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Abstract

The physical effects brought about by the presence of wetland plants are the most important aspects of their role in water purification. Through a wide variety of physiological or biochemical mechanisms, helophytic plants significantly aid in ecosystem remediation. In this study, the role of ten halophytes dominated or common in Egypt in wastewater treatment are evaluated. These plants are; Phragmites australis, Typha domingensis, Cyperus papyrus, Cyperus rotundus, Scirpus littoralis, Scirpus maritimus, Juncus acutus, Juncus maritimus, Avicennia marina and Rhizophora mucronata. The potential of each species to accumulate and absorb specific heavy metals are investigated. This study concluded that, the plants have high biomass e.g. Phragmites australis, Cyperus Spp., Avicennia marina and Rhizophora mucronata are more effective in wastewater treatment. Additionally, mixed vegetation acted to remove pollutants more effectively than single-species ones. If treated wastewater should be reused, water losses have to be avoided. This can be achieved by i) Selection of more efficient plants to minimize evapotranspiration losses, and or ii) Smaller footprints of the treatment system to avoid evaporation.

1. Introduction

Constructed treatment wetlands (CWs) are manmade engineered systems designed to employ the natural plant-water-soil-microorganism interaction to treat pollutants in water resources such as waste streams, groundwater, surface water... etc (ITRC, 2003 and Ulsido, 2014). The judicious selection of suitable wetland species can significantly enhance the removal of heavy metals by vegetation in wetlands. The type of remedied elements, the geographical location, environmental conditions, and the species' known capacity for accumulation serve as the bases for species selection (Zayed et al., 1998). The physical effects brought about by the presence of wetland plants are generally considered to be the most significant functions of emergent wetland plants in relation to water purification. Microbes can attach to and grow on the huge surface area that the plants provide. The physical parts of the plants help to keep the beds' surface stable, slow down the flow of water, which helps the sediment settle and get trapped, and finally, the water transparency is increased. The buried roots and rhizomes fundamentally determine the function of vegetation in wetlands. Plants as autotrophic organisms collect solar energy to transform inorganic carbon into organic carbon. Through their stems and leaves, they can carry oxygen from the atmosphere to the middle, where the roots are. This oxygen creates regions, subsequently; aerobic microorganisms use the available oxygen to carry out a variety of organic matter degradation and nitrification reactions (Dominínguez-Patiño et al., 2012). Hollow vessels in the plant tissues enable oxygen to be transported from the leaves to the root zone and the surrounding soil (Armstrong et al., 1990). This enables the active microbial aerobic decomposition process and the uptake of pollutants from the water system to take place. By reducing the resuspension of the constructed wetland (CW) sediment (14 to 121 kg m-2), macrophytes increased sediment retention (Sandoval et al., 2019). Macrophytes increased the hydraulic efficiency by reducing short-circuit or preferential flow. The presence of plants decreased saturated hydraulic conductivity in horizontal subsurface flow. According to (Truijen and Van der Heijden, 2013), the roles of plants in constructed wetland systems can be divided into 6 categories:

1) Physical - Macrophytes stabilize the surface of plant beds, provide good conditions for physical filtration and provide a huge surface area for attached microbial growth. The macrophytes'

growth decreases current velocity, allowing for sedimentation and longer contact times between the plant surface area and the effluent.

2) Soil hydraulic conductivity - An emergent plant bed system enhances the hydraulic conductivity of the soil. Decay of root mass creates macropores in a constructed wetland soil system allowing for greater percolation of water, thus increasing effluent/plant interactions.

3) Organic compound release - Plants have been shown to release a wide variety of organic compounds through their root systems, at rates up to 25% of the total amount of carbon fixed through photosynthesis. This carbon release may act as a source of food for denitrifying microbes (Brix, 1997). Decomposing plant biomass also provides a durable, readily available carbon source for microbial populations.

4) Microbial growth - Macrophytes have biomass above and below ground to provide a large surface area for the growth of microbial biofilms. These biofilms are responsible for a majority of the microbial processes in a constructed wetland system, including Nitrogen reduction (Brix, 1997). Plants create and maintain the litter/humus layer that may be likened to a thin layer of bacteria. Leaves and stems fall to the surface of the substrate as plants grow and die, forming multiple layers of organic debris (the litter/humus component). The accumulation of partially decomposed biomass results in the creation of highly porous substrate layers that offer microbial organisms a significant amount of surface for attachment. The water quality improvement capability in natural and constructed wetlands is reliant upon and related to the high conductivity of this litter/humus layer and the enormous surface area for microbial attachment.

5) Creation of aerobic soils - Macrophytes act as a conduit for oxygen to go through the hollow plant tissue and leak from root systems into the rhizosphere, where it will be used for nitrification and aerobic degradation of organic matter. Wetland plants have adaptations with lignified layers in the hypodermis and outer cortex to minimize the rate of oxygen leakage.

6) Aesthetic values - The macrophytes have additional site-specific values by providing habitat for wildlife and making wastewater treatment systems aesthetically pleasing.

2. Using Halophytes in Wastewater Treatment

Halophytes are characterized as plants that can survive and reproduce in environments where the salt concentration exceeds 200 mM of NaCl (~20 dS m−1). These species are capable of completing their life cycle under highly saline (NaCl) conditions (Stuart et al., 2012). Helophytic plants contribute significantly to the remediation of ecosystems through a wide range of physiological or biochemical mechanisms including the role of endophytic bacteria (Syranidou et al., 2017). Salt marsh plants (e.g. Phragmites australis, Scirpus maritimus, Juncus maritimus) able to uptake metals (e.g., Cd, Cu, Pb, Zn), concentrating them in their tissues (enrichment factor (EF) > 1), or immobilize them in their rhizosphere zone (Almeida et al., 2004, 2006a, 2011), reducing metal availability to other estuarine organisms (Almeida and Mucha, 2017). Pollutants bioavailability has shown to be a key factor in the success of phytoremediation application that needs to be taken in consideration. This bioavailability has been shown to be affected by sediment characteristics, namely sandy versus muddy sediments. For instance, muddy sediment, in general with higher organic matter content and low grain size particles, can decrease pollutants' bioavailability, both of metals and hydrocarbons (Almeida et al., 2006b, Ribeiro et al., 2015). Phragmites australis and J. maritimus, have been shown to clearly improve the potential of rhizosphere microorganisms for the degradation of hydrocarbons in estuarine sediments (Ribeiro et al., 2013).

Three categories, physical, chemical and biological, are used to categorize the general methods used in CWs to remove contaminants using the plants. These categories are listed in (Table 1) according to Choudhary, et al., (2011).

Table (1): Mechanisms for removing contaminants in constructed wetlands (after Choudhary, et al., 2011)

Parameters	Physical	Chemical	Biological
Suspended solids	Sedimentation Filtration		Biodegradation
Biochemical oxygen demand	Sedimentation	Oxidation Reduction	Biodegradation
Chemical oxygen demand	Sedimentation	Oxidation Reduction	Biodegradation Phytodegradation Phytovolatilization Plant uptake
Nitrogenous Compounds	Sedimentation Volatilization	Adsorption	Bio-denitrification - nitrification Plant uptake
Phosphoric Compounds	Sedimentation	Adsorption Precipitation	Microbial uptake Plant uptake
Metals	Sedimentation Filtration	Adsorption Precipitation	Plant uptake
Pathogens	Filtration UV ray action	Adsorption Oxidation	Natural death Exposure to natural toxins Bacteriophage attack

In this study, we will overview some of the dominant or common macrophytes (higher plants) in Egypt which can be used in wastewater treatment.

2.1. Phragmites australis (Cav.) Trin. ex Steud.

Phragmites australis (common reed) is a robust, erect, aquatic or subaquatic, perennial grass; culms 2.5 to 4.5 m (sometimes 6 m) high (in dry localities much shorter than aquatic), strongly tufted, with stout creeping rhizomes, often also with stolons; leaf sheaths loose and overlapping; blade flat, up to 60 cm long, 8 to 60 mm wide; inflorescence a feathery panicle, somewhat nodding, 15 to 50 cm long, tannish, brownish or purplish, rather dense, very many-flowered, the branches slender, ascending; spikelets several flowered (Holm et al., 1977). Phragmites australis is widespread in Egypt. It is common in water and moist places of all phytogeographical regions: Nile Valley and Delta, Oases, Mediterranean coast, Deserts, Red Sea coast and Sinai Peninsula (Zahran and Willis, 2009).

Elkhouly and Abu- El Nasr (2004) observed that the inflorescence, young branch, and leaves of the old plants of P. australis were highly palatable and preferable for all livestock in Siwa Oasis. Common reed has been suggested for shoreline and earthen dam stabilization due to its dense root matrix and coarse stems (USDA NRCS, 1999). It is used by mining operations for stabilizing ditch banks (Walker and Grimes, 1997). Common reed has also been used to trap silt and improve water quality (Frankenberg, 1997). The oxygen supply in the root zone is sufficient to support the growth of aerobic bacteria that decompose the organic compounds. The plant which is grown for the treatment is also useful for biofuel production. As a result, there is absolutely no issue with disposing of the plants.

Phragmites australis is established using stem cuttings or rhizomes (Frankenberg, 1997). Rhizomes should be planted into weed-free soil that has been tilled to a depth of 10 to 15 cm (4 to 6 in). Recommendations for rhizome spacing vary. Rhizome sections 30 to 46 cm (12 to 18 in) long should be planted 10 to 15 cm (4 to 6 in) deep at a rate of 1 rhizome per foot of row. The source area for rhizome collection should share similar characteristics to the planting site. In saline environments, common reed clones from freshwater sites should not be used (Frankenberg, 1997). Fawzy et al., (2012), found that when P. australis was used for heavy metal (Cd, Cu, Pb, Zn) contaminated sediment phytoremediation, roots contained higher concentrations of Cu and Zn than shoots, while leaves acquired the highest concentration of Pb. Bonanno (2011) investigated that, the general decreasing trend of trace elements (Ag, Al, As, B, Ba, Be, Co, Fe, Mo, Pd, Pt, Rh, Sb, Se, Sr, Tl, and V) content was root> rhizome> leaf> stem of P. australis. The bioaccumulation of selected heavy metals (Ni, Pb, Co, Cd, Fe, Mn, Zn, Cu, Cr) in P. australis has also been reported, with the majority of the metals were retained in roots except for Cd and Pb for which higher concentrations were found in leaves (Rzymski et al., 2014). The ability of Phragmites australis to uptake heavy metals (Cr, Cu, Fe, Mn, Zn, Co, Ni, Mo, Cd, Pb and Hg) and other trace elements (Se, As, Ba), from estuarine sediments was investigated by Cicero-Fernández et al., (2015). From contaminated (MIC) and non-contaminated (GAL) estuarine sediments, bioaccumulation (BCF) and translocation factors (TF) were calculated in vegetative and senescence periods respectively, for two populations of P. australis that were growing in estuarine contaminated sediment (RIA) from ría del Carmen y Boo, Santander Bay, Spain. Following the vegetative phase, the underground tissues (root) of P. australis populations from MIC had a greater capacity for accumulation than the shoots. On the other hand, following senescence, a TF>1 was recorded for Se (5.00), Mo (2.26), Ni (2.09), Zn (2.22), Cr (1.77), Ba (1.37), and Mn (1.36). During treatment, both P. australis populations displayed significant rhizosphere growth, however, P. australis population from MIC showed a rhizosphere surface increment 6 times higher than that of P. australis population from GAL. This study indicates that P. australis can be used to immobilize some metals (Co, Cd, Pb, Cu, Fe) and As and store them belowground. P. australis showed a temporal variation in the accumulation of other metals in the aboveground biomass (Ni, Mo, Cr, Mn, Zn, Se, and Ba), with the highest values occurring during the vegetative and senescence phases of plants collected from estuarine sediments from GAL and MIC, respectively. This study indicated the potential of P. australis to remove heavy metals from estuarine sediments using an ex-situ phytoremediation approach. Almeida and Mucha (2017) showed that P. australis and its associated microorganisms have a potential for removal of the antibiotic enrofloxacin, a pollutant of emerging concern (Fernandes et al., 2015).

A horizontal subsurface flow constructed wetland was designed by Khazaleh and Gopalan (2018). This wetland cell was 0.3 m deep, 1.5 m long and 0.6 m wide. The unit was made of plastic. It was filled as follows (from bottom to top): the first layer of 0.15 m consisted of coarse aggregate gravel 2 cm in size, the second layer of 0.15 m consisted of fine aggregate sand 2 mm size and 0.075 m freeboard. After establishment over one month in a natural bed, the plants having 0.3 m stem were transplanted at a density of 2 seedlings per m² in the unit. The unit was planted with 9 Phragmites australis plants in 3x3 rows. The initial application of freshwater lasted for a month. After the plants had been established properly, the experiments commenced. The plants exhibited a good survival and growth rate with 9 plants transplanted increasing to 93 plants at the end of the 12th month, demonstrating a vigorous spread a few weeks after planting. In a half year, the plants started to sprout. The health, growth, and general appearance of the plants were monitored. The length of the stems was viewed as like that of wetland plants in natural wetlands. Regular measurements revealed that the plant's growth was 0.3 m per month on average. Ordinary grass and other invasive plants were immediately uprooted and eradicated. The microcosm was fed with freshwater daily at start-up. After the plants were well-established, the addition of wastewater began. The wastewater was fed in batch mode once in the hydraulic retention cycle to acclimatize the soil microbes and to support the growth of the plants. The microcosms were checked 3 times/per week. The concentrations of TSS, COD, BOD, TN and TP of the source influent ranged from 22-572 mg. l-l, 249-1946 mg. l-l, 99-658 mg. l-l, 2.1-138 mg. l-l, and 1.69-35 mg. l-l, respectively, whereas the treated effluent ranged 10-348 mg. l-l,51-1187 mg. l-l, 18-139 mg. l-l,0.2-70.2 mg. l-l, and 0.24-29.8 mg. l-l, respectively, and percentage removal ranges were 33-70%, 24-79%, 70-85%, 3-90% and 12- 87%. Březinová and Vymazal (2022) concluded that sequestration of heavy metals (Cu, Cd, Cr, Ni, Pb and Zn) by Phragmites australis followed the same pattern in both natural and constructed wetlands. Base parts of stems accumulated the highest amount of heavy metals and followed by the top part of leaves, except for the highest accumulation of Cu and Zn in top leaves in constructed wetlands. The accumulation of heavy metals decreases from the base to the top in stems, while the accumulation in leaves decreases in the opposite direction.

2.2. Typha domingensis Pers.

Typha domingensis is a tall, perennial marsh that grows to a height of between 2.0 and 2.5 meters. It grows naturally in both pristine and disturbed habitats with wildly varying water levels. Typha domingens is a widespread and dominant plant species in many aquatic systems in Egypt (Boulos, 2009). Typha domingensis is known commonly as cumbungi or southern cattail. It is found throughout temperate and tropical regions worldwide. In Turkish folk medicine, the female inflorescences of this plant are used externally to treat wounds such as burns (Yesilada, 2002).

Hegazy et al., (2011) studied the capacity of Typha domingensis to absorb and accumulate aluminum, iron, zinc and lead. The findings suggested that Typha domingensis was able to accumulate heavy metal ions from wastewater more readily than from sediments. Roots, rhizomes, and old leaves had the highest levels of metal accumulation in plant organs. Rhizofiltration was found to be the best mechanism to explain Typha domingensis phytoremediation capability. Farrag et al., (2013) found that the metal accumulation rates by T.domingensis varied according to the accumulating organ and the type of heavy metal. Accumulation of lead (Pd) recorded maximum values ranged between (96.41 and 98.33 mg. kg^{-1} DW) in different plant organs of T. domingensis growing in the contaminated soil, while minimum values were obtained for the accumulation of cadmium (Cd) (0.02 to 0.08 mg. kg^{-1} DW) for different plant organs growing in the noncontaminated site. T. domingensis accumulated the measured elements and metals in the following order; Pd>Cu>As>Fe>Cr> Mn> Ca> Ni> B> Mo> K> Mg> P> N> Co> Cd.

Maine et al. (2022) used vertical flow wetlands planted with Typha domingensis and Canna indica to remove Cr, Ni, and Zn from landfill leachate. T. domingensis planted wetlands had higher levels of metal removal than C. indica planted ones. Removal % reached 80/71, 76/62, 73/59% for Cr, Ni, and Zn at 1.0 mg L−1, and reached 60/54, 49/47, 61/47% for Cr, Ni, and Zn at 0.2 mg L−1, for T. domingensis/C. indica, respectively. Metals removal efficiencies were significantly enhanced by recirculation. Metal concentrations in roots were significantly higher than in shoots, this finding was confirmed with Scanning electron microscopy and X-ray microanalysis that showed that metals were absorbed by internal root tissues. The hybrid wetland may be applied also to improve COD and total N removal.

2.3. Cyperus papyrus L.

Cyperus papyrus is one of the largest emergent aquatic sedges found growing in both lentic and lotic environments (Kaggwa et al., 2001). It had been considered by lower ancient Egypt as its symbol. (Sculthorpe, 1967). Papyrus showed a giant growth form with an average height of up to 4 m in June and August in both natural and managed stands, respectively (Serag, 2003). The importance of this plant to ancient cultures is demonstrated in the paintings and carvings on ancient Egyptian tombs (Tackholm, 1976; Rzóska, 1976). An agro-industrial study was made to use papyrus for paper production and products for tourists (Ragab, 1978).

García-Avila et al., (2019) compared the ability of two species of plants sown in small-scale subsurface-constructed wetlands with a vertical flow that received municipal wastewater through primary treatment to purify domestic wastewater. Phragmites Australis and Cyperus Papyrus were the species used. For this purpose, a constant flow of 0.6 m3.day-1 was fed from the primary lagoon to each of the two wetlands built on a pilot scale with continuous flow. Each unit was filled with granite gravel in the lower part and with silicic sand in the upper part of different granulometry, the porosity of the medium was 0.34, with a retention time of 1.12 days and a hydraulic load rate of 0.2 m. day-1. To analyze the purification capacity of wastewater, physical, chemical and biological parameters were monitored for three months. Samples were taken at the entrance and exit of each experimental unit. The experimental tests for the two plants species revealed that Cyperus Papyrus exhibited a greater capacity for the removal of pollutants in terms of BOD (80.69%), COD (69.87%), ammoniacal nitrogen (69.69%), total phosphorus (50%), total coliforms (98.08%) and fecal coliforms (95.61%). The species with greater efficiency in the treatment of municipal wastewater for this study was Cyperus papyrus.

Hamad (2020) used a constructed wetland planted with Typha latifolia and Cyperus papyrus as an eco-friendly technology supported with zeolite substrate for water purification. Cyperus papyrus bed achieved removal efficiency of 85.5%, 86.2%, 83.9% and 92.3% for COD, BOD, TSS and ammonia, respectively. As a result, bacteriological parameters were decreased to 99.9%, and Cyperus papyrus was able to completely eradicate Salmonella sp. in just three days. The removal efficiency of Cu and Zn were 72% and 84%, respectively under the optimum conditions; initial metal concentration (15 mg L−1), time (72 h) and 16 plant stems.

2.4. Cyperus rotundus L.

The perennial Cyperus rotundus can grow to a height of up to 55 inches. White, fleshy rhizomes are the initial form of a young plant's root system. Some rhizomes grow upward in the soil and then form a bulb-like structure from which new shoots and roots grow, and from the new roots, new rhizomes grow. Other rhizomes form dark reddish-brown tubers or chains of tubers as they grow horizontally or downward. Cyperus rotundus, also referred to as coco-grass, purple nut sedge, red nut sedge, and other names, is native to southern Asia, Africa, and southern and central Europe (Martin and Chanthy, 2009).

Cyperus rotundus has several medicinal uses. The decoction of the roots and tubers is an excellent antidote to all poisons. The root is often used for developing high memory. This herb also harmonizes the liver, spleen, and pancreas. It is used as an insect repellent, for perfuming clothing (Gamble, 2008).

Kurnia (2014) stated that Cyperus rotundus can treat leachate waste with COD and BOD removal efficiency of 72.69% and 75.69%. A toxicity test using the Range Finding Test (RFT) method was used to determine whether C. rotundus could tolerate tempe wastewater. Toxicity tests were carried out for 7 days in reactors containing 0%, 10%, 25%, 50%, 75% and 100% of tempe wastewater (v/v diluted by tap water). Cyperus rotundus's lethal concentration of boiling waste was 25%, marinade waste was 25% and mixed waste was 25% on 6 days of the research period (Purwanti et al., 2018). Shingare et al., (2017) evaluate the efficiency of different substrate materials along with macrophytes, Typha latifolia and Cyperus rotundus in the treatment of domestic wastewater for agricultural reuse. Eight treatments were set up in triplicate to elucidate the effects of different substrates and vegetation on bacterial pathogens and parasites removal efficacy. The experimental columns were designed using PVC pipes of 25 cm diameter and 100 cm length with a basement and open top. On one side near the basement, an outlet (1.2 cm diameter) was provided for collecting the effluent (Fig. 1). The study was conducted for 6 months with different retention times, and observations were taken twice per month. Maximum parasites were removed by the treatment having sand alone as a substrate containing C. rotundus. The results suggest that T. latifolia aids in bacterial pathogens removal, while C. rotundus aids in parasites removal. Thus, wastewater treatment through constructed wetlands having mixed plantations of these species along with sand can eliminate some of the major enteric pathogens.

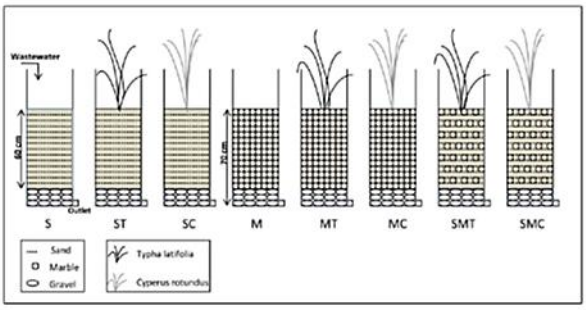

Fig (1). Schematic representation of columns with different substrates and macrophytes (After Shingare et al., 2017).

The cost-effective methods for the treatment of food industry wastewater using locally available plants, Cyperus rotundus and Pennisetum perpureim and Napier grass were studied by Swathy and Habeeba (2017). Wastewater was passed through the prepared two reed beds and one reed-less bed. Reed bed plants were planted in a plastic container having dimensions 60 cm in length, 40 cm in width and 30 cm in height. Plastic buckets having 35 liters capacity were used as wastewater holding tanks. A flexible pipe was connected from the holding bucket to the distribution pipe. The distribution pipe was provided with holes at suitable intervals for the smooth distribution of wastewater. A collection pipe was placed at the bottom of the plant bed for the collection of water after treatment. The collection pipe was connected with a manual operating pipe outside. Three layers of filter media were used to prepare the plant bed. The bottom-most layer 10 cm in height consists of aggregates 20 to 30 mm in size. The second layer of 5 cm consists of aggregates 10 to 20 mm in size. The final 5 cm layer was placed with washed sand, three units were prepared. Cyperus rotundus was planted in one unit, pennisetum purpureum in another, and a reed-free bed was kept in the final one. Hydraulic retention times of 1, 2, 3, 4, 5, and 6 days were used to evaluate these plants' efficacy in removing pollutants from wastewater. The results show that the BOD content of the wastewater was higher before the treatment in the reed bed system. But after the treatment, it was reduced by 93.5%, 94% and 44.22% in the cyperus rotundus, pennisetum perpereium and reed less bed respectively. According to the findings, the use of cyperus rotundus and pennisetum perpereium in reed bed technology is an extremely efficient method for treating wastewater that contains more COD, because after the treatment period, the COD of the wastewater was reduced considerably. The percentage reduction was recorded as 81.6%, 85.5 % and 65.18% for Cyperus rotundus, Pennisetum perpereium and reed less bed respectively.

2.5. Juncus acutus L

Juncus acutus is a tussock-forming, shortly rhizomatous perennial. Flowers are clustered, with 1-6 clusters per cluster and 5-50 clusters per inflorescence, and the culms are terete, 30–160 cm long, and 2.0–4.0 mm wide. Juncus acutus inhabits the sandy sea shores and dune slacks, occasionally in salt marshes. The plant is easily grown in a moist soil, bog garden or shallow water and prefers heavy soil in the sun or light shade (Huxley, 1992).

Juncus acutus showed high tolerance to Zn-induced stress since all plants survived and none of them showed any toxicity symptoms, such as chlorosis, necrosis or growth reduction at concentrations up to 100 mmol. l−l Zn. The integrity and functionality of the photosynthetic apparatus were unaffected even at zinc concentrations greater than 500 mg. kg−k on tillers. Similarly, the absorption of nutrients was relatively unaffected. Zn tolerance was related to the accumulation capacity of Zn in roots (up to 2500 mg. kg−1) and essentially prevents its transfer to tillers. This species is a useful phytostabilizer for revegetating Zn-contaminated lands because of these characteristics and its ability to establish itself in plenty of ecosystems (Mateos-Naranjo et al., 2014). Juncus acutus emerges as a possible hyperaccumulator species, able to tolerate exogenous Zn concentrations as high as 60 mM. Zinc concentrations found in seedlings that germinated in the presence of high Zn concentrations were above the described upper toxic limits for higher plants. With an EC50 value in the range of 10–20 mM of metal, growth inhibition only accounted for approximately 30% of control seedling biomass even at the highest Zn concentration (Santos et al., 2014). The efficiency of Juncus acutus on the removal of mixed contamination; ciprofloxacin (CIP), sulfamethoxazole (SMX), bisphenol A (BPA) and heavy metals (chromium (Cr), nickel (Ni), cadmium (Cd) and zinc (Zn)), was investigated by (Christofilopoulos et al., 2016) in a hydroponic experiment in order to evaluate its potential for use in the alternative remediation technology of constructed wetland (CW) systems. Concentrations of the compounds ranged from mg. L−1 to well beyond environmentally relevant values (50 mg. L−1 for the organics and more than 1000 mg. L−1 in the case of Zn and Cr). Antibiotics (CIP and SMX), BPA, and heavy metals were successfully eliminated after 28 days without causing phytotoxicity symptoms in J. acutus, and the concentrations were even higher than those typically found in industrial or hospital wastewater. Extremely high concentrations of heavy metals induced severe physiological damage to the plants. In conclusion, with regard to all the pollutants examined at environmentally relevant concentrations, the halophyte J. acutus demonstrated its extraordinary efficacy. In higher concentrations of antibiotics and mixtures of organic and inorganic contaminants, the contribution of the plant was also demonstrated. Findings from this work suggest that J. acutus plants are an ideal candidate for phytoremediation applications in CW systems, targeting urban, industrial or pharmaceutical wastewater treatment. Aydın Temel et al. (2017) designed and operated a full-scale horizontal subsurface flow constructed wetland (HSFCW) to treat domestic wastewater of Kızılcaören village in Samsun city of Turkey using Juncus acutus L. and Cortaderia selloana. The average removal efficiencies were determined as 24.2–38.9% for TN; 24.4–28.7% for NH4-N; 35.4–43.3% for TP; 18.9–27.1% for orthophosphate; 60.3–57.7% for BOD; 35.3–44.3% for TSM; 29.5–37.2% for TSS and 31.4–49.8% for OM.

2.6. Juncus maritimus Lam.

Juncus maritimus known as the sea rush grows on coastlines. The plant reaches heights of 50 to 100 cm. The grasses propagate by sowing in spring or by division in spring or in early summer, and prefer a sunny to the half-shady situation on moist soil. The substrate should be loamy, clay or loamy clay soil with a pH between 4 and 6.

The role of J. maritimus seemed to be markedly dependent on the sediment composition. Only the levels of Cd and Cu in the rhizosediment and sediment or the roots of J. maritimus varied significantly at the sandy site throughout the year (an increase in autumn and a decrease from winter to summer). The same variations were noticed in both compartments, probably brought about by the plant's activity and tidal water movements. All of the studied elements, with the exception of Pb, showed seasonal variations at the muddy site. The rhizosediment's changes in Cd and Zn were in opposition to those in the roots (uptake of Cd and Zn by J. maritimus roots in summer may have decreased rhizosediment levels). Both Fe and Mn's rhizosediment (whose contents significantly increased in the summer) and roots displayed similar patterns of variation. Changes in mass, increased availability of the elements, or accumulation at the surface of the root in (hydr)oxide forms could account for the summertime roots' higher levels of Fe and Mn. The fact that there were no significant correlations between the variations in rhizosediment and roots for the remaining elements suggests that the uptake and release of those elements by roots were not based on a single exchange with the sediment. J. maritimus appeared to be useful for the phytostabilization of these metals because it was able to accumulate Cu, Zn, and especially Cd (Almeida et al., 2006b). Marques et al., (2011) studied two-time scales were looked at: a yearlong study was completed, and a 180-day decay experiment was done. Both Juncus maritimus and

Scirpus maritimus have distinct life cycles, which may have an impact on the chemical environment of the Hg-contaminated salt marsh sediment in terms of Eh and pH. Additionally, J. maritimus had faster rates of belowground biomass decomposition as well as rates of biomass turnover. All of these species-specific factors, according to the findings, have an impact on the dynamics and sequestration of mercury. This indicates that the mercury sequestration capacity (per square meter) of J. maritimus belowground biomass is approximately 4–5 times greater than that of S. maritimus, indicating that in S. maritimus colonized areas, Hg is exchanged more extensively between the rhizosediment and belowground biomass. By inference, J. maritimus appears to give a similarly higher environment administration through phytostabilization (Hg complexation in the rhizosediment) and phytoaccumulation (Hg sequestration in the belowground biomass). Almeida et al., (2011) found that J. maritimus concentrated metals, at least Cd, Cu and Zn in their belowground structures ([M]belowground tissues/[M]non-vegetated sediment > 1). J. maritimus, metal burden distribution between above and belowground structures depended on the metal. J. maritimus retaining for instance much more Cd and Cu in the aboveground than in the belowground structures. According to Speranza et al., (2015), Juncus maritimus compared with Scirpus maritimus, seems to provide a better ecosystem service through phytoaccumulation (Hg sequestration in the belowground biomass) and phytostabilization (Hg complexation in the rhizosediment).

Juncus maritimus usage in vertical-flow filters was also efficient in the treatment of domestic wastewater (Yahiaoui et al., 2020). The mean removal efficiency obtained was 78.45 % for total N, 95.14 % for total P, 86.67 % for TSS and 91.05 % for BOD5. The main mechanisms for limiting the level of contaminants in the vegetated vertical-flow filter were adsorption, uptake by plants, microbial activity and physical sedimentation.

2.7. Scirpus littoralis Schrad.

Scirpus littoralis is a large, perennial herb with a short rhizome, stems are erect, stout, 60-150 cm tall and 3-10 mm wide and round, leaves are reduced to short leaf sheaths, flower clusters are 2-8 cm long, and spikelets are solitary. Occurs in brackish swamps and saline pools near the sea; the habitat includes landward margins of mangroves and brackish water fish ponds (Backer & Bakhuizen van den Brink (1963-8); Kern (1974). Appropriate for: medium (loamy), heavy (clay), and light (sandy) soils. Proper pH: alkaline, neutral, and acidic soils. It can grow in semi-shade (light woodland) or no shade and prefers moist soil. Distributes in the Nile Delta of Egypt in irrigation and drainage canal bank habitat, also distributes in the reed swamps habitats of Siwa oasis (El Khouly and Khedr, 2000; Mashaly et al., 2009). Scirpus littoralis propagates vegetatively by tubers and rhizomes. It is used for making mats.

Mn, Ni, Cu, Zn, and Pb were all accumulated by Scirpus littoralis up to a maximum of 494.92, 56.37, 144.98, 207.95, and 93.08 ppm dry weight, respectively in below-ground organs (BO) in 90 days under waterlogged and field conditions for 90 days (Bhattacharya et al., 2006). All metals had metal content ratios BO/soil (B/S) that were higher than shoot/soil (T/S), with Ni having the highest ratio. Metal ratios BO/water (B/W) were also greater than shoot/water (T/W) ratios, but Zn had the highest B/W ratio. At intervals of 30 days, the changes in the nutrient status (N, P) of the soil, water, and plants were also studied. Except for Ni, all of the metals had a non-significant negative correlation with nitrogen. Meanwhile, P take-up showed a positive correlation with every one of the metals and all were significant at 1% confidence limit.

Scirpus littoralis were grown for three months in waterlogged conditions. During these three months, metal accumulation and plant growth increased with time. It was observed that plant development and phytoextraction of metals were most extreme in 25% fly debris amendment. The concentration of total phytoextracted metal after three months in 25% fly ash dosed plant roots were 6433.96 μg for Mn, 677.43 μg for Ni, 638.3 μg for Cu, 1264.25 μg for Zn, 409.5 μg for Pb. It was concluded that S. littoralis, can be used for phytoextraction of fly ash at 25% amendment level as this amendment showed maximum growth and accumulation of metals. However, the differences in metal content in the plant parts between the different treatments were not statistically significant (Bhattacharya et al., 2011).

As inland-based shrimp rearing necessitates a sizable intake of high-quality freshwater, Pham et al. (2021) used Scirpus littoralis to implement a continuous closed recirculation aquaculture system made up of a constructed wetland with the horizontal subsurface flow as a water treatment filter (Fig. 2). The CW was 125 cm long, 20 cm wide (0.25 m2) and 50 cm high, giving a practical volume of about 50 L at a water level of 20 cm. Additionally, a swirl filter (approximately 8 liter capacity) was added to the inlet of the system to remove suspended matter (feces and feed pellets). Results demonstrated that the developed system was appropriate and significantly improved the water quality of the shrimp culture. Nitrite was completely eliminated, and nitrate and COD were simultaneously reduced by 78% and 76%, respectively. A 3 Log reduction in the total amount of aerobic bacteria was achieved and Vibrio sp. cells were completely eliminated.

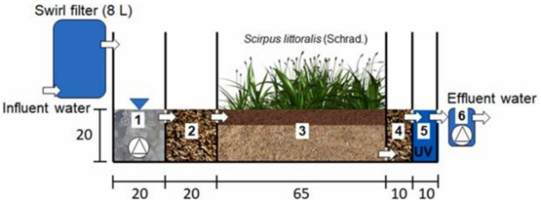

Fig. 2. Schematic representation of the constructed wetland using Scirpus littoralis with successive compartments (After Pham et al., 2021).

2.8. Scirpus maritimus L.

Scirpus maritimus is a perennial sedge, 15-180 cm tall, erect. Stem is sharply triangular, usually smooth, with horizontally creeping rhizome forming hard, round tubers at the nodes. Leaves are stiff and flat. Generally occurs in brackish habitats (Kern, 1974). The plant can withstand marine exposure. Scirpus maritimus distributes in the Western Desert of Egypt (Boulos, 2008). Scirpus maritimus communities were restricted to Lake Manzala (Shaltout and Galal, 2006).

The root of the plant is astringent and diuretic (Chopra et al., 1986). It is used in the treatment of amenorrhoea, dysmenorrhoea, abdominal pain or tumors for post-partum females, abdominal distension and indigestion (Yeung, 1985). The leaves are used in weaving and basketry (Moerman, 1998). The leaves have been used to secure the edges of woven mats, as the warp for sandals, as the warps and twining wefts for clothing, to secure the edges of skirts etc. They have been used to make twined mats for the insides of houses (Moerman, 1998).

Scirpus maritimus is suitable for light (sandy), medium (loamy) and heavy (clay) soils, also, suitable for acidic, neutral and basic (alkaline) soils and can grow in saline soils. It can thrive in water, but it prefers moist or wet soil. Cultivation of the plant succeeds in any wet to moisture-retentive ground, pond margins and shallow water in full sun or shade (Huxley, 1992).

The simultaneous removal of physiochemical parameters in moderate-strength wastewater using a lab-scale horizontal subsurface flow constructed wetland (CW) was assessed by Shuib et al., (2011). Natural zeolite served as a substrate for the constructed wetland. In this study, high-density polyethylene tanks (0.36 m2) were planted with Phragmites australis and Scirpus maritimus. The system was subjected to two hydraulic retention times for (HRT) 4 and 3 days respectively. Averaged data reported coincided with the plant age (4 to 39 weeks) and covered the entire cold season and the early part of the hot season. The physicochemical characteristics of the wastewater changed significantly as the wastewater flowed through the respective wetland cells. Based on the 39 weeks of operation, the CW unit with zeolite achieved significantly higher removal for COD, ammonium and total nitrogen at 4 and 3 days HRT. This unit was highly effective in removing COD, NH4-N, TN, and TSS compounds which were found to be 89%, 99%, 96% and 956% respectively at 4 days HRT. At 3 days HRT, the removal was slightly changed to 85 %, 99.6%, 91% and 91.3% for COD, NH4-N, TN, and TSS. A simple mineralogical survey of filter materials for the zeolites may render many installations of constructed wetlands successful.

2.9. Mangrove species

Mangroves are a group of trees that can grow under conditions of flooding with brackish water in tidal zones of tropical and subtropical regions (Tomlinson, 1986). Some genera of mangroves such as Rhizophora and Avicennia have developed a special root system that supports respiration and stability. Prop roots and pneumatophores reduce current velocities, increasing the sedimentation of suspended material. Therefore mangroves can advance seawards to occupy new coastal habitats (Woodroffe, 1992) and they are especially important for protecting coasts from erosion. Mangroves are used as many kinds of biomaterials, such as building materials, firewood, charcoal, fodder, medicine, etc. (Dahdouh-Guebas et al., 2000; Morton, 1965; Shaltout and El-Bana, 2006), not only for local subsistence but also for a wide range of commercial demands. Mangrove forests can protect coastal areas from wave erosion (Mazda et al., 2006) and can defend against tsunamis (Dahdouh-Guebas et al., 2005), because of their dense structure above and below ground. They can also provide suitable habitats for many kinds of fish and birds (Evans, 1987; Fishelson, 1970; Frazier, 1987; Ormond and Edwards, 1987).

In Egypt, there are two species of mangrove plants, Avicennia marina and Rhizophora mucronata. All mangrove forests are distributed in the Red Sea area of Egypt, these forests are pure of Avicennia marina, occasionally mixed with Rhizophora mucronata in the southern part of the Red Sea (Kassas and Zahran, 1967). In contrast to A. marina, which grows in more saline habitats and has the highest silt value, R. mucronata habitat has low soil salinity, silt, and pH values (El-Khouly and Khedr, 2007).

Mangrove sediments act as an efficient trap for the immobilization of nutrients (in particular phosphorus) and heavy metals (Tam and Wong, 1993). Moreover, mangrove plants are very productive and considerable amounts of nutrients can be bounded in the biomass. Thus, it has been suggested that mangroves can be utilized as an alternative low-cost, easy-maintained, simple and effective method for sewage treatment (Tam, 1998). The commonly found heavy metal stress showed a high bioconcentration factor in the roots of Mangrove plants, while these metals' concentration factors in leaves were typically much lower than one. The limited translocation of the toxic metals to the aerial parts renders the mangrove plants high endurance ability to high levels of heavy metal stress. To protect the cellular components from oxidative damage by heavy metal stress, mangroves have developed both enzymatic and nonenzymatic antioxidant mechanisms to scavenge the reactive oxygen species. The concentration of most metals increased with leaf age, thereby returning metals to the upper layers of the soil during the senescence of mangrove leaves.

In comparison with other common plants used in the wetland system, mangroves are more advantageous for the following reasons: being the perennial tree species with high growth, they have a high potential biomass sink for nutrients (Aksornkoae, 1993); they are inherently tolerant of periodically inundated water conditions (Bunt, 1984) and; they are tolerant of extreme environmental conditions such as high temperature, fluctuating salinity and shifting anaerobic/ aerobic soil substrate (Tam and Wong, 1993); they have extensive above-ground roots which help settle small particulate (Tam, 1998). Therefore, it is expected that by applying the appropriate engineering adaptation and construction to the natural mangrove wetland, it can be used as an efficiently constructed wetland system for wastewater treatment (Boonsong et al., 2002).

Rhizophora mucronata trees were growing better under low to medium tides compared with high tides. The high level of salinity (80 % of seawater) negatively affected the growth of Rhizophora mucronata seedlings. The wild seedling nursery transplanting method had the highest survival rate, at 61%, and was more suitable for the establishment of mangrove seedlings (Khalifa, 2016).

Badawy et al., (2019) studied the potentiality of Avicennia marina for remediation of the contaminated water in the Red Sea. They collect samples of water, rhizosediment, sediment and plant parts (shoots & pneumatophores) from three sites in the habitat of Avicennia marina in Safaga, Qulaan and Ras-Mohamed. Sediment contents of Cu, Zn, Ni, Mn, Cr and Cd in all sites were lower than sediment quality guidelines (SQG). They found that the accumulation of metals occurs in sediment and subsequently inside plant tissues over time, thus A. marina accumulates great quantities of heavy metals and therefore plays an important role in cleaning the coastal environment from these toxic heavy metals. The stimulatory effects of the roots of these plants on microbial activity in studied areas can be employed in hydrocarbon remediation.

Fieldwork has been conducted in 300-hectare natural mangrove intertidal wetlands in southern China, to study the feasibility of using mangrove wetlands as a sewage treatment facility (Wong et al., 1997). The results were obtained in December 1994 and December 1995. For the investigation, two parallel elongated sites, Sites A and B, extending from land to sea were selected, each measuring 180 m X 10 m. Site A has been receiving settled municipal sewage three times per week since September 1991 during the low ebb tide, when sediments in landward regions were dry. Within 50 m of the discharge stations, wastewater was absorbed into the sediments before the next incoming tide at a hydraulic loading of 20 m3 per discharge. Site B was the control. Surface sediments and plant leaves were collected at two distinct locations in 1994 and 1995 every six months at designated locations. Using the fixed plot method, the impact of sewage on the growth of mangrove plants was evaluated by measuring the height, diameter, and number of trees. The two predominant mangrove species, Kandelia candel and Aegiceras corniculatum, found in Site A had similar plant densities, stem diameters, and tree heights to those found in Site B. In terms of plant growth and death rates, there was no significant difference between the two locations. According to these findings, plant growth was unaffected by sewage discharge for roughly two years. Except in the very landward regions, which ranged from 2 to 40 meters from the land, the concentrations of organic matter and nutrients in the surface sediments of Site A were also not significantly different from those of Site B. However, the nutrient concentrations of sediments gathered at sample sites close to Site A's discharge points were significantly greater than those of the control. The concentrations of organic C, total N and P, NH4+-N, and NO3--N in the surface sediments of both locations showed a descending trend from landward to seaward, with significantly higher values in landward locations. There was apparent seasonal variation in the content of NH4+-N, and July had more ammonium nitrogen than December. Leaf samples from the two predominant plant species collected from Sites A and B had similar concentrations of total nitrogen and organic carbon. These findings suggest that mangrove intertidal wetlands have a lot of potential for natural wastewater treatment and are unlikely to harm higher plant communities.

Two types of pilot scale (100 x 150 m2) free-water surface constructed wetlands were set up in central Thailand (Boonsong et al., 2002). One system is a forest system that is naturally dominated by Avicennia marina. The other system is a brand-new mangrove plantation system in which Rhizophora spp. seedlings, A. marina, Bruguiera cylindrica, and Ceriops tagal were planted in 4 strips of 37.5 x 100 m2 each at intervals of 1.5 x 1.5 m. Wastewater from municipal and nearby areas was collected and pumped into the systems; then retained within the systems for 7 and 3 days, respectively, before discharging. After each treatment, the outlet gates were left open so that the natural seawater could flood over the systems during the high tide period. For each treatment, the water quality during discharge into each system and during flood over the systems on the first and last day of the specified detention time was studied. For each treatment, the water quality during discharge into each system and during flood over the systems on the first and last day of the specified detention time was studied. The results indicated that the average removal percentage of TSS, BOD, NO3-N, NH4-N, TN, PO4-P and TP in the recent systems of the plantation were 27.6-77.1 %, 43.9-53.9 %, 37.6-47.5 %, 81.1-85.9 %, 44.8-54.4 %, 24.7-76.8 % and 22.6-65.3 %, respectively. Whereas the removal percentage of those parameters in the natural forest system were 17.1-65.9 %, 49.5-51.1 %, 44.0-60.9 %, 51.1-83.5 %, 43.4-50.4 %, 28.7-58.9 % and 28.3-48.0 %, respectively. Generally, the removal percentage within the new-plantation system and the natural forest system were not significantly different. However, when the removal percentages with detention time were compared, TSS, PO4-P and TP removed percentages were significantly higher in the 7-day detention time treatment. Even with the highly varied and temporally dependent percentage removal of TSS, BOD and nutrients, overall findings indicated that a mangrove plantation might function similarly to a natural mangrove system as a built wetland for the purpose of treating municipal wastewater. As a result, mangrove plantations can be applied to treat municipal wastewater.

Intermittent subsurface flow mangrove microcosms were constructed to investigate their capabilities in treating primary settled municipal wastewater collected from a local sewage treatment work in Hong Kong SAR and the effect of hydraulic retention time (HRT). This study was carried out by Wu et al., (2008) in a greenhouse and without any tidal flushing or tidal cycle, with half of the tanks planted with Kandelia candel and half without any plants. The removal percentages of dissolved organic carbon (DOC), ammonia-N, inorganic-N and total Kjeldahl nitrogen in the planted systems were 70.43–76.38%, 76.16–91.83%, 47.89–63.37% and 75.15–79.06%, respectively, significantly higher than in the unplanted system during the 6-month treatment period. These results suggest that it is feasible to use the constructed mangrove wetland without tidal flushing as a secondary treatment process for municipal wastewater.

A constructed wetland wastewater treatment facility with mixed plant species was established successfully in Shenzhen, China (Tam and Wong, 2014). Three mangrove species commonly found in Hong Kong and Southern China, namely Kandelia obovata , Aegiceras corniculatum (Ac) and Bruguiera gymnorrhiza , and seven non-mangrove species, including Canna indica , Cyperus alternifolius , Cyperus papyrus, Thalia dealbata , Arundo donax var. versicolor , Acorus calamus and Iris tectorum, based on the wide application and availability in Shenzhen and Southern China, were chosen. The type of constructed wetland was a 4-stage tandem-type sub-surface flow. The sewage inlet section of the constructed wetland was planted with mangrove plants, which are known to have higher tolerance levels to salts and pollutants than non-mangrove plants. The data from the effluent showed that the system was efficacious in getting rid of pollutants like COD, NH4+-N, TP, and heavy metals. The constructed wetland of mangrove and non-mangrove plants provided ecological, recreational, and educational functions for the local community in addition to a significant role in wastewater treatment.

Constructed Mangrove Wetlands (CMWs) were looked at as a low-cost, efficacious, and suitable method for removing nitrogen from coastal zone domestic sewage in peri-urban cities. Field investigations were made on horizontal surface flow constructed mangrove wetlands located at Jangwani beach in Tanzania (Mahenge, 2015). A wetland of 40m x 7m was constructed to receive domestic sewage from the septic tank of a Hotel and was operated in an intermittent continuous flow mode (Fig. 3 and 4). The wetland cell was filled with 60% sewage, 40% of which was seawater moving at a rate of 2 m3/day; and sixty percent was sewage flowing at a rate of three millimeters per day). The wetland used the already existing mangrove plant species Avicennia marina. The wetland's effectiveness at removing nitrogen species was assessed. The observed removal rates of TKN (Total Kjeldahl Nitrogen), NH3-N and NO3-N, and were 61%, 85% and 76%, respectively. The mineralization of organic nitrogen to NH3-N helped to remove TKN. Nitrification, volatilization, and mangrove uptake mechanisms all helped to remove NH3-N. Under aerobic conditions, the nitrification process changed NH3-N into NO3-N, and the volatilization process changed NH3-N into a gaseous form that eventually left the water phase and entered the atmosphere. The de-nitrification process, which transformed NO3-N into nitrogen gas that escaped into the atmosphere, contributed to the removal of NO3-N. The forcing functions pH, temperature, and DO, which had average values of 7.75, 29o C, and 1.55 mg/L, respectively were used to explain the removal processes. The constructed mangrove wetland can be used to treat sewage because it has demonstrated a high potential for removing nitrogen from wastewater.

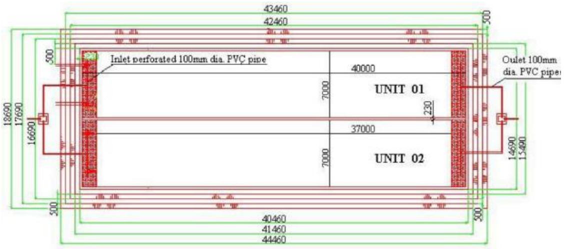

Fig. 3. Plan horizontal surface flow constructed mangrove wetland (units are in mm) (After Mahenge, 2015)

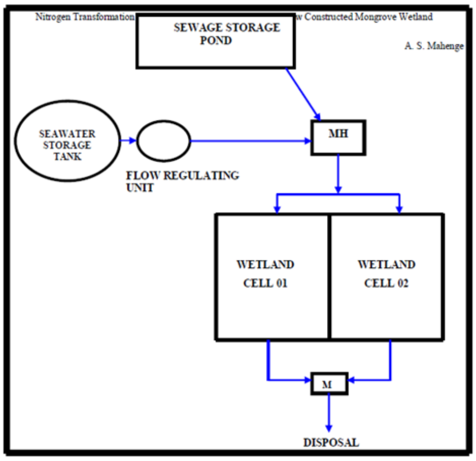

Fig. 4. Layout of Constructed Mangrove Wetland Systems (After Mahenge, 2015)

3. Costs

Site investigation, land, system design, liners, earthwork, flora, filtering or rooting media, hydraulic control structures, and other expenses (such as barriers and access roadways) are the fundamental investment costs for constructed wetlands. However, there are significant regional differences in the amounts of individual expenses. Additionally, bigger systems show better efficiencies of scale (Wallace and Knigh, 2006). Pretreatment maintenance, replacement and repair of equipment, and vegetation harvesting are all included in constructed wetlands' low operating and maintenance costs. This includes pumping energy (if necessary), compliance monitoring, the upkeep of access roads and berms, and constructed wetlands. The financial total costs vary even more, they could be as high as 257 EUR/m2 in Belgium, or medium as 33 USD/m2 in Costa Rica or low as 29 USD/m2 in India (Vymazal 2010). On the other hand, using halophytic plants in wastewater treatment is an eco-friendly method and low in-direct cost. Most of these plants are characterized by high biomass, known as C4 species, so, they have a high potential to sequester carbon. Halophytes may also be considered as a source of bioenergy, which would be a very promising strategy instead of the current biofuel production techniques, which are based on the exploitation of plants consumed by humans (sugar cane, maize, etc.).

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2. Conclusion

The plants have high biomass e.g. Phragmites australis, Cyperus Spp., Avicennia marina and Rhizophora mucronata are more effective in wastewater treatment. These plants have a high number of vegetative organs and/ also high value of water content than other species investigated.

The populations of P. australis at different growing stages, i.e., vegetative and senescence have different effects on treat sediments contaminated with Co, Ni, As, Mo, Cd, Pb, Se, Ba, Cr, Cu, Fe, Mn, Zn and Hg. The BCF and TF in the underground tissues (root) of P. australis populations showed a greater accumulation capacity compared to the shoots following the vegetative period. The HCW unit planting by Phragmites australis and Scirpus maritimus was highly effective in removing COD, NH4-N, TN, and TSS compounds. Possible differences in performance between subsurface horizontal flow constructed wetlands planted with different species (Phragmites australis and Scirpus) can be attributed to different organic input loads, particularly load peaks.

Cyperus papyrus has greater efficiency in the treatment of municipal wastewater than Phragmites australis. The construction of VFCW planted with Cyperus papyrus is recommended because it achieves high yields in the elimination of both physicochemical and biological pollutants present in urban/domestic wastewater, especially for small communities.

Using Cyperus rotundus has been remarkably effective in removal of the pollutants such as BOD, COD, TSS, TDS and NO3 from the food industry wastewater.

Typha domingensis accumulates high concentrations of Al3+, Fe3+, Zn2+ and Pb2+ in their roots. This plant has the potential to be used in purposes to remove metal pollutants from contaminated wastewater.

Juncus acutus provided a significant contribution to the removal of CIP and SMX. When treating industrial wastewater from pharmaceutical companies that contain a mix of organic and inorganic impurities, Juncus acutus may potentially play a competitive role. Thus, J. acutus appears to be an ideal candidate for CW. systems treating wastewater from a wide range of sources.

Juncus maritimus has capacity to accumulate Cu, Zn and particularly Cd, thus appearing to be useful for the phytostabilization of these metals. Through phytoaccumulation (Hg sequestration in the belowground biomass) and phytostabilization (Hg complexation in the rhizosediment), Juncus maritimus appears to provide a relatively higher level of ecosystem service. Using mixed plantation of Phragmites australis and Scirpus maritimus in the CW unit was highly effective in removing COD, NH4-N, TN, and TSS compounds at 4 days HRT. At 3 days HRT, the removal was slightly decreased for COD, NH4-N, TN, and TSS.

Constructed Mangrove wetland has shown high potential in Nitrogen removal from sewage, therefore it can be used for sewage treatment. Mangrove plantations had shown good potential to be used as constructed wetlands to treat municipal wastewater. Avicennia marina accumulates great quantities of heavy metals and therefore plays an important role in cleaning the coastal environment from these toxic heavy metals. The stimulatory effects of the roots of these plants on microbial activity can be employed in hydrocarbon remediation. For maintaining saline conditions, the wetland system of Mangrove should be located at a point where it can receive tidal seawater both neap and spring tide.

Many results reported in the literature indicate that mixed vegetation is more effective at pollutant removal than single-species vegetation.

If treated wastewater should be reused water losses have to be avoided. This can be achieved by i) The selection of more efficient plants to minimize evapotranspiration losses, and ii) Smaller footprints of the treatment system to avoid evaporation.

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3. References

Aksornkoae, S. (1993), Ecology and Management of Mangroves. IUCN, Bangkok, Thailand, 176.

Almeida C.M.R., Mucha A.P., Vasconcelos M.T.S.D. (2004), Influence of the sea rush Juncus maritimus on metal concentration and speciation in estuarine sediment colonized by the plant, Environmental Science and Technology, 38, 3112-3118.

Almeida C.M.R., Mucha A.P., Vasconcelos M.T.S.D. (2006a), Comparison of the role of the sea club-rush Scirpus maritimus and the sea rush Juncus maritimus in terms of concentration, speciation and bioaccumulation of metals in the estuarine sediment, Environmental Pollution, 142, 151159.

Almeida C. M. R., Mucha A. P., Vasconcelos M.T.S.D. (2006b), Variability of metal contents in the sea rush Juncus maritimus-estuarine sediment system through one year of plant's life, Marine Environmental Research, 61, 424-438.

Almeida, C.M.R., Mucha, A. P. and Vasconcelos, M. T. S. D. (2011), Role of different salt marsh plants on metal retention in an urban estuary (Lima estuary, NW Portugal). Estuarine, Coastal and Shelf Science, Volume 91, Issue 2, Pages 243-249.

Almeida, C.M.R., Mucha, A. P. (2017). Using phytoremediation technologies as a nature-based solution to improve and recover impacted estuarine environments. 15th International Conference on Environmental Science and Technology, Rhodes, Greece, 31 August to 2 September 2017.

Armstrong, W., Armstrong, J. and Beckett, P.M. (1990). Measurement and modelling of oxygen release from roots of Phragmites australis . In: Use of Constructed Wetlands in Water Pollution Control (eds Cooper, P.F & Findlater, B.C.). Pergamon Press, Oxford, UK. pp. 41-53.

Aydın Temel, F., Avcı, E., & Ardalı, Y. (2018). Full scale horizontal subsurface flow constructed wetlands to treat domestic wastewater by Juncus acutus and Cortaderia selloana. International journal of phytoremediation, 20(3), 264-273.

Badawy, R. K., El-Shazly, M. M., Aboulsoud, Y. I. E. and Elkhouly, A. A. (2019) . "Chemical contaminations and microbial determinations of Avicennia marina (Forsk.)Vierh. in Red Sea habitat, Egypt". International Journal of Agriculture and Environmental Research, 5(2), 16-32.

Backer and Bakhuizen van den Brink (1963-8). In: Mangrove Guidebook for Southeast Asia: Part 2: DESCRIPTIONS – Grasses & grass like plants.
http://www.fao.org/tempref/docrep/fao/010/ag132e/ag132e03.pdf

Bhattacharya, T., Banerjee, D. K. and Gopal, B. (2006). Heavy Metal Uptake by Scirpus littoralis Schrad. from Fly Ash Dosed and Metal Spiked Soils. Environmental Monitoring and Assessment, 121: 363–380.

Bhattacharya, T., Chakraborty, S., & Singh, G. (2011). Phytoextraction of few metals from flyash amended soil by Scirpus littoralis. Recent Research in Science and Technology, 3(1).

Boulos, L.: Flora and Vegetation of the Deserts of Egypt. — Fl. Medit. 18: 341-359. 2008.

Bonanno G. (2011). Trace element accumulation and distribution in the organs of Phragmites australis (common reed) and biomonitoring applications. Ecotoxicol Environ Saf. 74(4):1057-64.

Boonsong, K.; Piyatiratitivoraku, S. and Patanapolpaiboon, P. (2002). The Use of a Mangrove Plantation as a Constructed Wetland for Municipal Wastewater Treatment. J. Sci. Res. Chula. Univ., Vol. 27, No.1.

Březinová, T. D., & Vymazal, J. (2022). Distribution of heavy metals in Phragmites australis growing in constructed treatment wetlands and comparison with natural unpolluted sites. Ecological Engineering, 175, 106505.

Brix, H. (1997) Do macrophytes play a role in constructed treatment wetlands? Water Science and Technology 35(5): 11-17.

Bunt, J. S. (1984). "Mangrove dependent ccosystems", Workshop on Human Induced Stresses on Mangrove Ecosystems. 2-7 October 1984. Bogor, Indonesia, 9-14.

Chopra. R. N., Nayar. S. L. and Chopra. I. C. (1986). Glossary of Indian Medicinal Plants (Including the Supplement). Council of Scientific and Industrial Research, New Delhi.

Choudhary, A. K., Kumar, S., & Sharma, C. (2011). Constructed wetlands: an approach for wastewater treatment. Elixir Pollut, 37(8), 3666-3672.

Christofilopoulos, S., Syranidou, E., Gkavrou, G., Manousaki, E. and Kalogerakis, N. (2016). The role of halophyte Juncus acutus L. in the remediation of mixed contamination in ahydroponic greenhouse experiment. J Chem Technol Biotechnol 2016; 91: 1665–1674.

Cicero-Fernández, D., Peña-Fernández, M., ExpósitoCamargo, J. A. and Antizar-Ladislao, B. (2015): Role of Phragmites australis (common reed) for heavy metals phytoremediation of estuarine sediments, International Journal of Phytoremediation, DOI: 10.1080/15226514.2015.1086306.

Dahdouh-Guebas, F., Mathenge C., Kairo G. and Koedam N. (2000). Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. Economic Bot., 54, 513-527.

Dahdouh-Guebas, F., Jayatissa, L. P., Di Nitto, D., Bosire, J. O., Lo Seen D. and Koedam N. (2005). How effective were mangrove as defence against the recent tsunami? Current Biology, 15 R443-R447.

Domininguez-Patiño, M. L., Rodríguez-Martínez, A., and Jasso-Castillo, L. A. (2012). Design and Implement a System of Wastewater Treatment Based on Wetlands. Journal of Systemics, Cybernetics and Informatics, 6-11.

Elkhouly, A.A. and Abu- El Nasr, H.M. (2004). Evaluation of some dominant halophytes as forage resources in Siwa oasis, Egypt.Al-Azhar Bulletin of Science, Vol. 17, NO. 1: 45-76.

El-Khouly, A.A. and Khedr. A.A. (2000). Species diversity and phenology of the wetland vegetation in Siwa Oasis, western desert, Egypt. Desert Inst. Bull., Egypt. Vol. 50(2): 325 - 343.

El-Khouly A. A. and Khedr, A. A. (2007). Zonation pattern of Avicennia marina and Rhizophora mucronata along the Red Sea Coast, Egypt. World Applied Sciences Journal 2 (4): 283-288.

Evans, P. G. H. (1987) Sea birds of the Red Sea. In Red Sea. Key environments (Edwards, A.J. and Head, S.M. eds.), pp.315-338, Pergamon Press, London.

Farrag, Hussein F., Al-Sodany, Yasin M. and Otiby, Faleh G. (2013). Phytoremediation and Accumulation Characteristics of Heavy Metals by Some Plants in Wadi Alargy-Wetland, Taif-KSA. World Applied Sciences Journal 28 (5): 644-653.

Fawazy M.A., Badr NE-S., Abo-El-Kassem A. (2012). Heavy metal biomonitoring and phytoremediation potentialities of aquatic macrophytes in River Nile. Environ Monit Assess. 184(3):1753-71.

Fernandes J., Almeida C.M.R., Basto M.C.P., A. P. Mucha (2015), Response of a salt marsh microbial community to antibiotic contamination, Science of the Total Environment, 532, 301-308.

Fishelson, L. (1970). Littoral fauna of the Red Sea: the population of non-seleractinian anthozoans of shallow water of the Red Sea (Eilat). Marine Biol., 6, 106-116.

Frankenberg, J. 1997. Guidelines for growing Phragmites for erosion control. Cooperative Research Centre for Freshwater Ecology. Murray-Darling Freshwater Research Centre. Albury, NSW, Australia. 21p.

Frazier, J. G., G. C. Bertram and P. G. H. Evans. (1987). Turtles and marine mammals. In

Red Sea : Key environments (Edwards, A.J. and Head, S.M. eds.), pp.288-314.

Gamble, J. S. (2008). Flora of the presidency of Madras. Bishen Singh Mahendra Pal Singh Publishers.23-A, New Cannaught Place, Dehra Dun – 248001 (India). Vol, III. P-1641.

García-Ávila, F., Patiño-Chávez, J., Zhinín-Chimbo, F., Donoso-Moscoso, S., del Pino, L. F., & Avilés-Añazco, A. (2019). Performance of Phragmites australis and Cyperus papyrus in the treatment of municipal wastewater by vertical flow subsurface constructed wetlands. International Soil and Water Conservation Research, 7(3), 286-296.

Hamad, M. T. (2020). Comparative study on the performance of Typha latifolia and Cyperus Papyrus on the removal of heavy metals and enteric bacteria from wastewater by surface constructed wetlands. Chemosphere, 260, 127551.

Hegazy, A. K., Abdel-Ghani, N. T., El-Chaghaby, G. A. (2011). Phytoremediation of industrial wastewater potentiality by Typha domingensis . Int. J. Environ. Sci. Tech., 8 (3), 639-648.

Holm, L.G., Plucknett, D.L., Pancho, J.V. and Herberger, J.P. (1977). Phragmites australis (Cav.) Trin. (= P. communis Trin.) and Phragmites karka (Retz.) Trin. In: The World's Worst Weeds"Distribution and Biology". The University Press of Hawaii, Honolulu. pp. 609.

Huxley. A. (1992). The New RHS Dictionary of Gardening.. MacMillan Press 1992 ISBN 0-333-47494-5.

ITRC (Interstate Technology Regulatory Council Wetlands Team) (2003), USA (www.itrcweb.org/guidancedocument.asp?TID=24)

Kaggwa, R. C., Mulalelo, C. I., Denny, P. and Okurut, T. O. (2001): The impact of alum discharges on a natural tropical wetland in Uganda. Water Research, 35 (3): 795-807.

Kassas, M. and Zahran, M.A. (1967). On the ecology of the Red Sea littoral salt marsh, Egypt. Ecol. Monogr., 37(4): 297–315.

Kern (1974). In: Mangrove Guidebook for Southeast Asia: Part 2: DESCRIPTIONS – Grasses & grass like plants. http://www.fao.org/tempref/docrep/fao/010/ag132e/ag132e03.pdf

Khalifa, E. S. (2016). Potential of mangrove rehabilitation using different silvicultural treatments at Southeastern Coast of Egypt. J. Bio. Env. Sci. Vol. 8, No. 2, p. 298-305.

Khazaleh, M. and Gopalan, B. (2018). Constructed Wetland for Wastewater Treatment. Journal of Modern Science and Technology, Vol. 6., No. 1., Issue. Pp.78-86.

Kurnia, P. (2014). Pengaruh Jumlah Koloni Rumput Teki (Cyperus rotundus L.) pada Media Pasir terhadap Penurunan Konsentrasi BOD dan COD. Jurnal Teknik Lingkungan, Universitas Diponegoro, 3(2): 1-10.

Maine, M. A., Hadad, H. R., Camaño Silvestrini, N. E., Nocetti, E., Sanchez, G. C., and Campagnoli, M. A. (2022). Cr, Ni, and Zn removal from landfill leachate using vertical flow wetlands planted with Typha domingensis and Canna indica. International Journal of Phytoremediation, 24(1), 66-75.

Martin, R. and Chanthy P.O.L., (2009). Weeds of Upland Cambodia, ACIAR Monagraph 141, Canberra.

Mateos-Naranjo, E., Eloy Castellanos, M. and Perez-Martin, A. (2014). Zinc tolerance and accumulation in the halophytic species Juncus acutus. Environmental and Experimental Botany, Volume 100, Pages 114-121.

Mahenge, A. S. (2015). Nitrogen Transformation and Removal in Horizontal Surface Flow Constructed Mangroves Wetland. Huria: Journal of the Open University of Tanzania, 19(1), 36-55.

Marques, B., Lillebø, A. I., Pereira, E., & Duarte, A. C. (2011). Mercury cycling and sequestration in salt marshes sediments: an ecosystem service provided by Juncus maritimus and Scirpus maritimus. Environmental Pollution, 159(7), 1869-1876.

Mashaly, I. A., El-Habashy, I. E., El-Halawany, E. F and Omar, G. (2009). Habitat and Plant Communities in the Nile Delta of Egypt II. Irrigation and Drainage Canal Bank

Habitat. Pakistan Journal of Biological Sciences, 12(12), 885-895.

Mazda, Y., M. Magi, Y. Ikeda, T. Kurokawa and T. Asano. (2006). Wave reduction in a mangrove forest dominated by Sonneratia sp. Wetland Ecol. Mangement, 14, 365-378.

Moerman. D. (1998). Native American Ethnobotany Timber Press. Oregon. ISBN 0-88192-453-9.

Morton, J. F. (1965). Can the red mangrove provide food, feed and fertilizer. Econmic Bot. , 19, 113-123.

Ormond, R. F. G. and A. J. Edwards. (1987). Red Sea fishes. In Red Sea: Key environments (Edwards, A.J. and Head, S.M. eds.), pp. 251-287, Pergamon Press, London.

Pham, T. T. H., Cochevelou, V., Dinh, H. D. K., Breider, F., & Rossi, P. (2021). Implementation of a constructed wetland for the sustainable treatment of inland shrimp farming water. Journal of Environmental Management, 279, 111782.

Purwanti, I. F., Simamora, D., & Kurniawan, S. B. (2018). Toxicity test of tempe industrial wastewater on cyperus rotundus and scirpus grossus. Int. J. Civ. Eng. Technol, 9(4), 1162-1172.

Ragab, Hassan. "A New Theory Brought Forward About the Adhesion of Papyrus Strips." I.P.H. Yearbook of Paper History 1 (1978), 113-130. 14th International Congress of Paper Historians, Manchester, 1978.

Ribeiro H., Almeida C.M.R., Mucha A.P., Bordalo A.A. (2013), Influence of different salt marsh plants on hydrocarbon degrading microorganisms abundance throughout a phenological cycle, International Journal of Phytoremediation, 15, 715-728.

Ribeiro H., Almeida C.M.R., Magalhães C., Bordalo A.A., Mucha A.P. (2015), Salt marsh sediment characteristics as key regulators on the efficiency of hydrocarbons bioremediation by Juncus maritimus rhizospheric bacterial community, Environmental Science and Pollution Research, 22, 450-462.

Rzóska, J. (1976): Lake Tana, headwaters of the Blue Nile In: The Nile, Biology of Ancient River (Edited by J. Rzoska), Published by Dr. W. Junk BV, Publishers, The Hague PP 223-229.

Rzymski P, Niedzielski P, Klimaszyk P, Poniedzialek B. (2014). Bioaccumulation of selected metals in bivalves (Vnionidae) and Phragmites australis inhabiting a municipal water reservoir. Environ Monit Assess. 186(5): 3199-3212.

Sandoval, L., Zamora-Castro, S. A., Vidal-Álvarez, M., and Marín-Muñiz, J. L. (2019). Role of wetland plants and use of ornamental flowering plants in constructed wetlands for wastewater treatment: A review. Applied Sciences, 9(4), 685.

Santos, D., Duarte, B. and Caçador, I. (2014). Unveiling Zn hyperaccumulation in Juncus acutus: Implications on the electronic energy fluxes and on oxidative stress with emphasis on non-functional Zn-chlorophylls. Journal of Photochemistry and Photobiology B: Biology, Volume 140, Pages 228-239.

Sculthorpe, C. D. (1967): The Biology of Aquatic Vascular Plants, Edward Arnold, London. (Reprinted by Koeltz Scientific Konigstein, W. Germany, 1985).

Serag, M. S. (2003).Ecology and biomass production of Cyperus papyrus L. on the Nile bank at Damietta, Egypt. Journal of Mediterranean Ecology vol. 4, No.3-4,: 15-24.

Shaltout, K.H. and M. El-Bana. (2006). Environmental characteristics of the mangrove sites along the Egyptian Red Sea coast. Complementary report of assessment and management of mangrove forest in Egypt for sustainable utilization and development. : 74-103.

Shaltout, K. H., and Galal, T. M. (2006). Comparative study on the plant diversity of the Egyptian northern lakes. Egypt. J. Aquat. Res, 32(2), 254-270.

Shingare, R. P., Nanekar, S. V., Thawale, P. R., Karthik, R., & Juwarkar, A. A. (2017). Comparative study on removal of enteric pathogens from domestic wastewater using Typha latifolia and Cyperus rotundus along with different substrates. International journal of phytoremediation, 19(10), 899-908.

Shuib, N., Davies, W.R., Baskaran, K. and Muthukumaran, S. (2011). Effluent quality performance of horizontal subsurface flow constructed wetlands using natural zeolite (escott). International Conference on Environment Science and Engineering IPCBEE, vol.8.

Speranza, M., D'Arco, M., & Ferroni, L. (2015). Ecological performances of plant species of halophilous hydromorphic ecosystems. EQA-International Journal of Environmental Quality, 19, 55-70.

Stuart, J. R., Tester, M., Gaxiola, R. A., & Flowers, T. J. (2012). Plants of saline environments. Access Science. İMcGraw-Hill Companies, Pennsylvania.

Swathy M. R. and Habeeba, V. (2017). Experimental Study on Food Industry Wastewater Treatment by Reed Bed Technology Using Cyperus rotundus and Pennisetum perpureium plants. International Research Journal of Engineering and Technology (IRJET), Volume: 04 Issue: 04.

Syranidou, E., Christofilopoulos, S. and Kalogerakis N. (2017) .Juncus spp.—The helophyte for all (phyto) remediation purposes?. New Biotechnology, 38, 43-55.

Tackholm, V. (1976): Ancient Egypt, Landscape, Flora and Agriculture. In The Nile, Biology of Ancient River (Edited by J. Rzoska), Published by Dr. W. Junk B.V., Publishers, The Hague pp 51- 68.

Tam, N. F. Y. (1998). “Effect of wastewater discharge on microbial populations and enzyme activities in mangrove soils”, Environmental Pollution 102, 233-242.

Tam, N. F. Y. and Wong, Y. S. (1993). Retention of nutrients and heavy metals in mangrove sediment receiving wastewater of different strengths. Environmental Technology 14, 719-729.

Tam, N. F.Y. and Wong, Y.S. (2014). Constructed Wetland with Mixed Mangrove and Non-mangrove Plants for Municipal Sewage Treatment. 4th International Conference on Future Environment and Energy IPCBEE, vol.61.

Tomlinson, P. B. (1986). Botany of Mangroves. 399pp., Cambridge University Press, London.

Truijen, G.1 and Van der Heijden, P.G.M. (2013). Constructed wetland and aquatic treatment systems for fish farms in Egypt: Literature study report. Centre for Development Innovation, Wageningen UR (University & Research centre).

Ulsido, M. D. (2014). Performance evaluation of constructed wetlands: A review of arid and semi arid climatic region. African Journal of Environmental Science and Technology, 8(2), 99-106.

USDA NRCS. (1999). Streambank and shoreline protection conservation practice 580. Plant Materials Fact Sheet. Temple, TX. 2p.

Vymazal, J. (2010). Constructed wetlands for wastewater treatment. Water, 2(3), 530-549.

Wallace, S. D., & Knight, R. L. (2006). Small-scale constructed wetland treatment systems: feasibility, design criteria and O & M requirements. IWA publishing.

Walker, M.J. and C. Grimes. 1997. Ditch stabilization with shoreline common reed. National Meeting of the American Society for Surface Mining and Reclamation. Austin, TX. May 10-15. 1997.

Woodroffe, C. 1992. Mangrove sediments and geomorphology. In: Tropical Mangrove Ecosystems. (Robertson, A.I. & Alongi, D.M. eds). American Geophysical Union, Washington D.C.

Wong, S., Y; Tam, N. F. Y. and Lan,C. Y.(1997). Mangrove wetlands as wastewater treatment facility: A field trial. Hydrobiologia , 352(1):49-59 ·

Wu, Y.; Chung, A.; Tam, N.F.Y. ; Pi, N. and Wong, M.H. (2008). Constructed mangrove wetland as secondary treatment system for municipal wastewater. Ecological Engineering, Volume 34, Issue 2, 2, Pages 137-146.

Yahiaoui, K., Ouakouak, A., Guerrouf, N., Zoubeidi, A., & Hamdi, N. (2020). Domestic wastewater treatment by vertical-flow filter grown with Juncus Maritimus in Arid Region. In International Journal of Engineering Research in Africa

(Vol. 47, pp. 109-117). Trans Tech Publications Ltd.

Yeşilada, E. (2002). Biodiversity in Turkish folk medicine. In Biodiversity (pp. 119-135). Springer, Boston, MA.

Yeung. Him-Che. (1985). Handbook of Chinese Herbs and Formulas. Institute of Chinese Medicine, Los Angeles.

Zahran M. A. and Willis A. J. (2009). The vegetation of Egypt. 2nd ed. The Netherlands: Springer.

Zayed, A., Gowthaman, S. and Teryy, N.. (1998). Phytoaccumulation of trace elements by wetland plants: I. Duckweed', J. Environ. Qual. 27, 715–721..