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# Use of recycled construction and demolition waste as substrate in hybrid constructed wetlands for the treatment of Olive Mill Wastewater.

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**Abstract**
The objective of this study was to evaluate the effectiveness of hybrid constructed wetlands (CWs) for treating olive mill wastewater (OMW) using recycled aggregates from construction and demolition waste as substrate material. The experiment was conducted at the outdoor research facility of the University of the Aegean in Mytilene, Greece. Three identical pilot hybrid systems were developed, consisting of a vertical subsurface flow CW and a horizontal subsurface flow CW. The first hybrid system (S1) was filled with recycled demolition waste, the second system S2 was filled with rock (ignimbrite) processing residues while the third system (S3) was filled with gravel for comparison. In all three pilot hybrid systems, four plants of *Atriplex halimus* were placed in each VF-CW, while four plants of *Scirpoides holoschoens* were placed in each HF-CW. The experiment lasted for 4 months with hydraulic loading rate 30 L/d. The effluent results from the hybrid systems showed that the hybrid system filled with the rock processing residues had higher removal rates for all examined parameters (COD=87%, Turbidity=99%, Total Phosphorus =75%, Total Phenols=95%).

**Keywords:** olive mill wastewater; nature-based solutions for water; constructed wetlands; recycling

## 1. Introduction

Olive oil production is an important economic activity, especially in Mediterranean countries (Gikas et al., 2018), as it is a key element of the Mediterranean diet and is considered a product whose consumption contributes to the maintenance of good health (De Santis et al., 2022). The most important producers of olive oil are Italy, Spain, Greece, and Portugal. According to data from FAOSTAT, in the years 1994 to 2013, Spain is the world's leading olive oil producer with an average production of 1,059,194 t of olive oil, while Italy is second with 555,557 t . Other relevant producers are Greece with 344,615 t and Tunisia with 159,990 t (ISTAT, 2017; International Olive Council., 2018). However, more and more countries are pushing into olive oil production, such as Argentina, Australia, the USA, and South Africa. The growing popularity of olive oil is mainly attributed to its content of elements rich for human health and its antioxidant activities (Dermeche et al., 2013).

Although olive oil production has economic and nutritional benefits, the sector is associated with environmental problems derived from the productive process (Gullón et al., 2020). During the process of olive oil extraction, different by-products are produced such as olive pomace and olive mill wastewater (OMW) (Ghadraoui et al., n.d.). OMW is a dark brown effluent with a strong odor and it comes during the extraction of olive oil using the press (artisanal) or centrifuge (semi-modern) extraction methods (Bruzzoniti et al., 2020) and is characterized by a high organic content, relatively acidic pH, a very high electrical conductivity (EC), a high polyphenol content and a high large of solids (El Ghadraoui et al., 2020)

Their effects on the environment are more severe in water, where they cause the discoloring of rivers and streams, reduction of dissolved oxygen, and eutrophication (Ghadraoui et al., n.d.). Also, they are toxic to aquatic organisms and their direct disposal in the sea causes pathological changes in marine organisms (Danellakis et al., 2011). In soil, the spreading OMW could modify the physical characteristics including porosity, aggregate stability, water retention, and hydraulic conductivity (Ghadraoui et al., n.d.), while in controlled quantities they exhibit soil ameliorative activity (Mekki et al., 2013) important factor is their phytotoxic effect, mainly due to their phenol content, which does not seem to be significant in olive trees (Chartzoulakis et al., 2010). Solid residues from olive mills are olive leaves and olive pomace. The olive pomace is sold at the mills, while the leaves are disposed of in the fields. As regards liquid waste from twophase mills, it is disposed of uncontrolled in natural receptors without causing serious problems, as it has a relatively low pollutant load (RAC/CP, 2001). It follows from the above that waste from oil mills can cause serious problems in the environment. This highlights the need to treat them using techniques adapted to the characteristics of the olive oil industry in the area.

Constructed wetlands (CW) have been used for many decades to treat wastewater from small, decentralized communities or further polish effluents from conventional wastewater treatment plants. CWs are innovative, low-cost and low-energy practices for managing (Tunçsiper et al., 2015). They are designed and constructed to use the processes that take place in plants and infill substrates as well as microbial communities to treat wastewater (Gorra et al., 2014). The large surface area and the infill substrates help to develop different microbial processes that contribute as catalysts for the removal of organic and inorganic components in wastewater (Gorra et al., 2014) while plants have been reported as one of the most important factors in the efficient removal of contaminants in CWs. There are limited studies on OMW treatment using natural systems with empasis given to constructed wetlands(Gikas et al., 2018)**.** The objective of this study was to examine the use of construction and demolition waste as substrate in vertical flow and horizontal flow CW for the treatment of OMW. The successful implementation of these recycled materials will reduce the construction cost while promoting circular economy principles.

Moreover, in recent years, the recycling of construction and demolition waste has been promoted to reduce the environmental impact of waste disposal in landfills. Recycled aggregates obtained from these materials could be used as substrates in constructed wetlands. This application not only reduces the cost of wetland substrates but also utilizes a difficult-to-handle waste stream such as construction and demolition waste in the context of a circular economy. The aim of this work was to examine the use of construction and demolition waste as substrate in vertical flow and horizontal flow CW for the treatment of olive mill wastewater for the first time.

Table 1: Chemical characteristics of olive mill wastewater used in the experiment

| Parameter | Value |
|---|---|
| pH | 5.0 ± 0.5 |
| Conductivity (mS/cm) | 9.3 ± 0.3 |
| Total chemical oxygen demand (t-COD) (g/L) | 53.9 ± 6.0 |
| Total suspended solids (TSS) (g/L) | 53.0 ± 1.6 |
| Volatile suspended solids (VSS) (g/L) | 40.2 ± 1.6 |
| Total Phenols (g/L) | 6.0 ± 0.8 |

## 2. Materials and methods

### 2.1 Olive mill characteristics

The OMW was obtained from a local olive mill immediately after its release from the open containment pond of a three-phase centrifuge and stored at 4 oC before use. Table 1 shows the physicochemical parameters of the OMW used in the experiment. Due to the quite high organic matter content, the OMW were diluted 30 times before use.

### 2.2 Experiment setup

The experiment was conducted at the outdoor research facility of the Department of Environment, University of the Aegean in Mytilene, Greece from February 2023 until May 2023. Three identical pilot hybrid systems consisting of a vertical subsurface flow CW and a horizontal subsurface flow CW were developed. For the VF-CWs three open pallet tanks (length: 1.20 m, width: 1.00 m, height: 1.17 m) were used, while for the HF-CWs three open plastic tanks (length: 1.64 m, width: 0.92 m, height: 0.92 m) were used. Each hybrid system was filled with a different material. The first hybrid system (S1) was filled with recycled demolition waste, the second system S2 was filled with rock (ignimbrite) processing residues while the third system (S3) was filled with gravel for comparison. In all three pilot hybrid systems, four plants of *Atriplex halimus* were placed in each VF-CW, while four plants of *Scirpoides holoschoens* were placed in each HF-CW. During the experiment, the systems operated receiving olive mill wastewater at an HLR of 25 mm/d (for VFCWs).

Influent and effluent samples were analyzed for turbidity, EC, pH, TSS, VSS, COD, BOD, TP as well as Total Phenols. The pH was measured using a pH-meter (C932, Consort) and the Electrical conductivity (EC) using a portable conductimeter (LF95, WTW). Turbidity was monitored using a portable turbidimeter (2100Q, Hach). Moreover TSS,VSS, COD,TP, and Total Phenols analyses were conducted according to APHA (APHA et al., 2005). Biochemical oxygen demand (BOD) was determined using the closed respirometric method (OxiTop®, WTW).

## 3. Results and discussion

Table 2 summarizes the evolution of the physicochemical parameters during the treatment period by the 3 hybrid CWs systems. The pH measurement showed small increase differences (0.6 to 1.0) between the influent and effluents of the systems. Specifically, the mean pH in the influent was 6.2 ± 0.9 while in the effluent of S1, S2, and S3 was 6.9 ± 0.4, 6.8 ± 0.4, and 7.2 ± 0.3 respectively. The EC in the influent during the experiment was 6150 ± 1276 μS/cm while in the effluents of S1, S2, and S3 was 3720 ± 405, 4170 ± 690, and 3430 ± 567 respectively. Significant differences were observed between the influent and the effluents, as the conductivity in the effluents seemed to be decreasing, which was also observed in the case of turbidity the removal in S1 is 95%, in S2 96%, and in S3 99% removal.

Figure 1 shows the variation of total phenols and COD concentration of the influents and effluents of vertical and horizontal flow systems during the experimental period. High removal efficiencies were observed, while the use of recycled demolition waste and rock (ignimbrite) as substrate materials appear to produce better effluent quality compared to the use of gravel.

The COD showed a reduction in the three systems but the more effectives to remove the organic polluting load was the S1 with 97%, the S2 with 87% and lastly the S2 with 78% of removal. The total phenol concentration showed a reduction in the three systems also, the most effective was the S1 with 75 %,S3 with 58%, and last S2 with 54% of removal.

This study demonstrated that the hybrid VF-HF system filled with rock processing residues had higher removal rates for all examined parameters (turbidity, TSS,VSS, BOD5, COD, TP, Total phenols) compared to the system filled with gravel, indicating that the use of rock processing residues in CWs could be an efficient and sustainable practice.

Table 2: Influent and effluents quality of each system during the experiment.

| Systems[a] | pH | Turbidity (FNU) | Conductivity (μS/cm) | TCOD (mg/L) | BOD (mg/L) | TP (mg/L) | Total Phenols (mg/L) | TSS (mg/L) | VSS (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| Effluent _V_ RDW | 7.3 ± 0.4 | 683 ± 214 | 3000 ± 330 | 2615 ± 175 | 738 ± 160 | 1.9 ± 0.9 | 161 ± 57 | 193 ± 111 | 188 ± 104 |
| Effluent _H_ RDW | 6.9 ± 0.4 | 86 ± 40 | 3720 ± 405 | 109 ± 62 | 338 ± 43 | 1.3 ± 0.5 | 40 ± 17 | 48 ± 19 | 46 ± 19 |
| Effluent _V_ G | 7.5 ± 0.5 | 540 ± 94 | 3360 ± 6405 | 2164 ± 861 | 407 ± 96 | 1.7±0.5 | 132 ± 61 | 67 ± 45 | 62 ± 44 |
| Effluent _H_ G | 6.8 ± 0.4 | 83 ± 26 | 4170 ± 690 | 920 ± 83 | 272 ± 84 | 1.4±0.3 | 68 ± 33 | 30 ± 14 | 29 ± 14 |
| Effluent _V_RI | 7.7 ± 0.4 | 74 ± 39 | 1950 ± 407 | 744 ± 98 | 412 ± 30 | 2.0±0.9 | 72 ± 63 | 93 ± 62 | 91 ± 58 |
| Effluent _H_RI | 7.2 ± 0.3 | 11 ± 4 | 3430 ± 567 | 527 ± 66 | 122 ± 11 | 0.8 ± 0.3 | 14 ± 4 | 8 ± 5 | 7 ± 5 |
| Influent | 6.2 ± 0.9 | 1849 ± 195 | 6150 ± 1276 | 4213 ± 2062 | 687 ± 212 | 3.1 ± 1.9 | 298 ± 105 | 585 ± 81 | 570 ± 73 |

[a]= E_V_RDW: Effluent_Vertical _ Recucled Demolition Waste, E_H_RDW: Effluent_Horizontal_Recucled Demolition Waste, E_V_G: Efluent_Vertical_Gravel, E_H_G: Efluent_Horizontal_Gravel, E_V_RI: Efluent_Vertical_Rock (Igrimbrite), E_H_RI: Efluent_Horizontal_Rock (Igrimbrite).

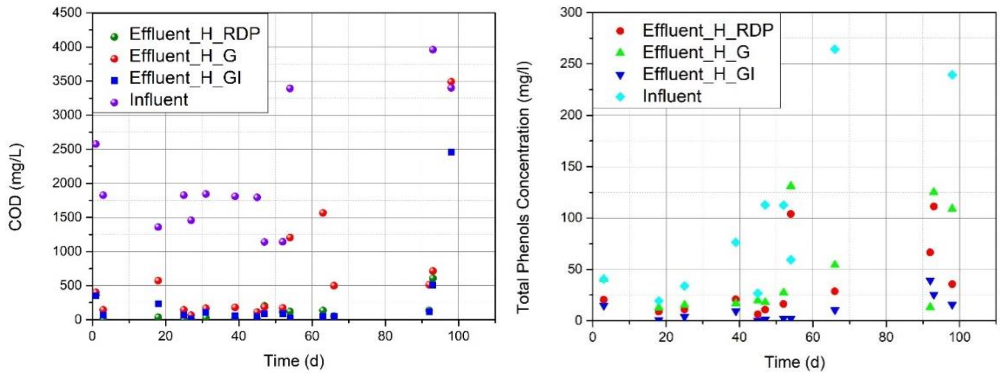


**Figure 1.** Total Phenols and COD values in the influents and effluents.

## 4. Conclusions

Recycled aggregates derived from construction and demolition waste were applied as substrate in hybrid constructed wetlands included (Vertical-Horizontal flow constructed wetlands) treat olive mill wastewater. The main conclusions are as follows:

(1) The use of Hybrid Constructed Wetlands seems a promising low construction cost solution for OMW treatment.

(2) The use of Constructed and Demolition waste as a substrate material had as a result better removal performance in relation to the use of gravel as a filling substrate.

(3) This study demonstrated that the hybrid VF-HF system filled with rock processing residues had higher removal rates for all examined parameters compared to the system filled with gravel, indicating that the use of rock processing residues in CWs could be an efficient and sustainable practice.

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