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Phytoremediation capacity of Umbrella palm and Vetiver in improving surface water quality by Floating Treatment Wetland

Kök Yüzdürme Yöntemi ile yüzeysel su kalitesinin iyileştirilmesinde Japon şemsiyesi ve Vetiverin fitoremediasyon kapasitesi

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Abstract

Surface water is polluted due to many reasons, mainly wastewater and irrigation discharges, and loses its value for potential uses. In this study, phytoremediation was applied to improve the surface water provided from a branch of the Gediz River, which meets the freshwater needs of Izmir Bird Paradise but is not qualified as a quality water source in terms of ecosystem. For this purpose, the removal efficiencies of *Cyperus alternifolius* L. (umbrella palm) and *Vetiveria zizanioides* (L.) Nash (vetiver) for total phosphorus (TP), total nitrogen (TN), and total organic carbon (TOC) were tested in the tanks, which were set with the floating treatment wetland (FTW) with a control group. TP, TN and TOC were measured in water on the 1st, 3rd, 7th and 14th days, while macro and micronutrients were measured in the plants at the beginning and end of the study. TP removal was 92%, 82%, and 45%; TN removal was 62%, 52%, and 24%; and TOC removal was 79%, 66%, and 13% in umbrella palm, vetiver and control tanks, respectively. The translocation factors (TF) that were expected to be >1 in plants were determined as Cd (1.55), Pb (1.27), B (1.19), and Cr (1.11) in vetiver, and B (1.33) and Pb (1.14) in umbrella palm. Considering the increase in biomass, it can be said that the umbrella palm accumulates metal at a higher rate. This study demonstrates that with the usage of umbrella palm and vetiver, FTW has the potential to be used as a green treatment method.

Keywords: Surface water, phytoremediation, *Cyperus alternifolius*, *Vetiveria zizanioides*, floating treatment wetland (FTW)

Öz

Yüzeysel su kaynakları atık su deşarjları, tarımsal drenaj suları başta olmak üzere birçok faktörden dolayı kirlenmekte ve potansiyel kullanım amaçları için değerini kaybetmektedir. Bu çalışmada İzmir Kuş Cennetinin (İKC) tatlı su ihtiyacını karşılayan ancak ekosistem açısından kaliteli bir su kaynağı olarak nitelendirilmeyen Gediz Nehri'nin bir kolundan sağlanan yüzey suyunun iyileştirilmesi amacıyla fitoremediasyon çalışması uygulanmıştır. Bu amaçla kök yüzdürme yöntemi (FTW) ile kurulan tanklarda *Cyperus alternifolius* L. (Japon şemsiyesi) ve *Vetiveria zizanioides* (L.) Nash (vetiver) türlerinin sudaki toplam fosfor (TP) toplam azot (TN) ve toplam organik karbon (TOK) giderim kapasiteleri kontrol grubu ile test edilmiştir. 1. 3., 7. ve 14. günlerde suda TP, TN ve TOK değerleri ile, çalışmanın başında ve sonunda bitkilerde makro ve mikro besin elementleri ölçülmüştür. Japon şemsiyesi, vetiver ve kontrol tanklarında sırasıyla TP giderimi %92, %82 ve %45, TN giderimi %62, %52 ve %24 ve TOK giderimi %79, %66 ve %13 olarak gerçekleşmiştir. Kirleticiler için >1 olması istenen translokasyon faktörleri (TF) vetiverde Cd (1,55), Pb (1,27), Bor (1,19) ve Cr (1,11); Japon şemsiyesinde ise Bor (1,33) ve Pb (1,14) olarak tespit edilmiştir. Biyokütlesindeki artış dikkate alındığında Japon şemsiyesinin daha yüksek miktarda metal aldığı söylenebilir. Genel olarak, bu çalışma FTW yönteminin, Japon şemsiyesi ve vetiverin yüzey suyu kalitesini iyileştirmede yeşil bir arıtma yöntemi olarak kullanılma potansiyeline sahip olduğunu ortaya koymuştur.

Anahtar Kelimeler: Yüzeysel su, bitkisel arıtım, *Cyperus alternifolius*, *Vetiveria zizanioides,* yüzen kök arıtımı

1. Introduction

Prevention of pollution in surface water bodies is one of the major issues getting in the way of sustainable water management. In recent years, water quality has been steadily declining (UN, 2021). The fact that surface waters are at risk of pollution is of vital importance not only for human beings but also for other living organisms that benefit from water.

Preventing pollution and improving water quality is one of the main issues in water management. One of the principles of the United Nations' sustainable development goals (Goal 6) is clean water and sanitation (URL-1). For the sustainability of water, which is the most basic life need, practices that encourage pollution prevention of water resources need to gain more importance.

In Türkiye the Regulation on Surface Water Quality Management (SWOR) entered into force with the T.C. Official Gazette No: 28483 (November 30, 2012) and revisions of the regulation were published in 2015, 2016, 2021 and 2023. The regulation specifies the technical principles of preserving surface and groundwater to meet all potential demands. Inland water quality is classified into four levels in the 2012 legislation, ranging from the best quality to the worst quality; however, in June 2021, the SWQR was revised, and the current classifications consist of three classes: Level I represents high status, Level II represents good status, and Level III represents moderate (RG, 2012).

The Gediz River within the Aegean Region of Türkiye, which has a length of about 400 km, receives domestic and industrial wastewater discharges from the upper regions it reaches. The parameters monitored when it reaches its discharge point include dissolved oxygen (DO), chemical oxygen demand (COD), ammonium, nitrite, total Kjeldahl, total phosphorus (P), lead (Pb), copper (Cu), and zinc (Zn), which are evaluated as Level III in the SWQR (ÇSB, 2014).

Instead of conventional treatment methods, advanced treatment methods are also developed. However, these new methods are often not very cost-efficient as they use more power. Also, the costs of operation and maintenance place financial pressure on local businesses and governments (Mujeriego and Asano, 1999; Prasse et al., 2015).

The method used in this study, phytoremediation, is simply defined as the removal of soil or water pollutants by the usage of plants while retaining them within the plant structure. All green plants in terrestrial and aquatic ecosystems are natural reservoirs for pollution control. Therefore, phytoremediation applications are being used for ongoing projects because of their on-site applicability, cost-effectiveness and eco-friendly nature (Hoda, 2007; Lakshmi et al., 2017)

Any terrestrial and aquatic plant species can be used in the application of phytoremediation technology due to their extensive potential for detoxification, degradation, and removal capacity of contaminants from the environment. Plant properties, such as endogenous, genetic, biochemical and physiological qualities, are important factors for improving soil and water quality on-site. When selecting plant species for the phytoremediation applications, featured parameters, such as the growth of the plant in the natural environment, adaptation to climatic conditions and existing vegetation resistant to insects and other diseases, increasing the amount of biomass, and having a strong root structure should be taken into consideration (Brix, 1997; Brisson and Chazarenc, 2009).

Recently, constructed wetlands have attracted considerable interest as a cost-effective, environmentally friendly, aesthetically pleasing, and efficient method for treating organic and inorganic matter, heavy metals, macro and micronutrients, and color (Panja et al., 2020).

In constructed wetlands, the treatment process occurs through physical, chemical, and biological processes and their interaction with each other. The treatment performance of constructed wetlands is mainly influenced by system design, type of pollutants, plant species, weathering factors, residence time, and interaction with the root zone (Davamani et al., 2021).

Floating treatment wetlands (FTWs) are the most promising type of constructed wetlands because they are relatively inexpensive compared to conventional wetlands, require less land area, and are easy to design (Chandanshive et al., 2020). In a FTW, the system is designed to place the plants above the wastewater surface, considering the maximum contact of the rhizosphere at the plant roots with the wastewater for effective treatment. In a FTW, the system is designed to place the plants above the wastewater surface, the plant root zone creates a very large surface area for microbial organisms, thus root adsorption and transfer of decomposed compounds to the plant structure, accompanied by microbial degradation increase the removal of biological pollution (Kyambadde et al., 2004; Li et al., 2007, Kale et al., 2015). The plant is used as the main key parameter because it should be able to tolerate high concentrations of toxic contaminants.

Headley and Tanner (2012) compared the yields of constructed wetlands (CTW) and floating treatment wetlands (FTW) and found that FTW were more efficient than CTW with removal rates for FTW being at 79% for BOI5, 55% for COD, 73% for NO3-N, 62% for total nitrogen, and 50% for total phosphorus while for CTW, the removal efficiencies were 65% BOD5, 45% COD, 52% NO3-N, 43% TN, and 49% TP. This is explained by the fact that the contact time and capabilities of plants whose roots are in sediment are more limited than those of plants whose roots are floating (Kadlec and Wallace, 2008).

To date, several studies have been conducted to treat soil and water using almost 400 different plant species (Richa et al., 2020). *Cyperus alternifolius L.* (umbrella palm) and *Vetiveria zizanioides* (L.) Nash (vetiver) have favorable features to tolerate high concentrations of contaminants and extreme conditions, which makes them successful vegetative candidates for the phytoremediation processes (Ali et al., 2020).

Umbrella palm is a perennial plant from the Cyperaceae family. The body of the plant is 2 meters long, as it can have many branches. It surrounds the ground with its extensive root system in freshwater margins, streams and moist soils. Although its leaves deteriorate in cold environments, the root system is not damaged, shoots continue to sprout in spring, and it is in the main group for resistance to harsh conditions (Shalabi and Gazer, 2015; Bryson and Carter, 2008).

Vetiver is a perennial plant of the Poaceae family that occurs naturally in the continental climate zone of Asia. The sedge-like plant grows about 2 meters high. The root system is very strong, and the ball-shaped fringed roots can penetrate rocky soil under suitable conditions. Although vetiver is a tropical plant, it can tolerate temperatures ranging from -15°C to 55°C (Xia et al., 1999), and it has been observed to survive cold temperatures of -11°C in Austria and -22°C in China for short periods. 13°C - 25°C is the ideal growth temperature (Danh et al., 2009), and 5°C is the temperature for dormancy (Wang, 2000).

These two plants have been tried in the removal of heavy metals, organic compounds, nitrogen, and phosphorus in sewage wastewaters (Parnian and Furze, 2021) showing their potential for municipal wastewaters.

The FTW method has been applied with different plant species in the treatment of; flood waters (Revitt et al., 1997; Kerr-Upal et al., 2000; Li et al., 2010), pig farm effluents (Liao et al., 2005; Hubbard et al., 2004), metal pollution removal from waterways around highways (Borne et al., 2014), nitrogen removal in stagnant waters (Keizer-Vlek et al., 2014; Xu et al., 2017), total organic carbon removal in textile wastewater (Anamaria et al., 2015; Almaamary et al., 2017; Kah et al., 2016), and TOC and phenol removal in palm oil and olive mill wastewater (Sa'at et al., 2017, Gören et al. 2021)

2. Material and methods

2.1. Characterization of IBP inlet water

The study was conducted in İzmir Bird Paradise (IBP) at the coordinates 38°34'8.81"N, 26°53'44.97"E, where the Gediz River flows into the Aegean Sea located in western Türkiye (Figure 1). The study took place during the vegetation which runs from March until November 2016 and 2017. Samples materials of the river were taken from a branch of the Gediz River to the freshwater areas of IBP was used.

Figure 1. Location of the study area within Turkiye and İzmir province
Şekil 1. Çalışma alanının Türkiye ve İzmir sınırları içinde gösterimi

2.2. Acclimatization of *Vetiveria zizanioides* L. Nash and *Cyperus alternifolius* L.

The plants of umbrella palm and vetiver were harvested from the nursery of the Aegean Forestry Research Institute in Izmir, where they are grown for research purposes (Figure 2). Plants were removed from the soil and rooted in an aqueous medium with fertilizer (N:P:K = 15:15:15 and pH = 6-7) for six weeks without sunlight until sufficient development of fresh shoots and roots were observed (Hoagland and Arnon, 1950).

Figure 2. Pre-treatments in the cultivation of plants
Şekil 2. Bitkilerin yetiştirilmesinde ön işlemler

2.3. Experimental set up and procedure

1.2 m^3 tanks (120x110 cm base and 116 cm depth) were used for the study. Plant-growing pots were placed on the styrofoam to allow the plant roots to float in the water (Figure 3). The surface of the tanks was covered with styrofoam to prevent evaporation of the water sample and sunlight penetration. Three replicates were performed with the control group, which consisted of nine tanks without umbrella palm, vetiver, or any plants. Plants were cut at a root and body length of 40 cm and placed on the styrofoam that floats on the water (4 kg in each tank).

Figure 3. Flotation device (left) and tanks (right)
Şekil 3. Yüzdürme düzeneyi(sol), tanklar (sağ)

The surface water in each tank was sampled over a 14-day period on days 1, 3, 7, and 14. At the end of each period, the tanks were cleaned to prevent any sediment or biofilm build-up, and a new sample of surface water sample was pumped from the inlet channel of IBP into the tank thus starting the next study. This process was repeated 21 times throughout the vegetation period in 2016 and 2017 (March-November). No new samples or nutrients were added during the experimental runs in order to maintain a constant pattern of contaminant removal.

2.4. Analytical methods

Experiments were conducted simultaneously in triplicate with both cases and controls to determine the TP, TN, TOC, pH, dissolved oxygen (DO) and metal analyses in water, micro- and macronutrients, and potentially toxic elements (PTEs) removal efficiency of the plants. Each tank was sampled over a 14-day period, on days 1, 3, 7 and 14. The amount of evaporation was calculated by evaluating the water levels on site. The pH, electric conductivity (EC) and dissolved oxygen (DO) of the samples were measured directly using a portative WTW pH meter on site and Thermo Orion 3 Star pH-meter at the laboratory, respectively (TS EN ISO 10523, TS 9748 EN 27888).

Samples were prepared by passing them through a 0.45 µm glass fiber membrane filter and later washed with 50 ml of distilled water for heavy metal, anion and cation analysis, and by filtering through black banded filter paper for TOC NPOC and TN analyses.

Phosphorus is generally found in the aquatic ecosystem as PO_4^{-3}. For the total phosphorus (inorganic and organic phosphate) analysis, all forms of phosphorus are converted to orthophosphate by chemical reactions and determined in that form. Phosphorus was measured in terms of PO_4^{3-}-P in this study (SM 4500-P). A 4 ml solution of ammonium molybdate was mixed with 100 ml of sample, and then 0.5 ml of stannous chloride was added. The prepared sample was read at a wavelength of 690 nm in the UV spectrophotometer after 10 minutes but not exceeding 12 minutes. The result was calculated using the calibration curve. The PO^4-P value was multiplied by 0.326 and expressed as total phosphorus (TP).

TOC measurement is recommended for the detection of organic pollution in river waters and at low concentrations (Chandler et al., 1976). In the literature, it is observed that there is a linear relationship between COD and TOC in different water samples and a constant coefficient for the same type of water used (Dubber and Gray, 2010; Lee et al., 2016). In this study, the TOC parameters were also measured, and the COD: TOC conversion coefficient was found to be 4.5.

The Shimadzu TOC-VCPH Total Organic Carbon Analyzer was used to do TOC and TN analyses. This analyzer converts carbon to CO_2 through catalytic oxidation at 680°C and measures CO_2 concentration using an NDIR (Non-Dispersive Infrared) detector. For surface waters, the measurement of organic carbon is recommended to be performed as Non-Purgeable Organic Carbon (NPOC), which refers to the fraction of organic carbon that cannot be removed by purging. In NPOC analyses, the pH of the samples is adjusted to 2 by dilution with 0.06 ml of hydrochloric acid before the program calculates NPOC values. The samples are next subjected to high-purity air for 15 minutes at a flow rate of 150 ml/min to remove any remaining inorganic carbon (ISO 8245).

The Total Nitrogen analysis was performed using the Shimadzu, TOC-VCPH Total Organic Carbon Analyzer with the attached Total Nitrogen module. In this method, nitrogen is combusted and converted to nitrogen dioxide, and then total nitrogen is measured using a chemiluminescence detector (ASTM D8083-16).

In evaluating the data on phosphate, nitrogen, and organic carbon analysis in water, the concentration values (mg/L) were calculated as total mass (gr) by multiplying the volume of water (L) measured in the tanks on the day the sample was taken. Accordingly, removal rates in planted and unplanted were calculated using the following Formula 1.

$$\text{Mass removal rate \%} = \left[\frac{V_0\,C_0\text{-}V_t\,C_t}{V_0 C_0}\right] 100 \qquad (1)$$

Where C_0 is the concentration on the first day and C_t is the concentration on the measurement days, and V_0 and V_t are the volumes of water for the first day and for the measurement day.

Samples for the plant analysis were ground by drying them in air at 65-70 °C for 24-42 hours. The moisture content of the ground plant samples was analyzed at 105 °C for 24 hours using the standard method ISO 11465 (1993). Thus, the calculation was made with the moisture correction coefficients obtained, correcting the weight of the plant analysis according to the weight measured at 105°C. (i) To determine the macro- and micronutrients and potentially toxic elements (PTEs) in the plant tissues, the dried samples were digested by performing a wet-burning microwave combustion system. B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn contents were measured using ICP-OES (Perkin Elmer Optima 2100 DV). (ii) P content was measured with a spectrophotometer (Thermo Scientific-Evolution 300 UV-VIS) at 479 nm using the vanadomolybdophosphoric acid colorimetric method. (iii) C, S and N content were analyzed by the Dumas method (dry burning) (TS ISO 10694 and TS ISO 13878).

The PTEs levels measured in the roots and stems of the plants were calculated using the Translocation Factor (TF), which expresses the transfer of pollution from the root to the stem, this process is called phytostabilization (Formula 2). TF > 1, indicates that the accumulation capacity of the plant is effective (Chanu and Gupta, 2016).

$$Translocation\ Factor = \left[\frac{C_s}{C_r}\right] \qquad (2)$$

Where C_s is the concentration of the heavy metal on the stem and C_r is the concentration of metal in the root.

Since the data on PO_4^{3-}-P, TN, and TOC removals in the tanks are stated as percentages, an arcsine transformation was applied. After these transformations, the overall means and standard deviations were calculated given.

An analysis of variance was performed to test the assumptions made for the study, and Duncan's test was used for comparisons between groups. Data from the macro-micro and heavy metal analysis of the plant samples were analyzed using their arithmetic means obtained from graphs and tables. Normal distribution was tested, and since the data did not show normal distribution, bioaccumulation differences between plants were tested using Kruskal-Wallis and Mann Whitney U.

3. Results

3.1. River water characteristics

The characteristic values of the freshwater of IBP, changing according to the seasons, are shown in (Table 1).

The Kruskal-Wallis test was used to assess the concentration of pollutants, as there were statistically significant between seasons (spring, summer, and autumn), for pH, EC, temperature, PO_4^{3-}-P and TN ($p < 0.001$). TOC concentration was not significantly different from the seasons ($P > 0.05$).

Table 1. Condition of IBP inlet water by seasons
Tablo 1. Mevsimlere gore İKC giriş suyu kalitesi

Season	EC µS/cm	pH	PO_4-P mg/L	TN mg/L	TOC mg/L
Spring	1273 ±199	8.4 ±0.1	3.1 ±0.5	9.6 ±2.5	11.1 ±1.7
Summer	1258 ±282	7.7 ±0.5	1.8 ± 1	10.0 ±2.6	10.8 ±3.1
Autumn	2127 ±771	8.1 ±0.4	3.7 ±1.4	25.1 ±12.3	10.8 ±2.9

The results of the PO_4^{3-}-P parameter, which causes the highest level of pollution in the IBP inlet water are given in Figure 4.

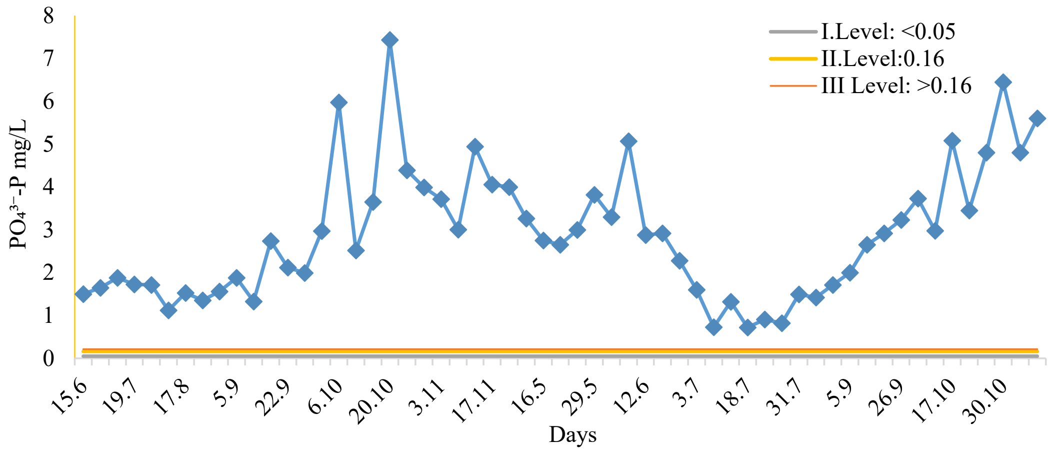

Figure 4. Average contents of TP in IBP influent
Şekil 4. İKC girişinde ortalama TP

3.2. Variation in pH

The initial pH of water is another important operating parameter affecting plant growth and pollutant removal efficiency. Water samples demonstrated an initial pH with a mean of 8.4±0.4. The pH of the unplanted control tanks considerably increased to 9.28±0.37 from 8.4. On the other hand, the pH decreased with both of the other plants. The pH of the umbrella palm considerably decreased to 7.4±0.4 at the end of the experiment, while for the vetiver plant it decreased to 7.7±0.5 (Table 2). The analysis of variance indicated that the pH values have shown a statistically significant difference between treatments ($p < 0.05$).

Table 2. Change of pH in measurement days
Tablo 2 Ölçüm günlerine göre pH değişimi

Days	Umbrella palm	Vetiver	Control
1st day	8.2±0.4	8.2±0.5	8.2±0.5
7th day	7.5±0.5	7.7±0.5	8.9±0.5
14th day	7.4±0.4	7.7±0.5	9.3±0.4

3.3. Water uptake capacity

The amount of remaining water in tanks was measured during the experiments. Volumetric changes in water in the control and the planted tanks are presented in Figure 5. The amount of reduced water in the tanks corresponds to the evaporation in the unplanted tanks and to the evaporation and consumption of the plants (evapotranspiration) in the planted tanks. The amount of water consumed was calculated according to the 14^{th} day measurements. The calculations showed that in the umbrella palm, min. 45 L- max. 357 L; in the vetiver min 21 L- max. 185 L and in the unplanted control tanks min. 14 L - max. 106 L of water decreased respectively. Therefore, the water consumption by plants was determined by subtracting the water loss in the control tanks, which was the result of evaporation from surfaces.

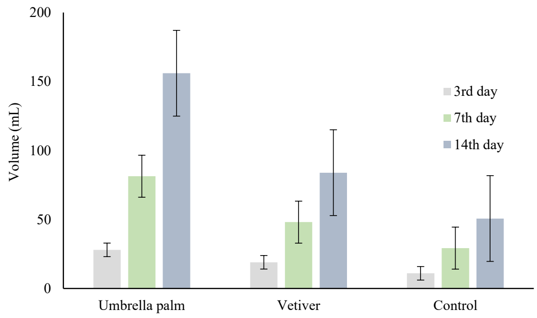

Figure 5. The evapotranspiration loss in tanks
Şekil 5. Tanklardaki evepotransprasyon kayıpları

3.4. Total phosphorus (TP) removal

The initial PO_4^{3-}-P value varied between 2.9±1.5 mg/L in the study. The removal ratio was calculated according to Formula 1. The data on the 3rd, 7th and 14th days in the tanks with and without plants were determined as 65-80-92% for umbrella palm, 53-66-82% for vetiver, while the initial phosphorus amount remained at 45% for the control groups. At the end of 14 day periods, the PO_4^{3-}-P concentration averaged at 0.27 mg/L, the minimum was 0.05 mg/L and the maximum was 1.03 mg/L in the umbrella palm tanks, while for the vetiver tanks the minimum was 0.06 mg/L and the maximum was of 1.78 mg/L and the average remained at 0.54 mg/L. The PO_4 removal rate in the planted tanks with FTW at the end of the 14^{th} day was significantly lower than the values calculated for the control tank ($p < 0.0001$).

Figure 6 shows the change in the 14th days ratios by the seasons. When TP removal rates were evaluated by variance analysis, the removal rates showed statistically significant differences between planted and unplanted tanks, retention times and seasons ($p < 0.0001$).

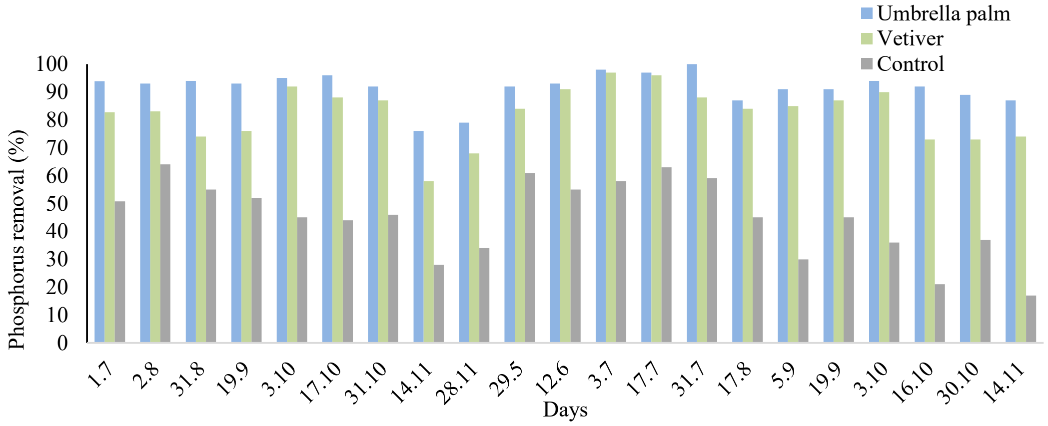

Figure 6. Removal rates of TP in planted-control tanks
Şekil 6. Bitkili ve kontrol tanklarında TP giderim oranları

3.5. Total nitrogen (TN) removal

The initial TN value varied between 17.9±11.8 mg/L throughout the experiment. The results on the 3rd, 7th, and 14th days in tanks with and without plants were determined as follows: 37-51-62% for umbrella palm; 28-42-52% for vetiver; and remained at 24% for the control group. At the end of the 14-day periods, the TN concentration averaged 3.84 mg/L, with a minimum of 1.5 mg/L and a maximum of 8.9 mg/L in umbrella palm tanks. For vetiver tanks, the average was 5 mg/L, the minimum was 2.8 mg/L, and the maximum was 12.5 mg/L. TN removal rate in planted tanks with floating root treatment at the end of the 14th day was significantly lower than the values in the control tank ($p < 0.0001$).

Figure 7 shows the change in the 14th days removal ratios through the two years for plants and control group. When TN removal rates were evaluated by variance analysis, the removal rates showed statistically significant differences between planted and unplanted tanks, retention times, seasons and years ($p < 0.0001$).

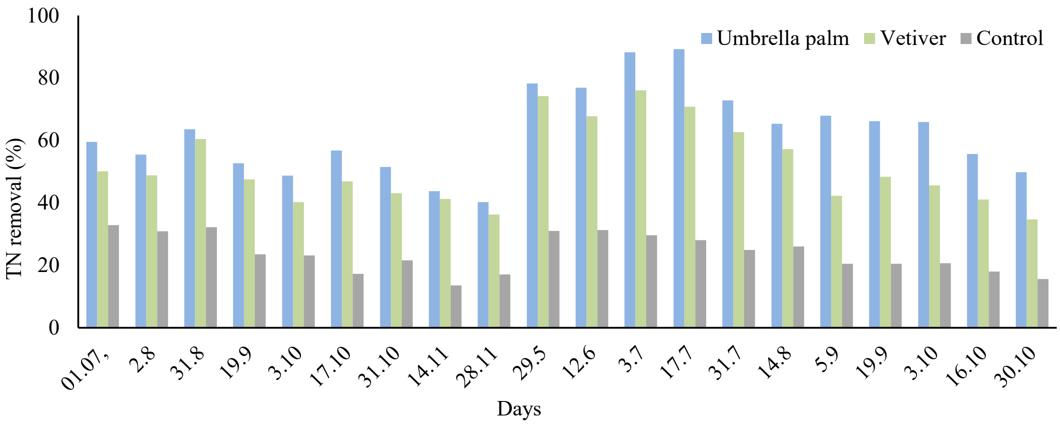

Figure 7. Removal rates of TN in planted-control tanks
Şekil 7. Bitkili ve kontrol tanklarında TN giderim oranları

3.6. Total organic carbon (TOC) removal

The initial TOC value varied between 10.82±2.9mg/L throughout the experiment. The removal ratio was calculated by Formula 1. The results on the 3rd, 7th, and 14th days in tanks with and without plants were determined as follows: 27-42-79% for umbrella palm; 18-27-66% for vetiver; while remaining at 13% for the control groups. At the end of 14-day periods, the TOC concentration averaged 2.6 mg/L, with a minimum of 0.7 mg/L and a maximum of 3.9 mg/L in umbrella palm tanks. For vetiver tanks, the average was 4.1 mg/L, the minimum was 2.1 mg/L, and the maximum was 4.8 mg/L. TOC removal rate in planted tanks with FTW at the end of the 14th day was significantly lower than the values in the control tank ($p < 0.0001$).

Figure 8 shows the change in the 14th days removal ratios of TOC through the two years for plants and the control group. When TOC removal rates were evaluated by variance analysis the removal it has not showed statistically significant differences between retention times, seasons and years ($p > 0.05$).

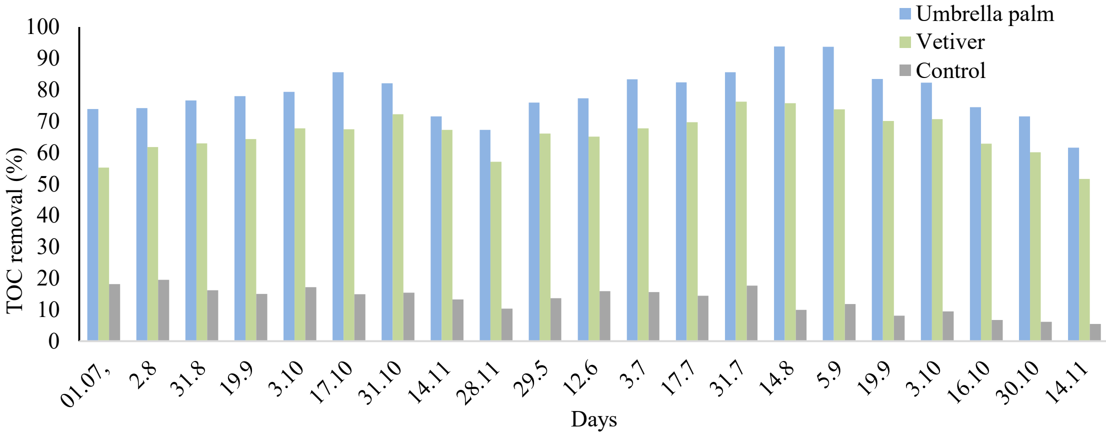

Figure 8. Removal rates of TOC in planted-control tanks
Şekil 8. Bitkili ve kontrol tanklarında TOC giderim oranları

3.7. Growth potential

The study started with 4 kg of biomass in each tank. During the study, the root length, stem length and total biomass of the plants were measured periodically. Pruning was done to have an average biomass of 11 kg in each tank. The pruned amounts were weighed. In the beginning, the plants had an average stem length of 70 cm and a root length of 40 cm. By the end of the study, the maximum root lengths were 135 cm for umbrella palm and 63 cm for vetiver (Figure 9).

Figure 9. Root and stem length measurement in plants umbrella palm (left), vetiver (middle), and weight measurement (right)
Şekil 9. Bitkilerde kök ve gövde uzunluğu ölçümü Japon şemsiyesi (sol), vetiver(orta) ve ağırlık ölçümü(sağ)

The results are shown in Table 3. The weights of the biomass as root and stem were taken separately when the study was completed. Considering the root/stem ratio, the biomass of the root parts was higher for both plants. This ratio was calculated as 61% for umbrella palm and 57% for vetiver.

Table 3. Some morphological features of plants
Şekil 3. Bitkilerin bazı morfolojik özellikleri

Plants	Bio mass* (kg)	Final root length* (cm)	Final stem length* (cm)
Umbrella palm	44±7	73±15	148±16
Vetiver	18±1	55±5	142±12

* Values are average

The weights of the biomass as root and stem were taken separately when the study was completed. Considering the root/stem ratio, the biomass of the root parts of both plants is higher. This ratio was calculated as 61% for umbrella palm and 57% for vetiver.

3.8. Tissue nutrient and PTEs concentrations

The raise between the initial and final amounts of macro and micro elements and PTEs in the plants was researched (Figure 10). The translocation factor (TF) from the root to the stem was calculated by the measurements made separately on the roots and stems of the plants. At the end of the study, there was a statistically significant increase in the total amounts of B, Pb, Cr, Ni, Co, Cd, and P accumulated in the roots and stems of the plants compared to the beginning ($p< 0.0001$).

4. Results and Discussion

This study aims to determine the capacities of plant species that can be used with the FTW method to counter the pollution originating from nitrogen, phosphorus and organic carbon in surface water resources. Firstly, the classification of the freshwater inlet at the Izmir Bird Paradise was done, later on to improve the water quality a FTW was performed.

According to the SWQR (RG, 2012), Izmir Bird Paradise freshwater quality is classified as Level III with the mean of 18±12 mg/L total nitrogen; and as Level III for COD pollutant with the mean of 49.5±12.5mg/L, Level III for the EC with the mean of 1716±729 µS/cm, and with the mean of TP 2.9±1.5 mg/L pollutant classified as Level III (Table 4).

Table4. Chemical and physicochemical quality criteria of inland surface waters (SWOR, 2012)
Tablo 4. Yüzeysel su sınıflandırması (RG, 2012)

Parameters	Level 1	Level 2	Level 3
EC µS/cm	<400	1000	>1000
COD mg/L	<25	50	>50
TP mg/L	<0.08	0.2	>0.2
TN mg/L	<3.5	11.5	>11.5

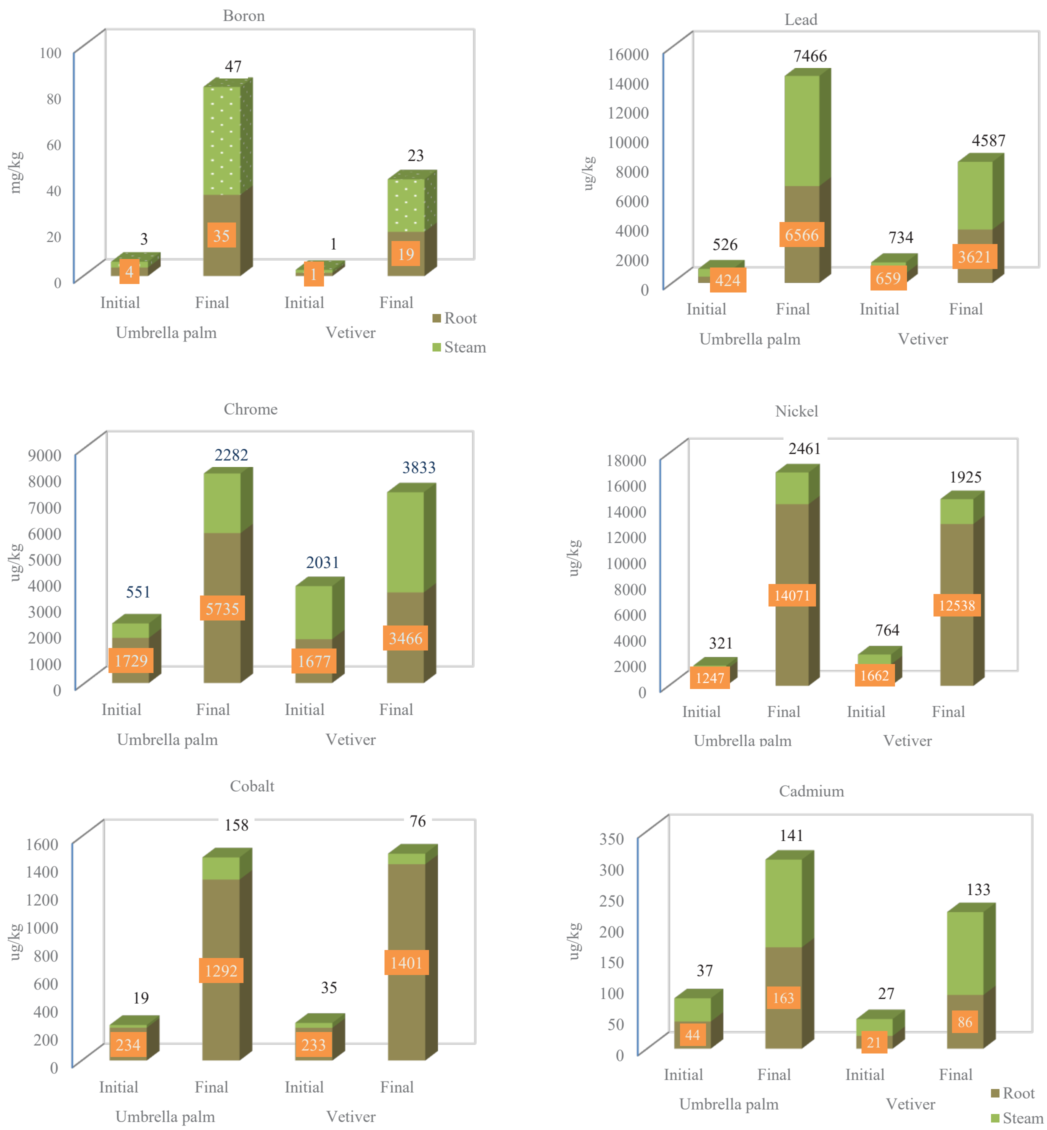

Figure 10. Contents of some PTEs in the root and stem of plants
Şekil 10.Bitkilerin kök ve gövdelerindeki ağır metal konsantrasyonları

The IBP site is an area that holds many international protection statuses such as and by chronological order the Wildlife Improvement Area (1982), Ramsar Site (1998), Grade I. Natural Site (1985), Strict Nature Reserve and National Wetlands Protection Area (URL-2). In accordance with the preventive measures and protection principles of the relevant legislation to improve this surface water quality, which is still used for various purposes, low-cost and easy-to-apply methods should be determined. In this context, the FTW application was carried out on a tributary of the Gediz River which has Level III quality, with umbrella palm and vetiver.

The efficiency of FTW treatment is closely related to the pH, dissolved oxygen, and temperature values of the medium, alongside the appropriate design and flow characteristics. In this study, an inversely proportional relationship was found between removal rates and pH, while a directly proportional relationship was observed between temperature and purification efficiency. The pH in umbrella palm tanks with the highest removal rate varied between 6.7-8.1, in vetiver tanks it ranged between 7.0-8.4 and in unplanted tanks it varied between 8.7-10.2.

In the literature, there are studies reporting that the pH value decreases in FTW applications. White and Cousins (2013) found that the pH value decreased from 8.6 to 6.2 in the aqueous media where the plant was floated, and Moortel et al. (2010) found that while the pH decreased from 7.5 to 7 in the planted tanks, it remained at 7.5 in the non-planted one.

Borne et al. (2014) reported that while the pH was 8.3 in control tanks, it decreased to 7.3 in the planted ones. In the studies that determined this change in pH value, it was interpreted that the humic compounds released by the plants decreased the pH, and the alkaline property was consumed during microbial nitrification. Vymazal (2017) determined the optimum pH range for nitrogen removal as 6.5 – 8.5. On the other hand, he has interpreted that tychopotamic algae in unplanted tanks increased the pH value measured during daylight hours, and the nitrogen and phosphorus removal in control tanks was a result of the functions of these algae.

Evapotranspiration is a parameter evaluated in treatment studies with plants. Evaporation varies depending on the wind and temperature, while transpiration from the leaves of the plant depends on the tolerance of the plant species to pollution (Headley and Tanner, 2012). According to the studies in the literature, the increase in evapotranspiration capacity and biomass also indicates that the plant is the appropriate choice in the fight against pollution. In this study, while the amount of water lost in the control tanks was 51 L on average, this amount was 156 L (40 kg plant) in umbrella palm and 84 L (20 kg plant) in vetiver. Meetiyagoda et al. (2017) studied with *Typha angustifolia*, *Scirpus atrovirens* and *Cyperus alternifolius*, and observed that the highest rate of evapotranspiration occurred in the umbrella palm. Chandra et al. (2017) reported that high water usage and transpiration provided an effective transfer of compounds from root to stem and increased biomass.

On the basis of the analysis which was conducted for water samples, the concentration of PO_4-P values for the umbrella palm, vetiver and control tanks were determined as 0.27 mg/L, 0.54 mg/L and 1,70 mg/L respectively. In terms of the SWQR (RG, 2012) classification, using the umbrella palm improved the water quality to Level II, and sometimes even Level I.

Phosphorus, which is indispensable for all life forms, is the limiting element in lakes (Correl, 1999). In the water sample while the highest PO_4 value was 7.4 mg/L and the average was 2.86 mg/L; TN was 58.1 mg/L at peak and had a mean of 17.57 mg/L. PO_4 quickly fell below 0.5 mg/L within the 14-day period. As PO_4 is the limiting element in the aquatic environment, within the scope of Liebig's Law of the Minimum, this can be a reason for TN and TOC concentrations reductions being less than PO_4 removal (Von Liebig, 1855).

In the tanks, the umbrella palm reached a total biomass of 43.8 kg, while vetiver reached a total biomass of 18.4 kg. The umbrella palm had a root length of 73.3 cm, and the weight of its roots was 60% of the total weight of the plant. In vetiver, the root length was 54.6, and the ratio of roots to total weight was 64%. Therefore, umbrella palm roots developed more.

Among the aquatic plant species found in the IBP area, another species, *Phragmites australis* (water cane) has a wide distribution. This plant, which has a taproot structure, will take heavy metal and macro and micro nutrients from the sediment along the canal. When the roots were floated with the FTW method, umbrella palm and vetiver made more biomass than phragmites in a 1 m^2 area. In one m^2 area, phragmites had a biomass of 10 kg.

The fact that the weight of the root parts of both plants with hairy root structure is higher than the stem is important for FTW. The root system of the plant is an important element for its removal capacity. Plants with fibrous root structure provide a large surface area to microorganisms compared to plants with taproot structure, both the surface area of the roots and the increase in the number of microorganisms are directly related to the removal rate (Schwab and Banks, 1994).

Darajeh et al. (2014) studied the effect of vetiver on BOD removal at different root lengths and densities for palm oil wastewater treatment and found that the BOD removal of 96% and 72% with 30 root tillers and 10 root tillers in wastewater. This difference in removal is explained as the increase in root density and the rate of removal. According to the results of the study conducted for the inlet water from IBP, root weight and root length of umbrella palm are higher than vetiver. This difference between biomass can be related to the difference in treatment efficiency.

Based on their health importance, the potentially toxic elements (PTEs) are classified into four groups, (i) essential: Cu, Zn, Co, Cr, Mn, and Fe. These metals beyond their permissible limit become toxic, (ii) *non-essential*: Ba, Al, Li, (iii) less toxic: Sn, and (iv) *highly toxic*: Hg, Cd, Pb, As (metalloid) (Bansal, 2020). The amount of these substances accumulated in the plant was evaluated both to determine the potential of these substances to prevent pollution in the water and to ensure the selection of appropriate methods for the final disposal of the plant.

At the end of the 2017 vegetation period, when the total amount of PTEs in the roots and stems of vetiver and umbrella palm plants was evaluated, the elements B (83.57 mg/kg), Cr (8,37 mg/kg), Mn (2.27 g/kg), Cd (326 ug/kg), and Pb (14.16 mg/kg) were recorded for the umbrella palm; while in vetiver Co (1,48 mg/kg) reached the highest concentration.

TF>1 indicates that plants not only tolerate the subject contaminant but utilize it in a beneficial way, and this is the characteristic feature of hyperaccumulators. Thus TF>1 is a determining factor for classification plant species for phytoremediation (Chanu and Gupta, 2016).

Vetiver showed a high tolerance to very adverse conditions which are high acid or alkaline levels and possess a high degree of heavy metals, and take Pb slowly and continuously for long periods at mine rehabilitation sites, tailings industrial waste dumps and garbage landfills (Truong, 2020; Roongtanakiat and Chairoj. 2001). Furthermore, the essential oils derived from vetiver roots can be used for perfume making, and its leaves use on roofs, or as a fire barrier. As well as its phytoremediation capacity for various types of pollutants, it could be used considering its economic value and adaptability to different climatic conditions (Ramos-Arcos et al., 2022).

The umbrella palm has come to the fore with its faster growth, accumulation potential and both removals of metal and dissolved organic materials compared to vetiver. In order to ensure the diversity of the plants and increase the removal rate, the umbrella palm and other plants known as hyperaccumulators (*Juncus acutus, Brassica juncea, Iris pseudacorus,* and *Alyssum* ssp) can be compared in the continuation of the study.

At the end of the vegetation, the polluted plants should be replaced with fresh plants. Regarding the disposal of these removed plants, the heavy metal concentrations accumulated in the plants should be compared with the heavy metal limits given in the regulation of soil pollution control etc., and a decision should be made on how to dispose of them (compost, storage or incineration, etc.). On the other hand, the possibilities of using the roots of the vetiver plant in perfumery can be evaluated.

In FTW it is important to choose the proper plant for different types of pollutants and pollutant concentrations. It should also be considered that the efficiency of phytotreatment depends on climatic conditions; therefore, the treatment can be carried out in areas where plant roots can reach, and the determination of biomass is suitable for the targeted removal efficiency. In this context, it would be efficient to conduct such studies with different plant taxa in different ecological conditions.

In Türkiye, there are currently no studies on determining the treatment capacity of umbrella palm and vetiver plants using the FTW method. Our study fills this gap and demonstrates that umbrella palm and vetiver plants can effectively improve water quality in terms of nitrogen, phosphorus, and organic carbon. Therefore, this study is of significance in this regard. The FTW method can be implemented as a preventive and remedial approach in various environments, including lakes, ponds, and streams, that are at risk of pollution.

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