nutrient capturing capacity, simplicity, low construction/ operation and maintenance cost, low energy demand, process stability, little excess sludge production, effectiveness and potential for creating biodiversity [7].

The macrophytes (phytoremediation/rhizo-filtration) growing in constructed treatment wetlands have several properties in relation to the treatment processes that make them an essential component of the design. The most important effects of the macrophytes in relation to the wastewater treatment processes are the physical effects of the

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plant tissues give rise to (e.g. erosion control, filtration effect, provision of surface area for attached microorganisms). The metabolism of the macrophytes (plant uptake, oxygen release, etc.) affects the treatment processes to different extends depending on design. The macrophytes have other site-specific valuable functions, such as providing a suitable habitat for wildlife, and giving systems [8]. Constructed wetlands are almost completely conversed with emerging macrophytes and are being managed as water quality improving systems, some commonly used macrophytes are the common reed (***Phragmites australls***), cattail (***Typha* spp.**) and bulrush (***Scirpus* spp.**), all characterized as water-tolerant macrophytes that are rooted in the soil but emerge above the water surface [9].

Nowadays, climate change and subsequently drought is the real challenge faces all life forms on our planet. Kurdistan Region of Iraq/ Northern Iraq (the most fertile lands of Mesopotamian) passes through drought since 1998 and still. In this context and concerning Sulaimani city, the largest in the region (population density estimated as 750000 and water demand foreseen as 165000m^3/day) the main conclusion here is that the quantity/ quality of available water resources for Sulaimani (i.e. Sarchinar springs, groundwater and Dukan Lake water project) are not adequate, thus finding out new alternatives are of commendable effort. In the present work an attempt was made for availability of reclamation/reuse of Sulaimani wastewater for irrigation purposes using phytoremediation "the low cost and less technology" of wastewater using staff of local aquatic macrophytes "e.g. ***Typha angustifolia***, ***Bolboschoenus maritimus, Phragmites australis***, ***Ando donax, Alisma plantago-aquatica*** and ***Mentha longifolia*** (Linn)" as biological waste purifiers, which may become part of the solution and the objectives were to;

a) Quantify levels of some heavy metals, namely; Fe, Mn, Zn and Cu in the wastewater of Sulaimani City,
b) Conduct phytoremediation processes, using six local species of macrophytes namely; ***T. angustifolia, B. maritimus*** *(*Linnaeus) Palla, ***Ph. australis*** (Cav.) Trin, ***A. donax***, ***A. plantago-aquatica*** and ***M. longifolia*** (Linn), to demonstrate their capability in feasibility of biological removal of Fe, Mn, Zn and Cu from the wastewater, and
c) Suggest an environmentally friendly wastewater reclamation project, using local aquatic macrophytes (as biological waste purifiers) cultivated in subsurface constructed wetland, to meet the present and future water demand for irrigation purposes and as an alternative to replace the existing wells and sanitary sewer if necessary.

II. METHODOLOGY AND EXPERIMENTAL SETUP

A. Project Area:

The raw wastewater canal close to Kostay Cham (one of the main sewage canals of Sulaimani/Iraq) Fig. 1 was selected for the purpose of the present study; an area of land (10 x 10m) was prepared for outdoor experiment implementation. The acquisition land was leveled within a slope of approximately 40º down the wastewater canal level; this for easy flow throughout/between the experimental units including storage tank then sand filtration pots and/or constructed wetlands, the plot area was cemented and fenced to protect the site from animal and other dwellers. No roofing for the experiment area (i.e. for prevention of rainfall interferences) was required, since all experiments/assessments were conducted only during dry seasons).

B. Duration:

Planning and construction of the proposed project was begun in May 25, 2007 and completed entirely in September 16, 2008. Meanwhile, macrophytes ***T.angustifolia****,* and ***B. maritimus*** pot experiments started in May 25, 2007 and completed in October 2, 2007. While ***Ph. australis*** and ***A. donax*** pot experiments and constructed wetland experiments started in May 10, 2008 and completed in September 16, 2008.

*C. Conventional Treatment Units (Sieving, Sedimentation Processes)***:**

A rectangular storage cement tank (230cm length, 150cm width, and 100cm height; capacity = 3450L) was constructed just close to trunk of the sewage canal, 8m from the experimental pots/wetland acquisition area. Two steel sieves were used for retaining large particles and/or debris into (pore size 8 mm) and out (pore size 4 mm) of storage/sedimentation unit, they were cleaned from time to time Fig. 2.

*D. Connection/ Distribution Pipelines***:**

Polyethylene pipelines were used for connection/ distribution of treatment units. The main pipeline (38mm diameter) was receiving discharged wastewater from the storage tank to 4 sub-main pipelines (31.75mm diameter) provided with valves to control the equal wastewater flow to sand pots/constructed wetland. The valves were connected to a rubbery tube for draining wastewater to each treatment unit. After treatment wastewater was collected by polyethylene pipelines (64mm) at the outlet of each pot to prevent flooding, also for easily water flow throughout the project units.

E. Pot Design:

Plastic experimental sand pots (40cm height, 36cm diameter and 41L capacity) were prepared Fig. 3. The wastewater was drained into each pot (10cm below the pot lip) through a controlled valve. Each pot was filled by; gravel at bottom and river sand as mid layer (each of 10cm depth). The effluent was allowed to percolate through the sand and gravel layers (filtration process).

F. Filtration Media:

Both quartz river sand (2.0mm diameter) and gravel (approximately 20mm in diameter) were prepared previously. To obtain the best effluent flow-rate and retention time, the effective size of sand was passed through a 2.0mm sieve. Only resistant sand which was not losing 5% of its weight after being placed in 40% HCl for 24 hours was used [10].

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G. Transplantation of Macrophytes:

Six species of local phytoremediation plants namely; ***Typha angustifolia*** *(*Linnaeus), ***Bolboschoenus maritimus*** *(*Linnaeus) Palla***, Phragmites australis*** (Cav.) Trin, ***Ando donax, Alisma plantago-aquatica*** and ***Mentha longifolia*** (Linn) Plates 1 to 4, were collected/identified within/around the sewage canal rout, they were used as biological waste purifiers. Only young plants were transplanted into the pots (five plants per pot, one central and others in peripheral manner) and wetland, and then they were left to stand for 45 days, the time needed for adaptation and acclimatization with their new habitat. It may be worth to mention that, the last two macrophytes species namely; ***Alisma plantago-aquatica*** and ***Mentha longifolia*** (Linn) were wiped out for unknown reasons, thus they were neglected.

H. Sand Pot Experimental Layout:

The experimental sand pots were designated for waste removal efficiency arranged in certain sequences as; single, double and triple pots in three replicates Fig. 4. The pots were jointed with each other by rubbery tubes and placed serially with a slope of approximately 30º. The flow rate of the effluent (refined water) from each pot was fixed approximately at 2 liter per hour. After the adaptation period, water samples were collected at the outlets of each single, double and triple pot on fortnightly (biweekly) interval periods for analysis and waste removal efficiency assessment by experimental macrophytes.

I. Microcosm in Constructed Wetlands:

Seven galvanized iron (rust proof) rectangular tanks were prepared (105cm length, 40cm width, and 40cm height and 168L capacity) Fig. 5 and Plates 5 and 6. All contained the same layer depths and types of media (sand and gravel) as described previously in sand pots and receiving effluent from storage tank after sieving. Pipeline of (25mm diameter) was connected to the microcosms (cells) of constructed wetlands by equally sectioned rubbery tubes. Plastic valves were used to control an equal flow of water to each microcosm of construction wetlands.

J. Microcosm Experimental Layout:

The microcosm constructed wetlands were arranged in four different series (control, single cell, double cells and triple cells) Fig. 6 and Plates 7 and 8 in a gradient level by approximately 30° slop to facilitate flowing of wastewater from the sedimentation tank toward the cells and between them. The internal connections between the cells were made by equally sectioned rubbery tubes which were easily removable for back-washing whenever required. Steel nets were placed at the mouth of the rubbery tubes (for each cell) to avoid running off the filtration sand from the cells. Each unit of cell, except the control was planted by (***T. angustifolia, B. maritimus, Ph. australis*** and ***A. donax)*** macrophytes all together (five plants of each species per cell). The flow rates of the effluent (refined water) from the cells were stabilized at 8 liter per hour. After adaptation period (45 days), water samples were collected at the outlet of the each single, double and triple cell for analyses, then the waste removal efficiency was assessed.

K. Wastewater Sample Collection:

Raw (Untreated) wastewater samples from Kustay Cham main sewage canal and different treatment stages were collected after stabilization period according to a regular schedule at biweekly interval periods and they were analyzed for their key physico-chemical characteristics during the studied period. Samples were collected using clean large pre washed polyethylene containers. Immediately samples were brought back to laboratory in cool and dark condition as described by [11] for analysis purposes.

L. Trace Heavy Metal Analysis:

Trace heavy metals in each water sample were determined by atomic absorption following [11]. Atomic absorption spectrophotometer, model (An Analyst 200-Atomic absorption spectrophotometer), Perkin-Elmer, China, was used for trace metal determination. For one liter suction-filtered water sample 4ml of conc. HNO_3 was added to minimize adsorption of the metals on the container walls. Measurements were in mg per liter. Plant shoot and root systems were digested according to [12] using (1:1 Conc. H_2SO_4 and H_2O_2) mixture for further metal analysis.

M. Removal Efficiency:

The equation described by [13] for detection of removal efficiency was used here, as given below:

Removal efficiency (%) = [(inlet pollutants-outlet pollutants)/ inlet pollutants] x 100

N. Statistical Analysis:

The data were analyzed after assumption of analysis of variance using revised least significant test (RLSD) to determine the significant variations between (different treatment stages) as a spatial variation and between the sampling date intervals as a temporal variation [14].

III. RESULTS AND DISCUSSION

Generally, removal of metals in wetlands may occur through a number of processes, including sedimentation/ coagulation, filtration, plant uptake/removal efficiency, adsorption (binding to sand particles and root), formation of solid compounds, cation exchange, and microbial-mediated reaction, especially oxidation [15].

A. Iron:

Iron Fe is present in a wide variety in wastewater [16]. Tables I, II and III, show the effect of purification treatment on the mean values of iron. A significant difference (*$P>0.01$*) in the mean values of iron were recorded between untreated wastewater and triple pots planted with ***T. angustifolia***, ***B. maritimus***, ***Ph. australis*** and ***A. donax*** experiment sand pots and microcosm constructed wetlands experiments. The mean

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values of iron calculated for raw wastewater were 1.011 and 1.147mg/l during 2007 and 2008 respectively, Tables I and II. These values were higher than those obtained by [17] in a study carried out on Dohuk wastewater and [18] on Hawler's wastewater. This may be related to nature of the activities at the studied areas. However, [19] demonstrated that metals can be present in raw household wastewater because of many commonly used household products contain metals (e.g. iron) such as pharmaceuticals, paint, battery, fuel combustion by transportation means… etc in addition to other sources include vegetable matter and human excreta.

From Tables I and II, it was clear that all experimental macrophytes were caused a decrease in iron concentrations into different levels, but the highest decreasing capability was clearer in triple pots planted by ***T. angustifolia*** and ***B. maritimus***, however, the mean values of iron concentration were decreased to 0.744 and 0.784mg/l respectively. Statements that of [20] may confirm the present results, however, they observed that macrophytes have the ability to remove trace metals from the wastewater through biological uptake and surface adsorption of their roots. Besides as explained by [21], submerged macrophytes play an important role in heavy metal recycling in wetlands.

The mean values of iron concentrations were decreased more when microcosm constructed wetlands tested in place of sand pots Table III. However, the mean iron value decreased from 1.147mg/l in raw wastewater to 0.669mg/l in triple-microcosm constructed wetland cultivated by all experimental macrophytes together. On the other hand, iron levels decreased from 0.962 to 0.696mg/l at the beginning of experiments, and decreased from 0.967 to 0.641mg/l at the end of the experiments, representing a decrease percentage from 28% to 51% of the initial levels. This may be related to the multi removal/bioaccumulation function of macrophytes all together to remove Fe. Reference [22] concluded that ***T. angustifolia*** alone reduced iron level from 14.3 to 0.8mg/l in a detailed constructed wetland experiment throughout its root system. Same findings that of [23] concerning Fe and Mn removal in constructed wetlands planted by ***Typha latifolia*** can be concluded here.

B. Manganese:

Although Manganese Mn in certain amounts is essential for aquatic organisms and plays an important role in many redox enzymatic reactions and photosynthesis, meanwhile it is toxic in high concentrations [24]. As shown in Tables IV, V and VI, the increase in Mn levels in sand pots caused a significant decrease ($P>0.01$) of Mn concentration in wastewater. The highest mean values of Mn 1.617 and 1.867mg/l were recorded in raw wastewater during 2007 and 2008, respectively Tables IV and V. As stated by [19], highest contents of Mn related to high inorganic material in the wastewater. The present values were seemed to be slightly higher than levels calculated by [18] for Hawler wastewater. Similar differences in Mn content were found by [25] in different wastewaters. On the other hand, the lowest mean Mn values of (1.051, 1.066, 1.287, 1.314 and 1.116mg/l) were calculated in pots planted with ***T. angustifolia***, ***B. maritimus***, ***Ph. australis***, and ***A. donax*** and microcosm constructed wetlands, respectively. Reference [20] concluded that macrophytes have uptake ability to remove trace metals from the wastewater in different mechanisms. Same conclusions can be given here**.**

Mn concentrations in the wastewater significantly ($P<0.001$) were decreased with time. However, in constructed wetland experiments, Mn levels were decreased from 1.799 to 1.121mg/l at the start date of experiments, and decreased from 1.867 to 1.116mg/l at the end of the experiments, representing a decrease from 32.7% to 74.9% of the initial levels. Similar conclusions were made by [25].

C. Zinc:

Zinc Zn is an essential micronutrient for plants, animals and microorganisms. It can be accumulate in their tissues without any damage concerns. Tables VII, IX and X, indicated that the experimental macrophytes caused significant ($P>0.01$) decrease in mean values of Zn in both experiments Pots/ microcosms in constructed wetland. The results showed that the mean values of Zn in raw wastewater were 0.882 and 0.938mg/l in 2007 and 2008, respectively. These values were higher than those obtained by [18] in Hawler wastewater, while they were comparable to values obtained by [26] in Sulaimani wastewater. The triple pots planted by experimental macrophytes ***T. angustifolia***, ***B. maritimus***, ***Ph. australis***, and ***A. donax*** were decreased the mean values of Zn to 0.717, 0.739, 0.769 and 0.815mg/l respectively.

It was clear that Zn reduction values in microcosm constructed wetlands, when all experimental macrophytes were planted together were highest, compared with pot experiments. However, Zn levels decreased significantly from 0.873 to 0.705mg/l at the start date of experiments, and decreased from 0.861 to 0.533mg/l at the end of experiments, representing a decrease from 19.3% to 61.5% of the initial levels, and the removal rate was estimated as 66.7%. Results obtained by [27]-[28], when they studied removal of heavy metals (including Zn) through sedimentation and filtration processes in the high reed biomass wetlands during a study for more than two years, may confirm the present findings.

D. Copper:

Copper Cu is considered as an essential nutrient in certain doses, but over than 50mg/l is a serious contaminant [29]. As shown in Tables XI, XII and XIII the experimental macrophytes affected significantly ($P>0.01$) the mean values of Cu concentrations in pot experiment and microcosm constructed wetland, the highest mean values of Cu concentration 0.617 and 0.638mg/l were recorded for untreated wastewater in 2007 and 2008 respectively. These values are agreed with those obtained by [26] in Sulaimani wastewater. While, the lowest mean values of Cu concentrations of 0.380, 0.413, 0.445, 0.473 and 0.350mg/l were recorded for ***T. angustifolia***, ***B. maritimus, Ph. australis*** and ***A. donax*** planted separately and all together in microcosms respectively. A significant ($P<0.001$) decrease of the copper concentrations in the wastewater with time was observed in all experiments, representing a decrease percentage from 33% to 100% of the initial levels. Similar results obtained by [25]-[27]-[28] can be concluded here.

E.Removal Rates of Heavy Metals in Different Experimental Stages:

From onset results Table XIV, it seemed that removal percentage rates of all studied metals; Fe, Mn, Zn, and Cu were clear throughout experiment sand pots and microcosms in the constructed wetland. However, in triple cells of constructed wetland at the end of experiments the highest mean removal values of 33.12, 42.82, 38.09 and 49.19% for Fe, Mn, Zn, and Cu were recorded respectively. Moreover, Fe and Mn concentrations were decreased by an average of 91% in the first year May 1996–May 1997, and by 94 and 98% in the second year July 1997–June 1998, respectively. Results those obtained by [30] seem to confirm the present findings, however, they studied the removal percentage rates of Fe and Mn in constructed wetland treatments planted by ***Typha latifolia*** at Springdale, Pennsylvania and they successfully removed Fe and Mn from the inlet water by 92%.

F. Biomass Production:

Macrophytes belonging to (**Typhaceae**, e.g. Cattails ***Typha*** *spp.*), (**Cyperaceae**, e.g. Sedges ***B. maritimus*** L. Palla), (**Poaceae**, e.g. Great reed ***Ph. australis*** Cav. Trin) and reed ***A. donax*** **L.**), have been used widely as phytoremediation systems in natural and constructed wetlands [31]. Figs. 7 and 8 refer to significant effects of experimental macrophytes on both aboveground biomass and root system phytomass in pot experiments. The highest mean values of aboveground biomass and root system phytomass of the harvested ***T. angustifolia*** were 679, 1393 and 2159g/pot and 302, 615 and 946g/pot were recorded for single, double and triple pots respectively. The biomass of ***T. angustifolia*** shoot increased almost 25 times from 27.5 to 679 g/pot. Reference [32] noted that ***T. angustifolia*** was able to grow in organic, highly reduced sediments, as well as on acidic site of neutrality with high concentrations of reduced metal ions in the interstitial water. This indicates that ***T. angustifolia*** possess an efficient mechanism for root-aeration. Same conclusions can be given here.

While, the lowest mean values of aboveground biomass and roots-rhizomes phytomass of the harvested ***A. donax*** of 165, 347 and 524g/pot and 75, 156 and 237g/pot were recorded for single, double and triple pots respectively. On the other hand, in the constructed wetland experiments the four macrophytes grown together were significantly affected the aboveground biomass and roots-rhizomes phytomass. The highest mean values of dry matter of shoot and root systems of the harvested ***T. angustifolia*** of 766, 1562 and 2383g/constructed wetland cell and 307, 624 and 952g/constructed wetland cell were recorded for single, double and triple cells respectively. While, the lowest mean values of aboveground biomass and roots-rhizomes phytomass for ***A. donax*** of 270, 556 and 843g/constructed wetland cell and 115, 228 and 354g/constructed wetland cell were recorded for single, double and triple cells respectively.

In the pot and constructed wetland experiments significant correlation coefficient (r=.9996) was recorded between the levels of pot and dry mater of shoot and root systems. These statistical relationships explain the role of increase levels of pot in increasing dry matter of macrophytes. In general the application of triple pot caused increase in dry matter compared with single and double pot. This may be due to the positive effect of root system in triple pot on nutrient balance when EC and other parameters decreased (data are not given here). These results were in agreement with those found by [33], however, they found a positive relationship between macrophytes planted together in a large size pot and increased in productivity of shoot/ root systems.

G. Metal Accumulation:

Macrophytes are considered as important components of the aquatic ecosystem not only as food source for aquatic invertebrates etc., but also they act as an efficient accumulator of heavy metals [34]. According to [35], an aquatic macrophyte for wastewater treatment must have the following characteristics: (a) fast growth rate, (b) high biomass production, and (c) the ability to accumulate high concentrations of nutrients and heavy metals over a long time exposure with no damage concerns.

1. Iron:

Reference [36] outlined that; the Fe content in aquatic plants examined from several sites exceeded the recommended phyto-toxic range from 5 to 200μg/g with no damage concerns. According to [37], the range between 40 to 500μg/g of Fe concentration is considered to be toxic to plants. The present results indicated that the highest mean value of Fe concentration of 667.7μg/g was recorded in roots of ***T. angustifolia*** in constructed wetlands. While the lowest mean value of Fe concentration 381.7μg/g was recorded in shoots of ***A. donax*** in constructed wetlands, Table XV. The present results were well agreed with those obtained by [38], however they found that ***T. latifolia*** has the ability to extract Fe from their water surroundings and generally, the roots contained higher concentrations of heavy metals than the stem and the leaves. As stipulated by [39], ***Typha spp.*** plays an important role in metal retention by virtue of immobilization of metals in oxygenated rhizosphere. Moreover, roots of macrophytes can accumulate great amount of heavy metals due to its cortex parenchyma with large intercellular air spaces [40]. Based on the present results, leaves of ***T. angustifolia*** and ***B. maritimus*** contained more Fe than leaves of ***Ph. australis*** and ***A. donax***. On the other hand, comparing the amount of Fe concentration in different parts of experimental macrophytes, it was found that; Fe concentration was higher in plant organs than in sediment and water. As stated by [41] marsh plants are known to absorb/accumulate heavy metals from contaminated water and sediments. Moreover, present results showed higher metal contents in submerged macrophytes compared with those of emerged macrophytes (such as ***Typha angustifolia***). Similar conclusions were made by [42]. However, [43] studied removal of heavy metals in constructed wetlands, and he found that Fe concentrations in shoots and roots of ***Juncus*** and ***Lythrum*** were 173 and 334µg Fe/g shoot and 718 and 3985µg Fe/g root, respectively. Iron levels in ***T. angustifolia*** shoots and roots were increased by 123.0 and 147.17% and 127.31 and 135.09% after treatment by pot and constructed wetland experiments, respectively. While the lowest increasing percentages of 52.62 and 110.21% and 60.36 and 102.13% were observed in shoots and roots of ***A. donax*** and ***Ph. australis*** in pots and constructed wetland experiments, respectively. In this context, [44] has observed high concentrations of heavy metals in ***T. Angustifolia*** roots; accordingly he concluded that adjustment of macrophytes such as ***T. Angustifolia*** to live under polluted conditions may cause an adaptation in its physiological mechanisms for tolerate itself from drastic conditions. This can be concluded for the present study.

Analysis of harvesting of the above-ground biomass of ***T.angustifolia***, ***B. maritimus***, ***Ph. australis*** and ***A. donax*** in constructed wetland experiments showed that 0.375, 0.303, 0.189 and 0.103g Fe/constructed wetland cell respectively have been removed at the end of experiment period, which equivalent to 3.69, 2.97, 1.86 and 1.01g Fe/m^2. These results are well agreed with same findings obtained by [45], when he used ***Typha angustifolia*** as a bio-monitor for some toxic heavy metals and he concluded that the accumulated heavy metals in ***T. angustifolia*** tissue were strongly correlated to the surrounding metal contents.

2.Manganese:

According to [37], concentrations from 50 to 500µg/g are toxic to most plants. Present results Table XVI indicted that ***T.angustifolia*** could accumulate considerable amount of Mn concentration in its tissues, but the highest mean Mn concentration of 826.0µg /g was found in shoots. While the lowest mean Mn concentration of 467.7µg/g was found in roots of ***A. donax*** in constructed wetland. Reference [46] found that metal concentrations in the belowground biomass were generally higher than in the aboveground of macrophytes, especially in ***P.australis*** parts, except for Mn.

The increase of Mn levels in roots and shoots of ***T.angustifolia*** were 99.4 and 98.1% and 111.3 and 126.4% for pot and constructed wetland experiments, respectively. While, the lowest increasing percentage was observed in ***B.maritimus*** in pot experiment and constructed wetland experiment in ***A. donax***. It was found that when the shoot systems of macrophytes ***T.angustifolia***, ***B.maritimus***, ***Ph. australis*** and ***A. donax*** being harvested in constructed wetland experiment caused the removal rate of 0.632, 0.415, 0.351 and 0.139g Mn/constructed wetland cell at the end of experiment period, which equivalent to 6.21, 4.07, 3.45 and 1.36g Mn/m^2. Statements of [47] may confirm the present results; however, they stated that the concentration of metals in aquatic plants may exceed 100 000 times greater than in the associated water.

3. Zinc and copper:

According to [48], the range from 10 to 100µg/g Zn considered as toxic doses for most plants. Generally, results Tables XVII and XVIII indicated that highest mean values of Zn and Cu concentrations were accumulated in ***T.angustifolia*** tissues and the minimum values of Zn and Cu contents were recorded for ***A. donax*** shoots in pot and constructed wetland experiments. However, the maximum mean values of Zn and Cu contents of 293.3 and 40.7µg/g dry weight plant respectively were observed at the roots of ***T.angustifolia*** cultivated in constructed wetland. On the other hand the maximum mean values of Zinc and copper content for shoots of 90.0 and 24.1µg/g dry weight plant respectively were also recorded for ***T.angustifolia*** in constructed wetland. Similar conclusions were made by [49]; however they reported that roots of ***T. angustifolia*** possess a high surface area to volume ratio and this may be behind the high metal bioaccumulation of heavy metals. While, [50] concluded that ***Typha latifolia*** exhibited highest metal concentrations in the root tissue with Zn demonstrating exponential increases under controlled laboratory and in-situ field conditions. Meanwhile, [51] observed that the greater proportion of heavy metals taken up by plants was retained in the roots with metal concentrations decreasing in the following order: roots > rhizomes > non-green leaves > green leaves under contaminated conditions. These can be concluded for the present findings.

The highest increased percentage of zinc and copper concentrations were recorded in roots and shoots of ***T. angustifolia*** after treatment processes 343.1 and 118.38% and 206.1 and 153.33% in constructed wetland experiments, respectively. While, the lowest increased percentages of zinc and copper concentrations were observed in ***A. donax*** roots and shoots from pot experiments Tables XVII and XVIII. Reference [52] made similar observations for ***T.angustifolia***, where a higher amount of metal in root was observed compared to the sediments in which they were growing. Moreover, they explained that the short life cycle of ***T. angustifolia*** is the main reason for more metals being accumulated in roots than in shoots.

Analysis of harvested shoot systems of ***T. angustifolia***, ***B. maritimus***, ***Ph. australis*** and ***A.donax*** in constructed wetland experiments showed that they removed about 0.691, 0.362, 0.252 and 0.120g Zn m^{-2} and 0.182, 0.132, 0.055 and 0.028g Cu/m^2 at the end of experiments respectively. Reference [53] reported that macrophytes possess high ability to accumulate Zn in the aboveground biomass. Moreover, [45] found similar ability of macrophytes for heavy metal accumulation in wetlands; and subsequently metals can be removed from the wastewater by harvesting of the aboveground biomass.

REFERENCES

[1] P.H. Gleick, “The World’s Water 2000–2001: The Biennial Report on Freshwater Resources”. Island Press, Washington, DC, USA, p 315, 2000.
[2] L.R. Buddhavarapu, and S.J. Hancock, “Advanced treatment for lagoons using duckweed”. J. Water Environ. Technol, vol. 3, pp. 41-44. 1991.
[3] A. R. Upadhyay, “Aquatic Plants for the Waste Water treatment”, Daya Publishing House, Delhi, 2004, ch 2.

[4] R.N. Kar, B.N. Sahoo, and L.B. Sukla, “Removal of heavy metal from mine water using sulphate reducing Bacteria”, J. Pollution Res. Vol. 11, pp. 1–13. 1992.

[5] A. Angelakis, “Management of wastewater by natural treatment systems with emphasis on land-based systems”, (2001). IN: Decentralised Sanitation and Reuse, “concepts, systems and implementation”. P. Lens, G. Zeeman and G. Lettinga , IWA Publishing, London. 2002.

[6] S. Wallace, “Putting Wetlands to Work”. Civil Engineering, 98-007-0057. American Society of Civil Engineers, New York. 1998.

[7] R. Haberl, “Constructed Wetlands: A Chance to Solve Wastewater Problems in Developing Countries”, J. Water Sci. Technol. 40(3), pp.11-17. 1999.

[8] H. Brix, “Functions of macrophytes in constructed wetlands”, J. Water Sci. Technol. Vol. 29, pp. 71-78. 1994.

[9] R.H. Kadlec, R.L. Knight, J. Vymazal, H. Brix, P. Cooper, R. Haberl, “Constructed wetlands for pollution control: Processes, performance, design and operation”, IWA specialist group on use of Report, No.8. London. UK: IWA publishing, p156, 2002.

[10] World Health Organization, W.H.O., “Health and Environment in Sustainable Development”, WHO, Geneva. 1997.

[11] [11] American Public Health Association, A.P.H.A., “Standard Methods for the Examination of Water and Wastewater”, 20th Ed, Washington. 1998.

[12] A.C.A. Schuffeelen, and J.C.H. Van Schauwenburg, “For soil and plant analysis used by small laboratories, Neth.”, J. Agric. Aci, vol.9, pp. 2-16. 1961.

[13] L. Xuerui, L. Chongyu, and S. Wensheng, “Treatment of landfill leachate by constructed wetland: A Microcosm Test. Proc”, 3rd International Vetiver Conference, Guangzhou, China, October 2003.

[14] J.S.Milton, and A. Jessec, “Introduction to probability and statistic”, 3rd Ed, Mc Graw. Hill, Inc. New York. 1995.

[15] [15] J.T. Watson, S.C. Reed, R.H. Kadlec, R.L. Knight, Whitehouse, and A.E. “Performance Expectations and Loading Rates for Constructed Wetlands”. In: D.A. Hammer, Constructed Wetlands for Wastewater Treatment, 1990, “Industrial and agricultural”. Lew Publishers, Chelsea, MI, 1989.

[16] H. L. Golterman, R.S. Clymo, and M.A. Ohan Stad, “Methods for physical and chemical Analysis of fresh waters”, 2nd Ed, Black Well Scientific publications, Oxford, London, p 220, 1978.

[17] R.O. Hussein, “Heavy metal contamination in some vegetables irrigated by wastewater of Duhok city, Kurdistan region, Iraq”, M.Sc. Thesis, Univ. of Duhok, Duhok, Iraq, 2005.

[18] M.A. Othman, “Phytoremediation of wastewater using ***Typha angustifolia*** L. and *Plantago lanceolata* L. for irrigation purposes”. M.Sc.thesis. Univ. of Salahaddin-Hawler, Iraq, 2006.

[19] W.L, Berry, A. Wallace, and O.R. Lunt, “Utilization of municipal wastewater for culture of horticultural crops”, Hort. Sci, vol. 15, pp. 169– 171, 1980.

[20] B.S. Collins, R.R. Sharitz, and D.P. Coughlin, “Elemental composition of native wetland plants in constructed microcosm treatment wetlands”. J. Bioresource Technol, 96 (8), pp. 937–948, 2005.

[21] M. Scholz, “Performance predictions of mature experimental constructed wetlands which treat urban water receiving high loads of lead and copper”, J. Water Res, 37(6), pp. 1270–1277, 2003.

[22] G.A. Brodie, D.A. Hammer, and D.A. Tomljanovich, “Treatment of acid drainage with a constructed wetlands at the Tennessee Valley Authority 950 coal mine” 1989). In: D. A. Hammer, “Constructed Wetlands for Wastewater Treatment”. Industrial and agricultural. Lew Publishers, Chelsea, MI, pp. 201–209, 1990.

[23] Z.H. Whiting, Z.Q. Lin, C. M. Lytle, J.H. Qian, and N. Terry, “Removal and Distribution of Iron, Manganese, Cobalt, and Nickel within a Pennsylvania Constructed Wetland Treating Coal Combustion By-Product Leachate”, J. Environ, Qual, vol. 30, pp.1464–1473, 2001.

[24] M.A.A. Al-Saadi, “Principle of ecology and pollution”, Dar-Al Yazori. Publication. P. 411. 2006.

[25] V. Diagomanolin, M. Farhang, M. Ghazi-khansari, and H.N. Jafarzade, “Heavy metals (Ni, Ct and Cu) in the Karoon waterway river”, Iran, Toxicol Lett, vol.151, pp. 63-67, 2004.

[26] O.M.M. Mustafa, “Impact of sewage wastewater on the Environment of Tanjero river and its basin within Sulaimani province, Sulaimani, Kurdistan region of Iraq”, M.Sc. Thesis. Univ. of Baghdad. Baghdad. Iraq, 2006.

[27] R.J. Hares, and N.I. Ward, “Sediment accumulation in newly constructed vegetative treatment facilities along a new major road”, J. Sci. of The Total Environ, vol. 334–335,pp. 473-479, 2004.

[28] W.R. Wenerick, Jr. Stevens, S.E., H.J. Webster, L.R. Stark, and E. DeVeau, “Tolerance of three wetland plant species to acid mine drainage: a greenhouse study”, 1989, In: D.A. Hammer Constructed Wetlands for Wastewater Treatment, Municipal, Industrial and agricultural”, Lewis Publishers, Chelsea, MI, pp. 801-807, 1990,

[29] [29] World Health Organization, W.H.O., “Guidelines for Drinking–Water Quality”, 3rd Ed, Recommendations, Geneva Switzerland, p.515, 2006.

[30] Z.H., Ye, S.N. Whiting, Z.Q. Lin, C.M. Lytle, J. H. Qian, and N. Terry, “Removal and Distribution of Iron, Manganese, Cobalt, and Nickel within a Pennsylvania Constructed Wetland Treating Coal Combustion By-Product Leachate”, J. Environ. Qual, vol. 30, pp. 1464–1473, 2001.

[31] R.H. Kadlec, and R.L. Knight, “Treatment wetlands”, Lewis Publishers, Boca Raton, New York, London, Tokyo, pp. 40-46, 69-70, 1996.

[32] W.R. Wenerick, Jr.S.E. Stevens, H.J. Webster, L.R. Stark, and E. DeVeau, “Tolerance of three wetland plant species to acid mine drainage: a greenhouse study”, 1989. In: D.A. Hammer, “Constructed Wetlands for Wastewater Treatment, Municipal, Industrial and agricultural”, Lewis Publishers, Chelsea, MI, pp. 801-807, 1990.

[33] Z. Zhang, Z. Rengel, and K. Meney, “Nutrient Removal from Simulated Wastewater Using *Canna indica* and *Schoenoplectus validus* in Mono-culture and Mixed-Culture in Wetland Microcosms”. J. Air and Soil pollution, vol. 183, pp. 95–105, 2007.

[34] I.H. Chung, and S.S. Jeng, “Heavy metal pollution of Ta-Tu River”, Bulletin of the Institute of Zoology, Academy of Sci., vol. 13, pp. 69-73, 1974.

[35] K.R. Reddy, and W.F. DeBusk, “Nutrient storage capabilities of aquatic and wetland plants”, 1987. In: K. R, Reddy, W.H. Smith, “Aquatic plants for water treatment and resource recovery”, Orlando, Florida: Magnolia Publishing, pp. 337–357, 1987.

[36] B. Markert, “Presence and significance of naturally occurring chemical elements of the periodic system in the plant organism and consequences for future investigations on inorganic environmental chemistry in ecosystems”, J. Vegetation, vol. 103, pp. 1–30, 1992.

[37] S.E. Allen, “Chemical Analysis of Ecological Materials”, 2nd Ed, Blackwell Scientific Publications, Oxford, 1989.

[38] A.C. Carranza, J.A. Alonso-Castro, C.M. Torre, and F.R. Cruz, “Accumulation and Distribution of Heavy Metals in ***Scirpus americanus*** and ***Typha latifolia*** from an Artificial Lagoon in San Luis Potosí, México”, J. Water, Air and Soil Pollution, vol. 188. pp. 297–309, 2007.

[39] M.L. Otte, S.C. Kearns, and M.O. Doyle, “Accumulation of arsenic and zinc in the rhizosphere of wetland plants”, Bull. Environ. Contam. Toxicol, vol. 55, pp. 154-161, 1995.

[40] [40] T. Sawidis, M.K. Chettri, G.A. Zachariadis, and J.A. Stratis, “Heavy metals in aquatic plants and sediments from water systems in Macedonia, Greece”, J. Ecotoxicol. Environ, Safety, vol. 32. pp. 73–80, 1995.

[41] D.J. Burke, J.S. Weis, and P. Weis, “Release of metals by the leaves of salt marsh grasses *Spartina alterniflora* and *Phragmites australis*”, Estuar. J, Coast. Shelf Sci., vol. 5, pp. 153–159, 2000.

[42] A. Samecka-Cymerman, and J. Kempers, “Bioaccumulation of heavy metals by aquatic macrophytes around Wroclaw, Poland”, J. Ecotoxicol. Environ. Safety, vol. 35. pp. 242–247, 1996.

[43] C. Chague-Goff, “Assessing the removal efficiency of Zn, Cu, Fe and Pb in a treatment wetland using selective sequential extraction”, J. Water, Air and Soil Pollution, vol. 160. Pp. 161-175, 2004.

[44] A.D. Montante-Montelongo, “Estudio geoquímico de metales traza en una laguna artificial de aguas residuals”, MSc thesis, Universidad Autónoma de San Luis Potosí, S. L.P., México. 1998.

[45] D.G.A. Ganjo, “***Typha angustifolia*** L. as a biomonitr for some toxic heavy metals in polluted ponds”. Scientific Conference of water-Hawler, Brayeti-Center, vol. **18. Pp.** 233-256, 2001.

[46] E. Lesage, D.P.L. RousseauE., Meers, A.M.K. Van de Moortel, G., Tack, F.M.G. Laing, N. Pauw and M. G. Verloo, “Accumulation of Metals in the Sediment and Reed Biomass of a Combined Constructed Wetland Treating Domestic Wastewater”, J. Water Air and Soil Pollution, vol. 183, pp. 253–264, 2007.

[47] P.H. Albers, and M.B. Camardese, “Effects of acidification on metal accumulation by aquatic plants and invertebrates. 1. Constructed wetlands”, J. Environ. Toxicology and Chemistry. 12 (6), pp. 959–967, 1993.

[48] L. Frisberg, G.F. Nordberg, E. Kessler, and V.B. Vouk, “Handbook of the Toxicology of Metals”, Vols I&II Elsevier Science Publ., Amsterdam.

[49] P. Mays, and G. Edwards, "Comparison of heavy metal accumulation in a natural wetland and constructed wetlands receiving acid mine drainage", J. Ecological Eng., vol. 16, pp. 487-500, 2001.

[50] J. B. Ellis, R. B. Shutes, D. M. Revitt, T. T. Zhang, "Use of macrophytes for pollution treatment in urban wetlands", J. Resour. Conserv. Recy., vol. **11**, pp. 1-12, 1994.

[51] J.S. Dunbabin, and K.H. Bowmer, "Potential use of constructed wetlands for treatment of industrial wastewaters containing metals", J. Sci. Total Environ., vol. 3, pp. 151-168, 1992.

[52] D. Demirezen, A. Aksoy, and K. Uruc, "Effect of population density on growth, biomass and nickel accumulation capacity of ***Lemna gibba*** (Lemnaceae)", Chemosphere, vol. 66, pp. 553-557, 2007.

[53] W. Rascio, "Metal accumulation by some plants growing on Zn mine deposits", Oikos, vol. 29, pp. 250-253, 1977.

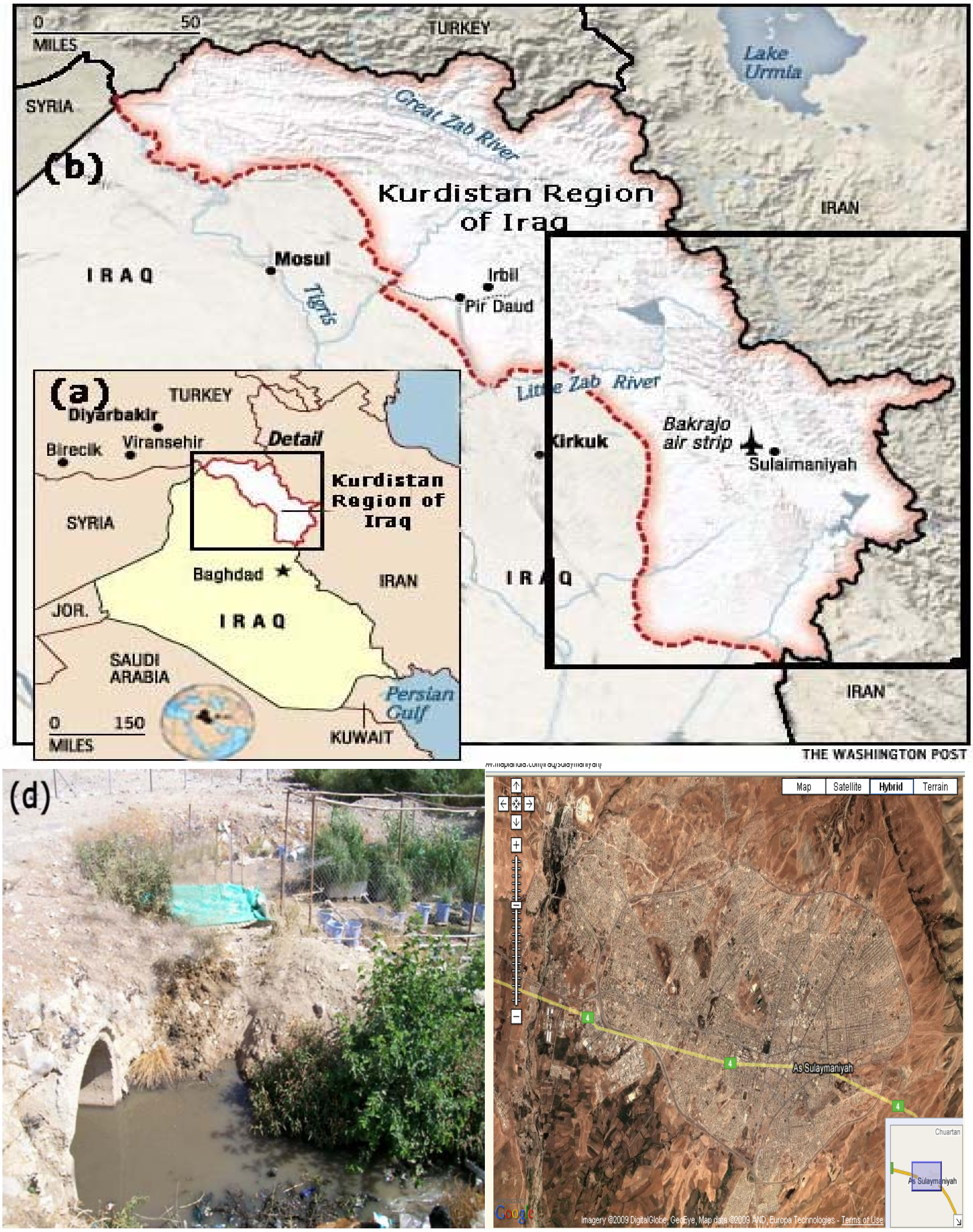

Fig.. 1 Location Map of the studied area showing; (a) Map of Iraq, (b) Map of Sulaimani City, (c) Sat Image of Sulaimani and (d) Kostay Cham (one of the main sewage canals of Sulaimani City.

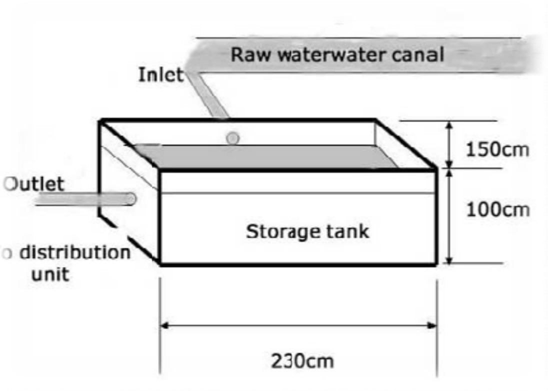

Fig. 2 Storage/ sedimentation unit

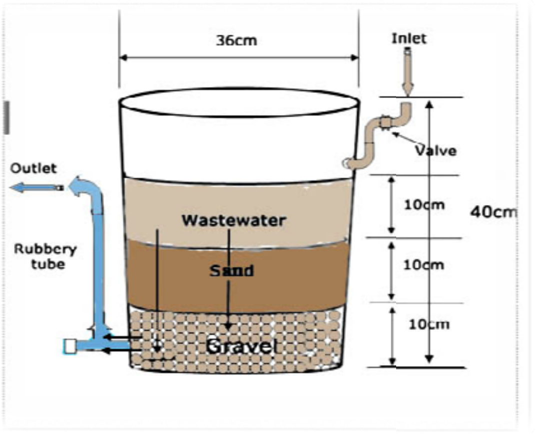

Fig. 3 Sand Filtration Pot

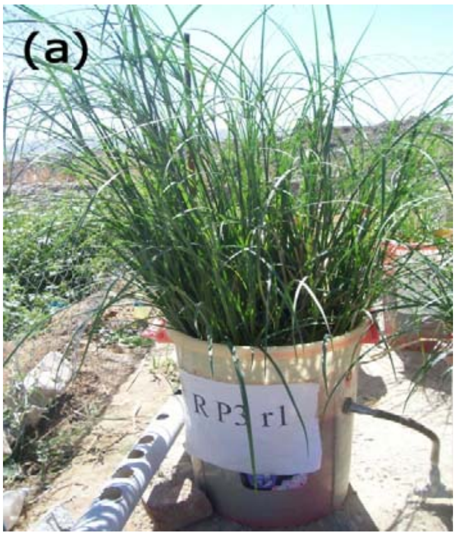

Plate 1 *Bolboschoenus maritimus*

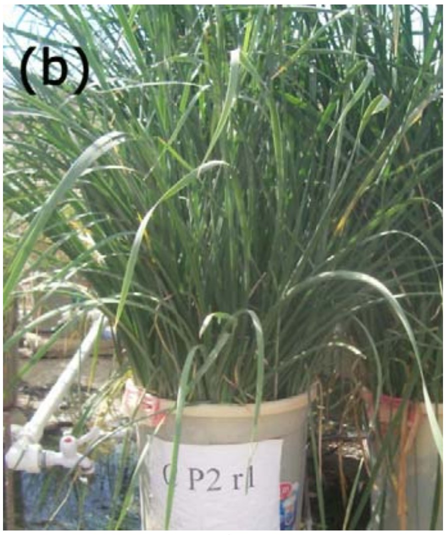

Plate 2 *Typha angustifolia (*Linnaeus)

Plate 3 *Phragmites australis*

Plate 4 *Arundo donax* L.

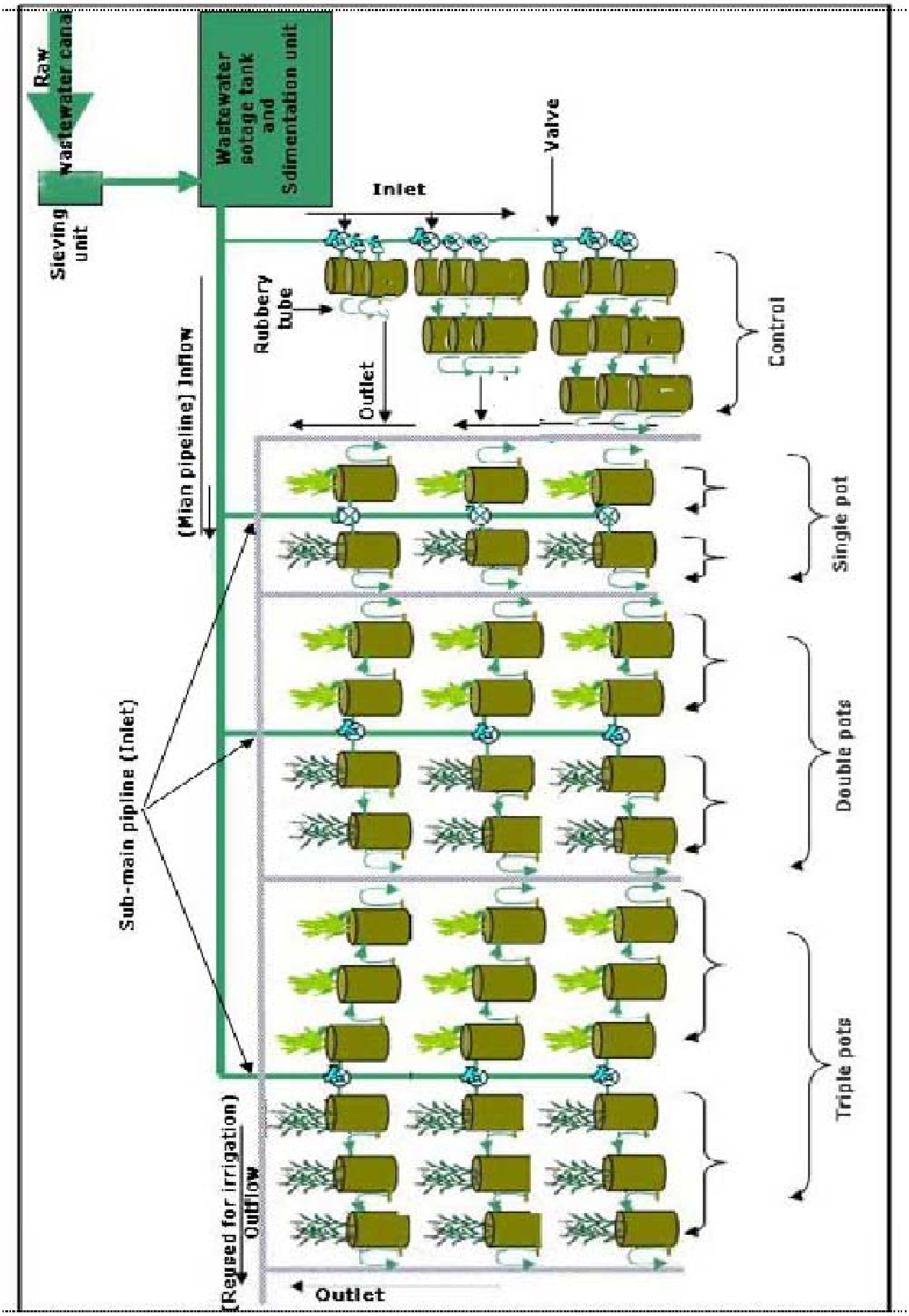

Fig. 4 Sand Filtration Pot Experiment Design.

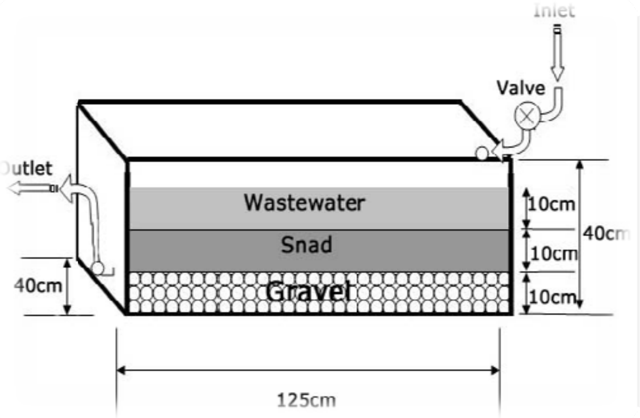

Fig. 5 Microcosm of constructed wetlands/ cells

Plates 5 and 6 Microcosm construction wetlands preparation stages and design.

Plates 7 and 8 Stages of macrophytes plantation and growth

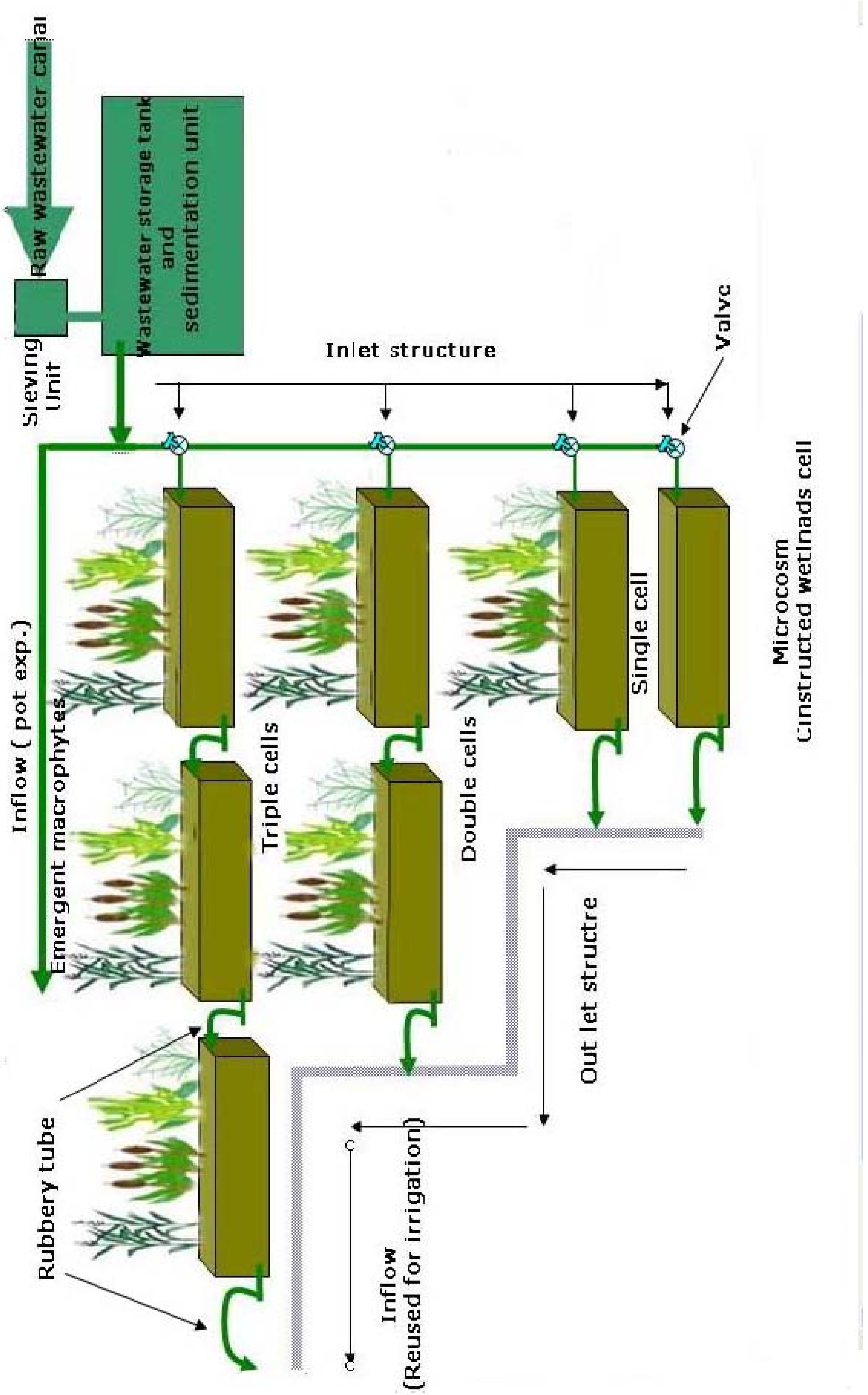

Fig. 6 Microcosm constructed wetlands experiment Design.

TABLE I
The mean values of Fe (mg/L) calculated from outlet points for ***T. angustifolia*** and ***B. maritimus*** experiment sand filtration pots during the studied period

Treatments (Sample of effluent)	**Date of Experiment - 2007**						**Mean**
	July	**August**		**September**		**October**	
	15	**01**	**16**	**02**	**17**	**2**	
Untreated raw wastewater	0.852	0.97	0.960	1.148	1.173	0.961	1.011
Effluent of Sedimentation unit	0.829	0.971	0.932	1.125	1.178	0.950	0.998
Control-Single pot (**Control-P1**)	0.804	0.952	0.912	1.106	1.131	0.923	0.971
T. angustifolia-Single pot (**CP1**)	0.783	0.891	0.854	1.054	0.988	0.870	0.907
B. maritimus -Single pot (**RP1**)	0.754	0.929	0.887	1.088	1.025	0.908	0.932
Control-Double pots(**Control-P2**)	0.785	0.925	0.886	1.087	1.062	0.903	0.941
T. angustifolia-Double pots(**CP2**)	0.765	0.803	0.899	1.031	0.972	0.853	0.887
B. maritimus -Double pots(**RP2**)	0.764	0.903	0.967	1.067	1.012	0.885	0.933
Control-Triple pots(**Control-P3**)	0.798	0.813	0.841	0.997	1.005	0.887	0.890
T. angustifolia-Triple pots (**CP3**)	0.745	0.815	0.741	0.762	0.750	0.654	0.744
B. maritimus -Triple pots (**RP3**)	0.747	0.822	0.811	0.815	0.753	0.758	0.784
Mean	0.784	0.89	0.881	1.026	1.005	0.868	0.909

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.0481	0.063	0.0355	0.0469	N.S	N.S

TABLE II
The mean values of Fe (mg/L) calculated from outlet points for ***Ph. australis*** and ***A. donax*** experiment sand filtration pots during the studied period

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	0.962	1.135	1.231	1.246	1.340	0.967	1.147
Effluent of Sedimentation unit	0.935	1.126	1.225	1.246	1.331	0.967	1.138
Control-Single pot (**Control-P1**)	0.916	1.132	1.236	1.132	1.285	0.958	1.109
Ph. australis -Single pot (**PhP1**)	0.893	1.042	1.078	1.062	1.117	0.902	1.016
A. donax -single pot (**TP1**)	0.844	1.014	1.094	1.103	1.142	0.936	1.022
Control-Double pots(**Control-P2**)	0.903	1.049	1.109	1.121	1.101	0.943	1.038
Ph. australis-Double pots (**PhP2**)	0.841	0.954	1.003	1.013	1.022	0.883	0.953
A. donax- Double pots (**TP2**)	0.807	0.939	1.033	1.041	0.998	0.895	0.952
Control-Triple pots (**Control-P3**)	0.889	1.040	1.036	1.047	1.073	0.829	0.986
Ph. australis-Triple pots (**PhP3**)	0.821	0.944	0.919	0.964	0.956	0.726	0.888
A. donax - Triple pots (**TP3**)	0.859	0.923	0.942	0.923	0.938	0.827	0.902
Mean	0.879	1.027	1.082	1.082	1.118	0.894	1.014

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.0653	0.0862	0.048	0.0637	N.S	N.S

TABLE III
THE MEAN VALUES OF FE (MG/L) CALCULATED FROM EFFLUENT POINTS FOR MICROCOSM CONSTRUCTED WETLAND SYSTEMS DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	0.962	1.135	1.231	1.246	1.340	0.967	1.147
Effluent of Sedimentation unit	0.935	1.126	1.225	1.246	1.331	0.967	1.138
Control-Single microcosm Constructed wetland ($\mathbf{CW_c}$)	0.882	1.032	1.069	1.076	1.136	0.924	1.020
Single-microcosm Constructed wetland ($\mathbf{CW_1}$)	0.735	0.891	0.829	0.995	1.071	0.857	0.896
Double-microcosm Constructed wetland ($\mathbf{CW_2}$)	0.715	0.769	0.718	0.790	0.793	0.753	0.757
Triple-microcosm Constructed wetland ($\mathbf{CW_3}$)	0.696	0.714	0.620	0.685	0.660	0.641	0.669
Mean	0.821	0.944	0.949	1.006	1.055	0.851	0.938
LSD	**Treatment**		**Period**		**Interaction**		
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**	
	0.063	0.0844	0.063	0.084	N.S	N.S	

TABLE IV
THE MEAN VALUES OF MN (MG/L) CALCULATED FROM OUTLET POINTS FOR ***T. ANGUSTIFOLIA*** AND ***B. MARITIMUS*** EXPERIMENT SAND FILTRATION POTS DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2007**						**Mean**
	July	**August**		**September**		**October**	
	15	**01**	**16**	**02**	**17**	**2**	
Untreated raw wastewater	1.549	1.928	1.244	1.545	1.885	1.554	1.617
Effluent of Sedimentation unit	1.510	1.911	1.220	1.515	1.862	1.523	1.590
Control-Single pot (**Control-P1**)	1.460	1.822	1.161	1.454	1.757	1.457	1.519
T. angustifolia-Single pot (**CP1**)	1.387	1.731	1.048	1.336	1.612	1.312	1.404
B. maritimus -Single pot (**RP1**)	1.396	1.766	1.048	1.314	1.647	1.359	1.422
Control-Double pots(**Control-P2**)	1.345	1.672	1.094	1.385	1.703	1.395	1.432
T. angustifolia-Double pots(**CP2**)	1.272	1.611	0.951	1.234	1.515	1.228	1.302
B. maritimus -Double pots(**RP2**)	1.257	1.632	0.969	1.283	1.555	1.247	1.324
Control-Triple pots(**Control-P3**)	1.195	1.338	0.972	1.238	1.419	1.299	1.244
T. angustifolia-Triple pots (**CP3**)	1.088	1.287	0.830	1.020	1.201	0.881	1.051
B. maritimus -Triple pots (**RP3**)	1.091	1.334	0.827	1.023	1.205	0.918	1.066
Mean	1.323	1.639	1.033	1.304	1.578	1.288	1.361

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.0704	0.093	0.0519	0.0686	N.S	N.S

TABLE V
The mean values of Mn (mg/L) calculated from outlet points for ***Ph. australis*** and ***A. donax*** experiment sand filtration pots during the studied period

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	1.799	1.762	2.103	2.086	1.590	1.861	1.867
Effluent of Sedimentation unit	1.644	1.853	2.097	2.079	1.496	1.846	1.836
Control-Single pot (**Control-P1**)	1.554	1.805	1.964	1.978	1.459	1.757	1.753
Ph. australis -Single pot (**PhP1**)	1.361	1.775	1.866	1.828	1.311	1.604	1.624
A. donax -single pot (**TP1**)	1.331	1.737	1.834	1.864	1.336	1.636	1.623
Control-Double pots(**Control-P2**)	1.271	1.471	1.604	1.625	1.320	1.466	1.459
Ph. australis-Double pots (**PhP2**)	1.252	1.487	1.528	1.484	1.238	1.333	1.387
A. donax- Double pots (**TP2**)	1.185	1.544	1.604	1.557	1.182	1.375	1.408
Control-Triple pots (**Control-P3**)	1.258	1.488	1.620	1.597	1.290	1.431	1.447
Ph. australis-Triple pots (**PhP3**)	1.166	1.310	1.557	1.483	1.090	1.119	1.287
A. donax - Triple pots (**TP3**)	1.208	1.380	1.53	1.510	1.101	1.153	1.314
Mean	1.366	1.601	1.755	1.736	1.31	1.507	1.546
LSD	**Treatment**		**Period**		**Interaction**		
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**	
	0.098	0.129	0.072	0.0956	N.S	N.S	

TABLE VI
The mean values of Mn (mg/L) calculated from effluent points for microcosm constructed wetland system during the studied period

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	1.799	1.762	2.103	2.086	1.590	1.861	1.867
Effluent of Sedimentation unit	1.644	1.853	2.097	2.079	1.496	1.846	1.836
Control-Single microcosm Constructed wetland (**CW**$_c$)	1.488	1.739	1.897	1.912	1.392	1.691	1.686
Single-microcosm Constructed wetland (**CW**$_1$)	1.271	1.699	1.007	1.302	1.326	1.300	1.317
Double-microcosm Constructed wetland (**CW**$_2$)	1.229	1.586	0.909	1.214	1.257	1.193	1.231
Triple-microcosm Constructed wetland (**CW**$_3$)	1.121	1.495	0.814	1.093	1.111	1.064	1.116
Mean	1.425	1.689	1.471	1.614	1.362	1.492	1.509
LSD	**Treatment**		**Period**		**Interaction**		
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**	
	0.086	0.1149	0.086	0.1149	N.S	N.S	

TABLE VII
THE MEAN VALUES OF ZN (MG/L) CALCULATED FROM OUTLET POINTS FOR ***T. ANGUSTIFOLIA*** AND ***B. MARITIMUS*** EXPERIMENT SAND FILTRATION POTS DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2007**						**Mean**
	July	**August**		**September**		**October**	
	15	**01**	**16**	**02**	**17**	**2**	
Untreated raw wastewater	0.981	0.852	0.984	0.856	0.856	0.764	0.882
Effluent of Sedimentation unit	0.977	0.848	0.992	0.851	0.849	0.759	0.879
Control-Single pot (**Control-P1**)	0.964	0.832	0.984	0.835	0.832	0.744	0.865
T. angustifolia-Single pot (**CP1**)	0.890	0.739	0.922	0.769	0.773	0.674	0.794
B. maritimus -Single pot (**RP1**)	0.894	0.684	0.957	0.805	0.807	0.708	0.809
Control-Double pots(**Control-P2**)	0.945	0.807	0.966	0.817	0.813	0.714	0.844
T. angustifolia-Double pots(**CP2**)	0.871	0.720	0.892	0.720	0.718	0.620	0.757
B. maritimus -Double pots(**RP2**)	0.869	0.755	0.926	0.753	0.753	0.656	0.785
Control-Triple pots(**Control-P3**)	0.925	0.783	0.845	0.789	0.789	0.691	0.803
T. angustifolia-Triple pots (**CP3**)	0.840	0.690	0.869	0.662	0.656	0.584	0.717
B. maritimus -Triple pots (**RP3**)	0.844	0.722	0.904	0.694	0.688	0.582	0.739
Mean	0.909	0.767	0.931	0.777	0.776	0.681	0.807

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.0304	0.040	0.0225	0.0297	N.S	N.S

TABLE IX
THE MEAN VALUES OF ZN (MG/L) CALCULATED FROM OUTLET POINTS FOR ***PH. AUSTRALIS*** AND ***A. DONAX*** EXPERIMENT SAND FILTRATION POTS DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	0.873	0.980	0.981	1.060	0.874	0.861	0.938
Effluent of Sedimentation unit	0.882	0.971	0.972	1.048	0.878	0.854	0.934
Control-Single pot (**Control-P1**)	0.866	0.962	0.964	1.013	0.846	0.846	0.916
Ph. australis -Single pot (**PhP1**)	0.790	0.910	0.909	0.954	0.814	0.779	0.859
A. donax -single pot (**TP1**)	0.791	0.912	0.945	0.987	0.816	0.816	0.878
Control-Double pots(**Control-P2**)	0.847	0.943	0.942	0.998	0.826	0.825	0.897
Ph. australis-Double pots (**PhP2**)	0.772	0.892	0.887	0.912	0.743	0.752	0.826
A. donax- Double pots (**TP2**)	0.774	0.927	0.924	0.947	0.775	0.786	0.856
Control-Triple pots (**Control-P3**)	0.823	0.923	0.925	0.976	0.806	0.803	0.876
Ph. australis-Triple pots (**PhP3**)	0.750	0.837	0.837	0.839	0.671	0.681	0.769
A. donax - Triple pots (**TP3**)	0.749	0.905	0.837	0.907	0.741	0.749	0.815
Mean	0.811	0.924	0.920	0.967	0.799	0.796	0.869

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.0300	0.0397	0.022	0.0293	N.S	N.S

TABLE X
THE MEAN VALUES OF ZN (MG/L) CALCULATED FROM EFFLUENT POINTS FOR MICROCOSM CONSTRUCTED WETLAND SYSTEM DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	0.873	0.98	0.981	1.060	0.874	0.861	0.938
Effluent of Sedimentation unit	0.882	0.971	0.972	1.048	0.878	0.854	0.934
Control-Single microcosm Constructed wetland (**CW_c**)	0.828	0.925	0.928	0.978	0.809	0.808	0.880
Single-microcosm Constructed wetland (**CW_1**)	0.784	0.901	0.902	0.944	0.772	0.77	0.845
Double-microcosm Constructed wetland (**CW_2**)	0.751	0.782	0.779	0.801	0.624	0.629	0.728
Triple-microcosm Constructed wetland (**CW_3**)	0.705	0.756	0.721	0.750	0.524	0.533	0.665
Mean	0.804	0.886	0.881	0.93	0.747	0.743	0.832

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.034	0.0461	0.034	0.046	N.S	N.S

TABLE XI
THE MEAN VALUES OF CU (MG/L) CALCULATED FROM OUTLET POINTS FOR ***T. ANGUSTIFOLIA*** AND ***B. MARITIMUS*** EXPERIMENT SAND FILTRATION POTS DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2007**						**Mean**
	July	**August**		**September**		**October**	
	15	**01**	**16**	**02**	**17**	**2**	
Untreated raw wastewater	0.568	0.567	0.544	0.638	0.725	0.657	0.617
Effluent of Sedimentation unit	0.540	0.539	0.534	0.658	0.686	0.639	0.599
Control-Single pot (**Control-P1**)	0.467	0.478	0.462	0.604	0.611	0.564	0.531
T. angustifolia-Single pot (**CP1**)	0.485	0.430	0.411	0.458	0.529	0.485	0.466
B. maritimus -Single pot (**RP1**)	0.450	0.431	0.448	0.490	0.567	0.520	0.484
Control-Double pots(**Control-P2**)	0.462	0.478	0.462	0.525	0.606	0.563	0.516
T. angustifolia-Double pots(**CP2**)	0.414	0.406	0.375	0.425	0.484	0.432	0.423
B. maritimus -Double pots(**RP2**)	0.449	0.440	0.410	0.460	0.517	0.468	0.457
Control-Triple pots(**Control-P3**)	0.480	0.468	0.448	0.487	0.587	0.450	0.487
T. angustifolia-Triple pots (**CP3**)	0.419	0.375	0.336	0.386	0.393	0.373	0.380
B. maritimus -Triple pots (**RP3**)	0.418	0.407	0.370	0.450	0.426	0.404	0.413
Mean	0.469	0.456	0.436	0.507	0.557	0.505	0.488

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.0648	0.085	0.0479	0.0633	N.S	N.S

TABLE XII
THE MEAN VALUES OF CU (MG/L) CALCULATED FROM OUTLET POINTS FOR ***PH. AUSTRALIS*** AND ***A. DONAX*** EXPERIMENT SAND FILTRATION POTS DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	0.669	0.765	0.654	0.565	0.634	0.541	0.638
Effluent of Sedimentation unit	0.637	0.764	0.648	0.557	0.629	0.536	0.629
Control-Single pot (**Control-P1**)	0.628	0.735	0.539	0.551	0.619	0.525	0.599
Ph. australis -Single pot (**PhP1**)	0.604	0.704	0.511	0.489	0.551	0.449	0.551
A. donax -single pot (**TP1**)	0.606	0.708	0.518	0.524	0.584	0.484	0.571
Control-Double pots(**Control-P2**)	0.619	0.713	0.53	0.544	0.613	0.513	0.589
Ph. australis-Double pots (**PhP2**)	0.543	0.637	0.439	0.454	0.509	0.410	0.499
A. donax- Double pots (**TP2**)	0.578	0.674	0.473	0.488	0.545	0.446	0.534
Control-Triple pots (**Control-P3**)	0.604	0.706	0.495	0.505	0.596	0.497	0.567
Ph. australis-Triple pots (**PhP3**)	0.522	0.577	0.378	0.376	0.457	0.358	0.445
A. donax - Triple pots (**TP3**)	0.523	0.611	0.413	0.410	0.491	0.392	0.473
Mean	0.594	0.690	0.509	0.497	0.566	0.468	0.554

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.0218	0.0288	0.016	0.0213	N.S	N.S

TABLE XIII
THE MEAN VALUES OF CU (MG/L) CALCULATED FROM EFFLUENT POINTS FOR MICROCOSM CONSTRUCTED WETLAND SYSTEM DURING THE STUDIED PERIOD

Treatments (Sample of effluent)	**Date of Experiment - 2008**						**Mean**
	July		**August**		**September**		
	01	**15**	**02**	**16**	**01**	**16**	
Untreated raw wastewater	0.669	0.765	0.654	0.565	0.634	0.541	0.638
Effluent of Sedimentation unit	0.637	0.764	0.648	0.557	0.629	0.536	0.629
Control-Single microcosm Constructed wetland (**CW**$_c$)	0.580	0.691	0.500	0.508	0.579	0.479	0.556
Single-microcosm Constructed wetland (**CW**$_1$)	0.550	0.66	0.469	0.480	0.540	0.442	0.523
Double-microcosm Constructed wetland (**CW**$_2$)	0.453	0.488	0.356	0.361	0.409	0.343	0.402
Triple-microcosm Constructed wetland (**CW**$_3$)	0.448	0.479	0.313	0.302	0.287	0.275	0.350
Mean	0.556	0.641	0.49	0.462	0.513	0.435	0.516

LSD	**Treatment**		**Period**		**Interaction**	
	0.05	**0.01**	**0.05**	**0.01**	**0.05**	**0.01**
	0.032	0.0426	0.032	0.0426	N.S	N.S

TABLE XIV
IRON, MANGANESE, ZINC AND COPPER REMOVAL PERCENTAGE RATES (MG/L) IN CONSTRUCTED WETLANDS, THROUGHOUT DIFFERENT EXPERIMENTAL STAGES DURING THE STUDIED PERIOD

Parameters	**Sedimentation**		**control**		**Single cell**		**Double cells**		**Triple cells**	
	1/July	**16/Sep**	**1/July**	**16/Sep**	**1/July**	**16/Sep**	**1/July**	**16/Sep**	**1/July**	**16/Sep**
Fe	2.80	0	8.31	4.44	23.59	11.37	25.67	22.13	27.65	33.12
Mn	8.61	0.80	17.29	9.13	29.34	30.14	31.68	35.89	37.68	42.82
Zn	1.03	0.81	5.15	6.15	10.19	10.56	13.97	26.94	19.24	38.09
Cu	4.78	0.92	13.30	11.46	17.78	18.29	32.28	36.59	33.03	49.16

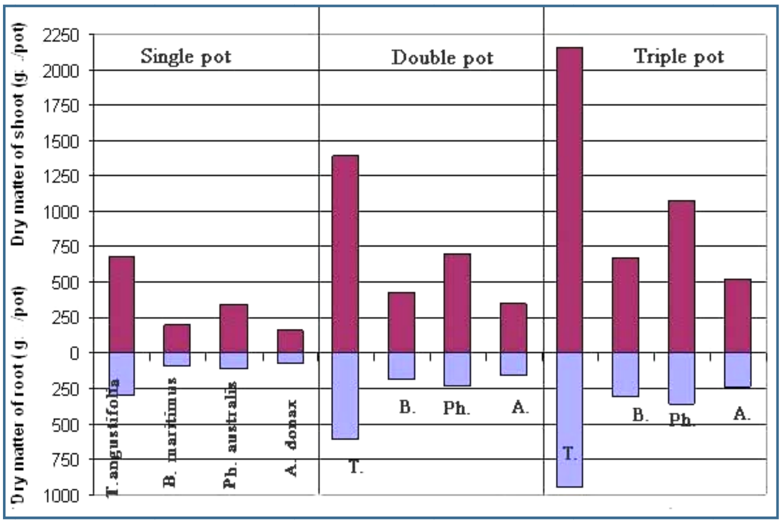

Fig. 7 Weight of macrophyte tissues (root and shoot) harvested from sand pot experiment.

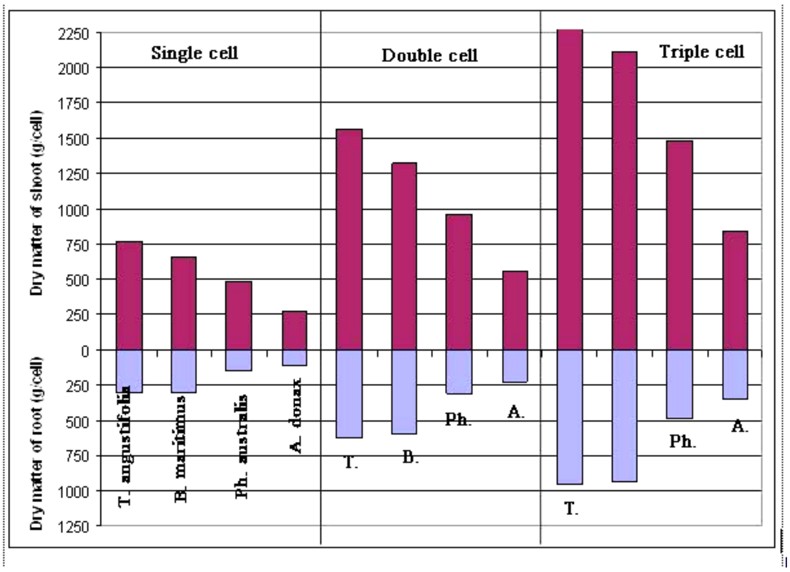

Fig. 8 Weight of macrophyte tissues (root and shoot) harvested from constructed wetland experiment.

TABLE XV
THE MEAN VALUES OF IRON FE CONCENTRATION AND UPTAKE OF MACROPHYTES FOR POT AND CONSTRUCTED WETLAND EXPERIMENTS

	Part	Macrophytes	Initial con. (µg/g)	Single pot or cell		Double pot or cell		Triple pot or cell		Mean	% Increase	Mean
				Final con. (µg/g)	Uptake g Fe/pot	Final con. (µg/g)	Uptake g Fe/pot	Final con. (µg/g)	Uptake g Fe/pot	Final con. (µg/g)		Uptake g Fe/pot
Pot experiment	**Shoot system**	***T. angustifolia***	200	470	0.319	460	0.641	408	0.881	446.0	123.00	0.307
		B. maritimus	230	410	0.083	368	0.158	340	0.229	372.7	62.03	0.078
		Ph. australis	220	430	0.147	370	0.260	325	0.350	375.0	70.45	0.126
		A. donax	242	380	0.063	354	0.123	374	0.196	369.3	52.62	0.064
		±SD	17.776	37.749	0.116	48.525	0.238	37.026	0.318	36.907	31.504	0.112
	Root system	***T. angustifolia***	265	730	0.220	670	0.412	565	0.534	655.0	147.17	0.195
		B. maritimus	276	650	0.059	642	0.119	512	0.156	601.3	117.87	0.056
		Ph. australis	284	630	0.072	621	0.145	540	0.195	597.0	110.21	0.069
		A. donax	276	620	0.047	614	0.096	540	0.128	591.3	114.25	0.045
		±SD	7.805	49.917	0.081	25.158	0.148	21.654	0.189	29.508	16.823	0.070
Constructed wetland experiment	**Shoot system**	***T. angustifolia***	216	492	0.3769	564	0.881	417	0.994	491.0	127.31	0.375
		B. maritimus	221	476	0.3118	410	0.541	456	0.962	447.3	102.41	0.303
		Ph. australis	242	384	0.1862	440	0.424	356	0.527	393.3	62.53	0.189
		A. donax	238	420	0.1134	380	0.211	345	0.291	381.7	60.36	0.103
		±SD	12.685	50 .000	0.119	80.802	0.280	52.335	0.343	50.632	32.484	0.121
	Root system	***T. angustifolia***	284	750	0.230	657	0.410	596	0.567	667.7	135.09	0.201
		B. maritimus	276	732	0.222	680	0.409	414	0.390	608.7	120.53	0.170
		Ph. australis	264	646	0.098	554	0.173	530	0.261	576.7	118.43	0.089
		A. donax	297	692	0.080	567	0.129	542	0.192	600.3	102.13	0.067
		±SD	13.865	46.202	0.080	63.280	0.150	76.583	0.165	38.675	13.493	0.064

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TABLE XVI
THE MEAN VALUES OF MN CONCENTRATION AND UPTAKE OF MACROPHYTES FOR POT AND CONSTRUCTED WETLAND EXPERIMENTS

	Part	**Macrophytes**	**Initial con. (µg/g)**	**Single pot or cell**		**Double pot or cell**		**Triple pot or cell**		**Mean**	**% Increase**	**Mean**
				Final con. (µg/g)	**Uptake g Mn/pot**	**Final con. (µg/g)**	**Uptake g Mn/pot**	**Final con. (µg/g)**	**Uptake g Mn/pot**	**Final con. (µg/g)**		**Uptake g Mn/pot**
Pot experiment	**Shoot system**	***T. angustifolia***	372	815	0.553	750	1.045	660	1.425	741.7	99.4	0.504
		B. maritimus	385	620	0.125	570	0.245	525	0.353	571.7	48.5	0.121
		Ph. australis	372	810	0.278	750	0.527	600	0.646	720.0	93.5	0.242
		A. donax	374	624	0.103	567	0.197	444	0.233	545.0	45.7	0.089
		±SD	6.238	110.02	0.207	104.79	0.389	93.543	0.536	100.57	28.618	0.189
	Root system	***T. angustifolia***	285	623	0.188	621	0.382	450	0.426	564.7	98.1	0.166
		B. maritimus	188	452	0.041	253	0.047	241	0.074	315.3	67.7	0.027
		Ph. australis	275	500	0.057	486	0.113	474	0.172	486.7	77.0	0.057
		A. donax	272	510	0.038	400	0.062	379	0.090	429.7	58.0	0.032
		±SD	45.011	72.403	0.072	154.32	0.156	104.744	0.163	104.94	17.143	0.065
Constructed wetland experiment	**Shoot system**	***T. angustifolia***	391	873	0.669	853	1.332	752	1.792	826.0	111.3	0.632
		B. maritimus	321	620	0.406	741	0.978	523	1.104	628.0	95.6	0.415
		Ph. australis	370	760	0.369	651	0.628	752	1.112	721.0	94.9	0.351
		A. donax	292	532	0.144	485	0.270	497	0.419	504.7	72.8	0.139
		±SD	45.16	150.66	0.215	155.45	0.457	140.121	0.561	136.67	15.798	0.203
	Root system	***T. angustifolia***	300	760	0.228	687	0.405	591	0.563	679.3	126.4	0.199
		B. maritimus	256	583	0.177	453	0.272	387	0.365	474.3	85.3	0.136
		Ph. australis	273	532	0.081	548	0.171	374	0.184	484.7	77.5	0.073
		A. donax	271	560	0.064	521	0.119	322	0.114	467.7	72.6	0.050
		±SD	18.31	102.97	0.078	98.32	0.126	118.38	0.201	102.13	24.55	0.067

TABLE XVII
THE MEAN VALUES OF ZN CONCENTRATION AND UPTAKE OF MACROPHYTES FOR POT AND CONSTRUCTED WETLAND EXPERIMENTS

	Part	Macrophytes	Initial con. (µg/g)	Single pot or cell		Double pot or cell		Triple pot or cell		Mean	% Increase	Mean
				Final con. (µg/g)	Uptake g Zn/pot	Final con. (µg/g)	Uptake g Zn/pot	Final con. (µg/g)	Uptake g Zn/pot	Final con. (µg/g)		Uptake g Zn/pot
Pot experiment	**Shoot system**	***T. angustifolia***	32.3	82	0.056	97	0.135	67	0.145	82.0	153.9	0.056
		B. maritimus	27.1	43	0.009	51	0.025	42	0.028	45.3	67.3	0.010
		Ph. australis	25.4	56	0.019	55	0.039	61	0.066	57.3	125.7	0.021
		A. donax	21.7	42	0.007	41	0.014	44	0.023	42.3	95.1	0.007
		±SD	4.404	18.626	0.023	24.712	0.055	12.396	0.056	18.038	37.5	0.022
	Root system	***T. angustifolia***	78.4	226	0.068	215	0.132	226	0.214	222.3	183.6	0.069
		B. maritimus	56.5	182	0.017	215	0.040	220	0.067	205.7	264.0	0.021
		Ph. australis	65.3	190	0.022	231	0.054	172	0.062	197.7	202.7	0.023
		A. donax	66.4	210	0.016	166	0.026	225	0.053	200.3	201.7	0.016
		±SD	8.999	19.866	0.025	28.194	0.048	25.966	0.077	11.067	35.1	0.025
Constructed wetland experiment	**Shoot system**	***T. angustifolia***	29.4	87	0.067	98	0.153	85	0.203	90.0	206.1	0.070
		B. maritimus	25.5	62	0.041	55	0.073	51	0.108	56.0	119.6	0.037
		Ph. australis	28.5	54	0.026	57	0.055	49	0.072	53.3	87.1	0.026
		A. donax	24.7	56	0.015	47	0.026	38	0.032	47.0	90.3	0.012
		±SD	2.277	15.218	0.022	22.911	0.054	20.320	0.073	19.317	55.5	0.025
	Root system	***T. angustifolia***	66.2	289	0.087	300	0.177	291	0.277	293.3	343.1	0.090
		B. maritimus	58.2	276	0.084	274	0.165	241	0.227	263.7	353.0	0.079
		Ph. australis	65.6	210	0.032	261	0.081	201	0.099	224.0	241.5	0.035
		A. donax	56.3	264	0.030	214	0.049	213	0.075	230.3	309.1	0.026
		±SD	5.060	34.702	0.031	36.022	0.063	40.012	0.098	32.121	50.4	0.032

TABLE XVIII
THE MEAN VALUES OF CU CONCENTRATION AND UPTAKE OF MACROPHYTES FOR POT AND CONSTRUCTED WETLAND EXPERIMENTS

	Part	Macrophytes	Initial con. (µg/g)	Single pot or cell		Double pot or cell		Triple pot or cell		Mean	% Increase	Mean
				Final con. (µg/g)	Uptake g Cu/pot	Final con. (µg/g)	Uptake g Cu/pot	Final con. (µg/g)	Uptake g Cu/pot	Final con. (µg/g)		Uptake g Cu/pot
Pot experiment	**Shoot system**	***T. angustifolia***	9.6	20.3	0.014	22.7	0.032	18.1	0.039	20.4	112.15	0.0141
		B. maritimus	9.1	16.7	0.003	15.2	0.007	13.4	0.009	15.1	65.93	0.0032
		Ph. australis	7.4	16.2	0.006	13.2	0.009	12.4	0.013	13.9	88.29	0.0047
		A. donax	8.8	17.2	0.003	15.4	0.005	10.7	0.006	14.4	64.02	0.0023
		±SD	0.943	1.846	0.005	4.170	0.012	3.169	0.015	2.977	22.575	0.0054
	Root system	***T. angustifolia***	15.1	38.7	0.012	35.2	0.022	32.4	0.031	35.4	134.66	0.0107
		B. maritimus	17.6	27.3	0.002	29.2	0.005	25.1	0.008	27.2	54.55	0.0026
		Ph. australis	16.9	23.5	0.003	29.1	0.007	24.4	0.009	25.7	51.87	0.0030
		A. donax	15.2	20.3	0.002	21.2	0.003	25.9	0.006	22.5	47.81	0.0018
		±SD	1.246	8.027	0.005	5.742	0.008	3.685	0.012	5.525	41.717	0.0041
Constructed wetland experiment	**Shoot system**	***T. angustifolia***	9.5	25.4	0.019	24.3	0.038	22.5	0.054	24.1	153.33	0.0185
		B. maritimus	8.8	19.4	0.013	18.4	0.024	20.6	0.043	19.5	121.21	0.0134
		Ph. australis	7.2	13.6	0.007	11.2	0.011	10.8	0.016	11.9	64.81	0.0056
		A. donax	6.1	11.5	0.003	9.5	0.005	10.4	0.009	10.5	71.58	0.0029
		±SD	1.538	6.251	0.007	6.828	0.015	6.371	0.021	6.427	42.071	0.0072
	Root system	***T. angustifolia***	18.5	42.2	0.013	40.7	0.025	38.3	0.036	40.4	118.38	0.0125
		B. maritimus	15.4	32.5	0.010	28.4	0.017	29.8	0.028	30.2	96.32	0.0092
		Ph. australis	16.2	26.8	0.004	25.6	0.008	27.1	0.013	26.5	63.58	0.0042
		A. donax	15.9	20.1	0.002	22.3	0.005	31.8	0.011	24.7	55.56	0.0031
		±SD	1.374	9.358	0.005	8.030	0.009	4.772	0.012	7.008	29.204	0.0044