# Use of ornamental plants in floating treatment wetlands for greywater treatment in buildings: preliminary results

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**Abstract:** Floating treatment wetlands (FTWs), have been recognized by many researchers for their efficiency in removing pollutants and thus improving wastewater quality. Despite their wide use for treating various types of wastewater, little is known about their efficiency in greywater treatment. In this study, ten FTWs planted with climbing and ornamental plants were examined for the performance of greywater treatment in the island of Lesvos, Greece. More specifically, Canna indica an ornamental flower plant and Hedera helix an ornamental climbing plant, were established in a pilot scale FTWs experiment, under natural weather conditions. The main operational variables in the experimental set-up design of the FTWs were (a) the presence /absence of plants, (b) the use of two different floating mats (polypropylene, geotextile), and (c) the use of two different water depths (30 cm and 40 cm). The determination of the optimal pollutant removal and plant growth regarding the different variables was investigated. In parallel, plant growth traits as well as water quality parameters were measured on a biweekly basis.
**Keywords:** floating treatment wetlands, ornamental plants, greywater treatment, *Canna indica*, *Hedera helix*, constructed wetland

## 1. Introduction

Excessive use of water resources coupled with rapid urbanization and climate change are some of the main driving forces of water crisis. Hence, search for alternative water sources for non-potable purposes has arisen (Patil & Munavalli, 2016). Among various types of wastewater, greywater which constitutes one of the two main domestic wastewater sources (Patil & Munavalli, 2016), has a great potential for reuse due its availability and its low concentration on pollutant load when compared with total domestic wastewater (Hernández Leal et al., 2007). Even though there are many technologies for greywater treatment, nature based systems such as constructed wetlands seem to be more promising due to their low energy consumption and system maintenance (Li et al., 2009; Masi et al., 2010).

Over the past years, Floating treatment wetlands (FTWs) have started drawing attention due to their successful removal of nutrients (N&P) from wastewater such as stormwater, agricultural runoff and secondary treated wastewater (Gao et al., 2017; Chang et al.,2012; Cao and Zhang, 2014). FTWs consist of floating vegetation such as emergent plants, which are inserted in a buoyant mat that is formed by floating supporting materials. Plants shoots grow above the water level, while roots which act as natural filters grow inside the water column (Colares et al., 2020).

Over the last 15 years ornamental plants such as *Canna indica*, *Strelitzia reginae*, *Zantedeschia aethiopica*, have established their appearance in FTWs as well (Sandoval-Herazo et al., 2019) apart from the genera *Carex*, *Cyperus*, *Juncus* and *Typha* which were mostly used (Ingrao et al., 2020, Calheiros et al., 2015). Due to the fact that most developing countries are in tropical and subtropical regions in combination with the difficulty of installing conventional wastewater treatment systems, the use of endemic ornamental plants in constructed wetlands was explored (Belmont and Metcalfe, 2003). Some of the main advantages regarding the use of ornamental plants is the aesthetic value that such colourful plants add to the systems (Chen et al., 2009, Patil and Munavalli, 2016) as well as their economic benefits in terms of selling the flowers in high markets (Konnerup et al., 2009) or using them in the colour extraction industry (Vankar et al., 2000).

Only a few peer-reviewed studies (Abed et al., 2017; Abed et al., 2019) are available that evaluate the performance of an FTW system for greywater treatment but common reed was the plant that was used. In this study, the use of ornamental plants as floating treatment wetland vegetation for greywater treatment, will be examined for the first time. Therefore, the level of the optimal pollutant removal in FTW systems for greywater treatment in Mediterranean climatic conditions, as a function of the presence of two different ornamental plants, floating mats and water depths, will be evaluated.

## 2. Materials and Methods

Ten identical experimental FTWs operated under real weather conditions, were installed in parallel-piped at the research facility of the University of the Aegean in Mytilene, Greece. Eight of the systems consisted of an open tank (internal width: 0.46 m, internal length: 0.93 m, internal height: 0.51 m) containing one of the studied plants, floating mats (polypropylene from

SEPULVEDA S.L.; geotextile from BioSoil expert) and filled with one of the two studied water depths (0.3 m and 0.4 m) (**Figure 1**). The remaining two systems had no plantation and were used as controls. The ornamental species that were studied were *Canna indica* and *Hedera helix*, which are used at a great extent in Greece and are well adapted in to the Mediterranean climate. Regarding the greywater, a modified version of synthetic greywater recipe (Diaper et al., 2008) was used in the experiment to simulate wastewater from hand basins, showers, baths and laundry machines.

**Figure 1** *Canna* spp. (up) and *Hedera helix* (down) growing on both studied floating mats in FTWs.

In parallel, plant growth traits as well as wastewater quality parameters were measured on a biweekly basis. More specifically, influent and effluent samples were analyzed for pH, total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP) as well as Total Nitrogen (TN) according to APHA, (2005). Turbidity was measured using a portable Turbidity Meter (2100Q, Hach). Regarding plant growth traits analysis, leaf chlorophyll fluorescence was measured using a Pocket PEA chlorophyll fluorometer (Hansatech), while chlorophyll content index (CCI) was measured using a CCM-200 plus (25 Opti-Sciences).

## 3. Results and Discussion

FTWs started operating with synthetic greywater from October 2020. More specifically, the systems were dosed with greywater every 6 hours receiving a hydraulic loading rate (HLR) of approximately 15.8 mm/d and a hydraulic retention time (HRT) of approximately 18.9 d in systems with 0.3 m depth and 25.2 d in systems with 0.4 m depth, respectively .

### *3.1 Removal efficiency of major pollutants*

**Table 1.** demonstrates the main chemical parameters that were studied regarding raw greywater and treated greywater by the FTWs. Raw greywater quality properties are mainly in accordance with that of Patil and Munavalli (2016) as well as Kotsia et al. (2020), with the only exception in turbidity and TSS which were much lower than this of Patil and Munavalli. (2016) (143 ± 54 FNU) during the first period of operation and Kotsia et al. (2020) (131 ± 33.4 mg/l). However even though raw greywater turbidity was lower, our results regarding *Canna* spp. properties differed from these of Patil and Munavalli (2016) in turbidity and COD. Turbidity in *Canna* spp. systems was much higher (14.1 ± 2.1 vs. 3 ± 0.96 FNU, respectively), while COD concentration was lower (30 ± 11 vs. 71 ± 9 mg/l, respectively) compared to their findings. Turbidity is mainly related to the SS parameter (Hannouche et al., 2011). Even though, TSS concentration was extremely low in this study, high turbidity concentration could be attributed to algae growth or to the presence of colloidal solids. Colloidal solids are not considered in TSS concentration, as their size range is much lower (von Sperling, 2014).

Our results for the systems where *H. helix* was planted, are mainly in accordance with these of Kotsia et al. (2020), which is the only study that has used this plant for the first time in constructed wetlands. Nevertheless a few differences were noticed, which could be explained due to the different CW systems that its study used as well as the different substrates.

**Table 1** Characteristics of raw and treated wastewater.

| Parameter | Number of samples | Influent mean and SE | Effluent mean and SE | Effluent mean and SE |
|---|---|---|---|---|
| | | | *Canna* spp. | *Hedera helix* |
| pH | 55 | 7.7 ± 0.1 | 7.9 ± 0.1 | 8.2 ± 0.3 |
| Turbidity (FNU) | 55 | 27.2 ± 3.7 | 14.1 ± 1.2 | 19.4 ± 1.0 |
| BOD (mg/l) | 33 | 106 ± 54 | 20 ± 9 | 38 ± 3 |
| COD (mg/l) | 55 | 241 ± 94 | 30 ± 6 | 51 ± 13 |
| TSS (mg/l) | 55 | 0.027 ± 0.011 | 0.011 ± 0.004 | 0.018 ± 0.007 |
| TN (mg/l) | 33 | 16.2 ± 3.7 | 14.9 ± 4.6 | 14.5 ± 1.8 |
| TP (mg/l) | 55 | 5.1 ± 0.6 | 3.8 ± 1.0 | 3.9 ± 1.2 |

Regarding COD, TSS and TP, *Canna* spp. outcompeted *Hedera helix* (77 ± 4% and 67 ± 11%, 55 ± 9% and 35 ± 14%, 30 ± 6% and 25 ± 13%, respectively) as it can be deduced from **Figure2**. However, TN removal in systems planted with *H. helix* was slightly higher than that of *Canna* spp (24 ± 9% and 17 ± 3%). *Canna* spp. findings may not be absolutely in accordance with Fowdar et al. ( 2017), who investigated the performance of living walls for greywater treatment but are more in accordance with Patil and Munavalli (2016), who noticed an approximately 50% removal rate for both COD and TP. Fowdar et al. ( 2017) removal rates for TSS, TN and TP in the designs with *Canna lilies* where much higher (95 ± 0.3%, 85 ± 12%, 49 ± 13%, respectively). This could be attributed to the fact that our plants have not been fully established yet. Moreover it has been suggested that matured wetland systems provide higher water quality (Al-Isawi et al., 2017).

With reference to *H. helix* removal efficiencies, Kotsia et al. (2020) noticed 11% TP and 95% TSS removals. Compared to our results, this study demonstrated higher

TSS removal but that wasn't the case for TP removal as well. Lower TSS removal could be attributed to the uncolonized roots which would otherwise filter the suspended contaminants (Dotro et al., 2017).

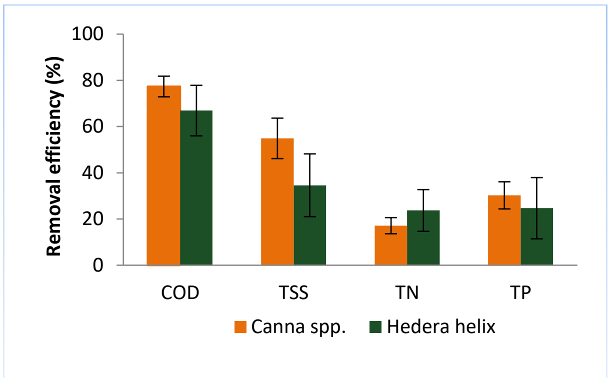


**Figure 2** Mean removal efficiency of COD, TSS, TN and TP in the examined FTWs.

### *3.2 Plant adaptation*

Regarding plants' health after 5 months of operation, it could be supported that plants adapted well during the first months of operation. However next months were very demanding due to low temperatures, during winter according to Hellenic National Metereological Service (**Table 2**.). In general, environmental conditions during tests, have not been studied extensively, while they appear to influence not only plants' adaptability but also their growth (Li et al., 2007). As a result, **Table 3.** demonstrates that, mean maximum quantum yield (Fv/fm) and mean chlorophyll content index (CCI) had much lower values than expected. Even though there is limited information regarding ornamental plants' adaptation in CWs for greywater treatment, both of the studied plants have been used in other CW types (Calheiros et al., 2015; Kotsia et al., 2020; Cao and Zhang, 2014).

**Table 2** Weather data for the study area during monitoring period.

| Monitoring period (11/20-03/21) | Dry temperature (average, min (°C) | Wind force (average, max average (knot)) |
|---|---|---|
| **November** | 14.7, 7.0 | 6.3, 13.2 |
| **December** | 13.2, 6.2 | 7.5, 14.3 |
| **January** | 11.8, 0.0 | 9.9, 18.7 |
| **February** | 11.4, 1.0 | 8.2, 16.3 |
| **March** | 11.2, 4.0 | 6.5, 13.1 |

**Table 3** Mean maximum quantum yield (Fv/Fm) and chlorophyll content index (CCI) in the examined ornamental plants.

| | **Fv/Fm** | | **CCI** | |
|---|---|---|---|---|
| | ***Canna indica*** | **Hedera helix** | **Canna indica** | **Hedera helix** |
| **Average** | 0.60 | 0.50 | 11.1 | 32.6 |
| **St.Deviation** | 0.17 | 0.21 | 5.5 | 15.5 |

According to Caputo et al. (2019) *Canna x generalis* plants in mesocosm CW experiment, developed at a greater extent when irrigated with greywater than with tap water. Moreover it was revealed that *Canna* plants not only grew more in the pilot scale CW experiment, but also flowered due to the greater efficiency of sunlight. On the contrary, at another CW system (Ecological Floating Bed), *Canna* plants managed to develop only in one of the EFBs as in the other two their leaves turned yellow and fell off after their establishment (Cao and Zhang, 2014). That result was attributed to morphology and physiology changes at the plant (Ma et al., 2010).

Regarding *Hedera helix*, even though in Kotsia et al. (2020) study, in winter months CCI values followed a decrease, the exact opposite trend occurred during growing season. Thus, it was deduced that ivy has a great ability to grow under the unpredictable and stressful conditions that prevail during winter but also in summer.

## 4. Conclusions

The main aim of this study was the determination of the optimal pollutant removal and plant growth of two ornamental plants in an FTW system for greywater treatment. Both plants appear to remove at a great percentage COD (77 % and 67 %, respectively) and TSS (55% and 35%, respectively) and at a modest - lower rate TP (30% and 25%, respectively) and TN (24% and 17 %). When comparing the two ornamental plants, *Canna* spp. outcompeted mostly *Hedera helix*. The unfavorable weather conditions during winter months in combination with the fact that greywater has lower mainly nutrients concentration, contributed to the lower growth rates of both plants.

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## 6. References

Abed, S., Almuktar, S. and Scholz, M. (2017). Remediation of synthetic greywater in mesocosm-Scale floating treatment wetlands, *Ecological Engineering*, **102**, 303-319.

Abed, S., Almuktar, S. and Scholz, M. (2019). Phytoremediation performance of floating treatment wetlands with pelletized mine water sludge for synthetic greywater treatment, *Journal of Environmental Health Science and Engineering*, **17**, 581-608.

Al-Isawi, R., Ray, S.and Scholz, M. (2017). Comparative study of domestic wastewater treatment by mature vertical-flow constructed wetlands and artificial ponds, *Ecological Engineering*, **100**, 8–18.

APHA, (2005). Standard Methods for the Examination of Water and Wastewater. American Public Health Association

(APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF).

Belmont, M.A. and Metcalfe, C.D. (2003). Feasibility of using ornamental plants (*Zantedeschia aethiopica*) in subsurface flow treatment wetlands to remove nitrogen, chemical oxygen demand and nonylphenol ethoxylate surfactants - A laboratory-scale study, *Ecological engineering*, **21**, 233–247.

Calheiros, C.S.C., Bessa, V.S., Mesquita, R.B.R., Brix, H., Rangel, A.O.S.S. and Castro, P.M.L. (2015). Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility, *Ecological engineering*, **79**, 1–7.

Cao, W. and Zhang, Y., 2014. Removal of nitrogen (N) from hypereutrophic waters by ecological floating beds (EFBs) with various substrates, *Ecological engineering*, **62**, 148–152.

Caputo, L., Siqueira, C., Caputo, B., Bacchi, C., Magalhães Filho, F. and Paulo, P. (2019). Effects of graywater on the growth and survival of ornamental plants in nature-based systems, *Journal of Environmental Science and Health, Part A*, **54**, 1023-1034.

Chang, N.B., Islam, K., Marimon, Z. and Wanielista, M.P. (2012). Assessing biological and chemical signatures related to nutrient removal by floating islands in stormwater mesocosms, *Chemosphere*, **88**, 736–743.

Chen, Y., Bracy, R.P., Owings, A.D. and Merhaut, D.J. (2009). Nitrogen and phosphorous removal by ornamental and wetland plants in a greenhouse recirculation research system, *HortScience*, **44**, 1704–1711.

Colares, G., Dell'Osbel, N., Wiesel, P., Oliveira, G., Lemos, P., da Silva, F., Lutterbeck, C., Kist, L. and Machado, Ê. (2020). Floating treatment wetlands: A review and bibliometric analysis, *Science of The Total Environment*, **714**, 136776.

Diaper, C., Toifl, M. and Storey, M. (2008). Greywater Technology Testing Protocol. CSIRO: Water for a Healthy Country National Research Flagship, Australia.

Dotro, G.,Molle, P., Nivala, J., Puigagut, J. and Stein, O. (2017). Treatment Wetlands. 1st ed. IWA Publishing, London, UK 9781780408767.

Fowdar, H., Hatt, B., Breen, P., Cook, P. and Deletic, A. (2017). Designing living walls for greywater treatment, *Water Research*, **110**, 218-232.

Gao, L., Zhou, W., Huang, J., He, S., Yan, Y., Zhu, W., Wu, S. and Zhang, X. (2017). Nitrogen removal by the enhanced floating treatment wetlands from the secondary effluent, *Bioresource Technology*, **234**, 243-252.

Hannouche, A., Chebb,o G., Ruban, G., Tassin, B., Lemaire, B.J. and Joannis, C. (2011). Relationship between turbidity and total suspended solids concentration within a combined sewer system, *Water Science and Technology*, **64**, 2445-2452.

Hernández Leal, L., Zeeman, G., Temmink, H. and Buisman, C. (2007). Characterisation and biological treatment of greywater, *Water Science and Technology*, **56**, 193-200.

Ingrao, C., Failla, S. and Arcidiacono, C. (2020). A comprehensive review of environmental and operational issues of constructed wetland systems, *Current Opinion in Environmental Science & Health*, **13**, 35–45.

Konnerup, D., Koottatep, T. and Brix, H. (2009). Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with *Canna* and *Heliconia*, *Ecological engineering*, **35**, 248–257.

Kotsia, D., Deligianni, A., Fyllas, N., Stasinakis, A. and Fountoulakis, M. (2020). Converting treatment wetlands into "treatment gardens": Use of ornamental plants for greywater treatment, *Science of The Total Environment*, **744**, 140889.

Li, M., Wu, Y., Yu, Z., Sheng, G. and Yu, H. (2007). Nitrogen removal from eutrophic water by floating-bed-grown water spinach (*Ipomoea aquatica Forsk*.) with ion implantation, *Water Research*, **41**, 3152-3158.

Li, F., Wichmann, K. and Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses, *Science of The Total Environment*, **407**, 3439-3449.

Ma, X., Ma, F., Li, C., Mi, Y., Bai, T. and Shu, H. (2010). Biomass accumulation, allocation, and water-use efficiency in 10 Malus rootstocks under two watering regimes, *Agroforestry Systems*, **80**, 283-294.

Masi, F., El Hamouri, B., Abdel Shafi, H., Baban, A., Ghrabi, A. and Regelsberger, M. (2010). Treatment of segregated black/grey domestic wastewater using constructed wetlands in the Mediterranean basin: the zer0-m experience, *Water Science and Technology*, **61**, 97-105.

Patil, Y.M. and Munavalli, G.R. (2016). Performance evaluation of an Integrated On-site Greywater Treatment System in a tropical region, *Ecological engineering*, **95**, 492–500.

Sandoval-Herazo, L., Zamora-Castro, S., Vidal-Álvarez, M. and Marín-Muñiz, J. (2019). Role of Wetland Plants and Use of Ornamental Flowering Plants in Constructed Wetlands for Wastewater Treatment: A Review, *Applied Sciences*, **9**, 685.

Vankar, P.S., Ghorpade, B. and Tiwari, V. (2000). Ultrasound Energised dyeing of Cotton fabric with Canna Flower extracts using Ecofriendly mordants, *Asian Textile Journal*. 68−69**.**

von Sperling, M. (2014). Introdução à qualidade das águas e ao tratamento de esgotos. Belo Horizonte, Editora UFMG, 4 ed. 452p.

### 6.1 Websites

http://www.hnms.gr/emy/el/climatology/climatology_city> [Accessed 08 April 2021].