Research article

Use of Vetiver Zizinioides Floating Beds to Improve the Quality of Surface Water in a Mediterranean Climate

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Abstract.
Due to the negative effects of its main inflows, the water quality of Roxo stream, located in southern Portugal, an area characterized by Mediterranean climate, is degraded, causing consequences in irrigated agricultural activity. The eco technology of floating beds was used to improve the quality of this water. Three *Vetiver zizinioides* floating beds (3.3 m^2/unit; density 40.5 plants/m^2) were placed on the Roxo stream in May 2020 and the water quality was monitored until December 2020 in two places: at the floating beds location and 100 m higher up in the stream. The load mass was calculated for both sampling points and the removal rate for each parameter was monitored. The average removal rates obtained were: (i) TN = 33%; (ii) TP = 43%; (iii) COD = 44%; and (iv) Cl- = 15%. The DO level increased slightly, and the pH remained neutral. Although the water quality improved, the quality was still not high enough to be able to use the water for irrigation and to achieve good ecological status.

Keywords: Roxo stream, surface water quality, real scale, floating beds, *Vetiver zizinioides*

1. Introduction

The water bodies of Southern Portugal are subject to a great seasonal variability of strong and localized events [1]. This variability can lead to prolonged droughts, which severity has increased in recent decades as a result of temperature rise due to climate change [1]. The quantity and quality reduction of water induces destructive and often irreparable impacts on crop production, soil quality, increased risk of desertification and decreased biodiversity [2].

The Roxo stream, located on the right bank of the Sado river (Southern Portugal), near the city of Aljustrel, is a perennial water course and has been heavily influenced by mining and agricultural activity of the region. As a result, the quality of water for irrigation is bad [3], according Portuguese Law [4] and presents poor ecological state, when evaluated only for the physicochemical parameters [5]. Thus, solving this problem by using an effective and environmentally sustainable pollutant removal solution is considered relevant.

The use of Floating Beds (FB) is one of rivers Eco-rehabilitation strategies [6]. FB are floating matrices, which are associated with ecological communities such as macrophytes and microorganisms [6]. They have the ability to degrade pollutants by taking advantage of the benefits that ecosystems have, so they can be used to improve the surface water bodies quality [7].

Plants play a key role in this issue due having a dense root system, providing: (i) the creation of the necessary conditions for the circulation of water; (ii) the creation of laminar flow between the surface and bottom of the water column; (iii) the fixation of micro-organisms; (iv) the transport of atmospheric air through its upper organs to the roots; (v) nutrient assimilation; (vi) the occurrence of solid sedimentation processes and (vii) sediment storage capacity without causing excessive damage to the system [8].

Previous studies regarding artificial floating wetland technology have been focusing on the application of this treatment on standing or stagnant water such as wetlands, lakes and ponds [9]. However, in this study, the FB system is applied for the treatment of running water (dynamic system) (i.e., river, stream or channel), to which use there are a very few information [10].

The macrophyte *Vetiver zizinioides* has been widely studied for the reduction of environmental contamination. The main plant features are, among others: large and deep root system, resistance of a wide pH range (3,3 a 9,5), tolerance air temperatures between -20°C e 60°C, high efficiency to removing nutrients, resistance of high saturation levels of Al, Mn and heavy metals and is effective in herbicide retention [11].

The main aim of this work is to test, at real scale, the floating bed technology (FB) using floating matrix with the macrophyte *Vetiver zizinioides*, with the purpose to improve water quality of Roxo stream, contributing to it ecological improvement and also, in order to be possible to be used in irrigation proposes.

2. Material and methods

2.1. Meteorological data 2020

It was obtained the meteorological data of 2020 on region of Aljustrel, [12], to study its possible influence on the influx of pollutants into the water.

2.2. Field Installation

The FB are constituted by a floating system and a support system for plants (Network in PEAD and organic blanket), (Fig.1) on which were planted the macrophyte *Vetiver Zizinioides* (Density 40.5 plants/m^2) and tied to the borders of the watercourse. The choice of this macrophyte was based in previous studies, on pilot scale, where were tested several macrophythes and this one presented the best results in terms of production of biomass and without severe damage on its external and anatomical morphology [13].

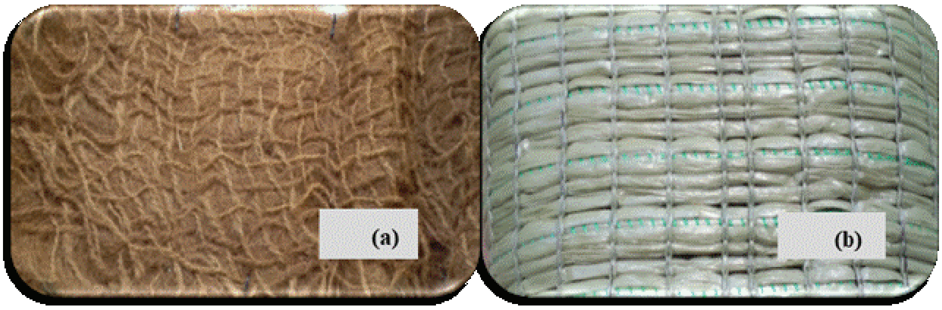

Figure 1: (a) Support System for Plants (organic blanket); (b) Floating System (PEAD Network).

Three floating beds with the dimensions of 3.3 m^2/unit were placed on Roxo stream (location: coordinates GPS: *37.944685-8.153876*), on May 2020, (Fig.2). They were placed in a water section, that presented the depth of 0,9 $\pm$ 0,3 m, the wide of 10.0 $\pm$ 1.3 m and a flow rate of 0.11 $\pm$ 0.10 m^3/s.

Figure 2: Field Installation of floating beds.

2.3. Experimental Procedure

The sampling collection was made in two points, namely after floating beds location (Outlet) and around 100 m before them at Roxo stream (Inlet). They were carried out by May 2020 to December 2020 according to Standard Methods of Analysis [14].

In *situ,* physical-chemical monitoring was performed bimonthly, for the parameters: pH, Temperature (ºC), Potential redox (Eh); Electrical conductivity (ECw) and Total Dissolved Solids (TDS), using multiparametric portable probe (HI9829 HANNA).

The remaining parameters were monitored monthly *in lab*, and were determined according to Standard Methods for the Examination of Water and Wastewater [13]: Sodium (Na^{+}); Potassium (K^{+}); Magnesium (Mg^{2+}); Calcium (Ca^{2+}); Total Suspended Solids (TSS); Chlorides (Cl^{-}); Ammoniacal Nitrogen (NH_4^{+}); Total Nitrogen (TN); Nitrates (NO_3^{-}); Nitrites (NO_2^{-}); Total Phosphorus (TP); Phosphate ($P_2O_5^{2-}$); Boron (B^{3+}); Chemical Oxygen Demand (COD) and Sulphates (SO_4^{2-}).

- The assays were made in duplicate.

2.4. Data Treatment

- It was calculated the load mass, for the parameters analysed, with the exception of the pH and Electrical Conductivity, in both sampling points.

- It was calculated the removal rate for each parameter using the Eq.1.

$$\%R = \frac{Inlet - Outlet}{Inlet} \times 100 \quad (1)$$

- It was calculated the average of removal rates, for each parameter, for the period of monitorization.

- The data was grouped by parameter, for both sampling points, and represented using the software *Excel 2016*.

3. Results and discussion

The Fig.3 shows the mean temperature, precipitation and wind velocity occurred on Aljustrel for the year of 2020.

On the Mediterranean climate the influent pollutants to the rivers are very closely related to the hydrological behaviour [1]. So, in 2020, precipitation on Aljustrel, occurred mainly in the Spring months of March (60 mm) and April (90 mm) and October (60mm), November (130 mm) and December (50mm). On June, July and August there was no

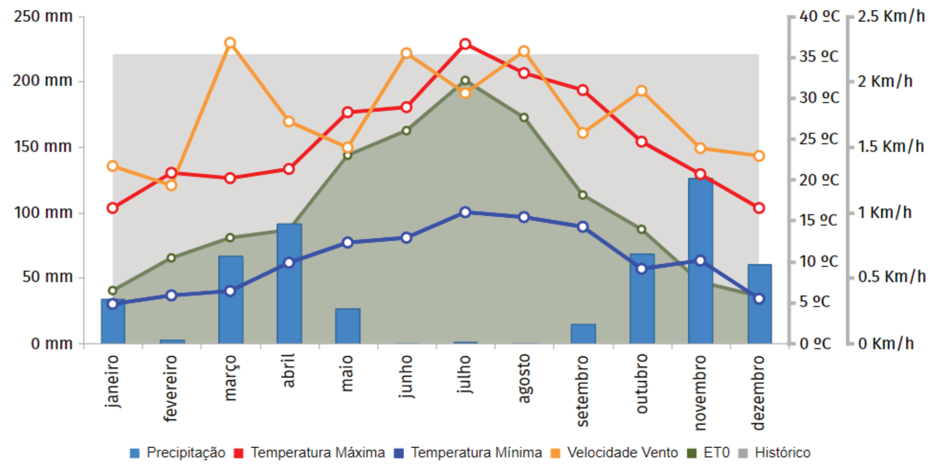

Figure 3: Meteorological data 2020 at Aljustrel, Portugal (Adapted from [12]).

precipitation. The temperature ranged between, approximately, 5°C in January and above 35°C in July.

Table 1. summarises the main results obtained in this work. They show some chemical physical characteristics of the Roxo stream water; i) high chemical oxygen demand (COD); ii) low dissolved oxygen (DO) levels; iii) high values of chlorides (Cl^{-}) and iv) low concentrations of nitrogen and phosphorous nutrients.

Also shows the importance of the precipitation on the increase of pollutants into the stream. In fact, with the rains of autumn, in October and especially in November, it can be observed an increase of concentration in almost all parameters. This may happened due to the soils drainage processes, which were very dry due to high summer temperatures.

On the other hand, the removal rates obtained for each parameter suffers large variations (ranges between 0%-90%) over monitoring period. It seems to be no relationship between the efficiency of the treatment with FB and the inlet mass load to the river bed.

In Fig. 4 is represented the results obtained for Electrical Conductivity (Ecw) and pH.

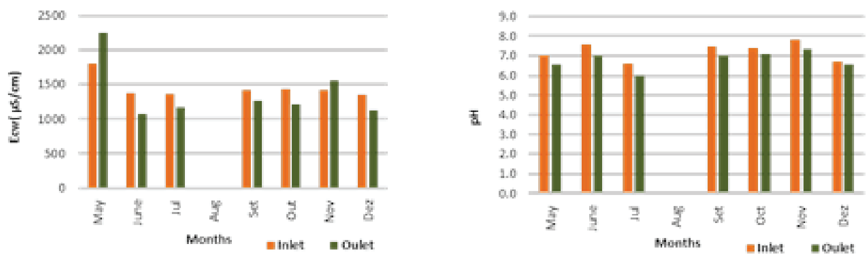

Figure 4: Representation of the values of Electrical Conductivity (ECw) and pH at inlet and outlet of FB obtained along the monitored period.

Table 1: Presentation of concentrations and mass load (ML) obtained on the two sampling points (inlet and outlet) for the main parameters studied along the monitored period of time.

Months Parameters	May	June	July	Aug.	Set.	Oct.	Nov	Dec.
DO (Inlet)								
[DO] (mg/L)	7	8	7	-	5	8	7	8
ML (kg/m^2.day)	4.8	3.9	1.0	-	5.0	3.4	29.3	1.8
DO (Outlet)								
[DO] (mg/L)	7	8	7	-	6	8	8	12
ML (kg/m^2.day)	4.8	3.9	1.8	-	6.0	3.4	33.5	2.7
R (%)	-	-	-	-	-	-	-	-
COD (Inlet)								
[COD] (mg/L O_2)	13	45	29	-	52	65	36	40
ML (kg/m^2.day)	8.9	22.2	7.6	-	52.1	27.6	150.5	8.8
COD (Outlet)								
[COD] (mg/L O_2)	13	15	13	-	14	27	30	140
ML (kg/m^2.day)	8.9	7.4	3.4	-	14..0	11.5	125.5	30.9
R (%)	0	66	55	-	73	58	17	0
Cl^-(Inlet)								
[Cl^-] (mg/L)	264	368	374	-	429	950	1250	1000
ML (kg/m^2.day)	180.4	181.2	98.4	-	430.2	406.3	5227.2	221.2
Cl^- (Outlet)								
[Cl^-] (mg/L)	264	178	500	-	310	950	1300	770
ML (kg/m^2.day)	180.4	87.4	131.5	-	310.7	406.3	5436.3	170.3
R (%)	0	52	0	-	23	0	0	23
TP (Inlet)								
[TP] (mg/L)	0.02	0.5	0.03	-	0.1	0.2	0.3	0.2
ML (kg/m^2.day)	0.01	0.25	0.01	-	0.10	0.09	1.25	0.04
TP (Outlet)								
[TP] (mg/L)	0.02	0.05	0.05	-	0.04	0.06	0.06	0.5
ML (kg/m^2.day)	0.01	0.025	0.01	-	0.04	0.025	0.26	0.11
R (%)	0	90	0	-	61	71	78	0
TN (Inlet)								
[TN] (mg/L)	3	3	2	-	2	1	7	4
ML (kg/m^2.day)	2.1	1.5	0.8	-	2.0	0.4	29.3	1.0
TN (Outlet)								
[TN] (mg/L)	3	6	0.7	-	0.5	0.5	5	4
ML (kg/m^2.day)	2.1	2,9	0.2	-	0.5	0.2	20.1	1,0
R (%)	0	0	77	-	74	50	31	0

Electrical conductivity (ECw) is associated to dissolved ions content in waters, and is often used as a reference of salinity.

The values obtained from ECw, in both sampling points, were always high and indicate that this water body presents mild to moderate risk of salinity (Ce=700-3000 μS/cm) [15]. The treatment of FB seems to promote a slighted decrease of ECw against the inlet values during almost every month.

The parameter pH remains neutral. According [7] the macrophytes don't promote significant pH changes in medium.

The results related to the inflows and outflows loads for the parameter DO are presented in Fig.5.

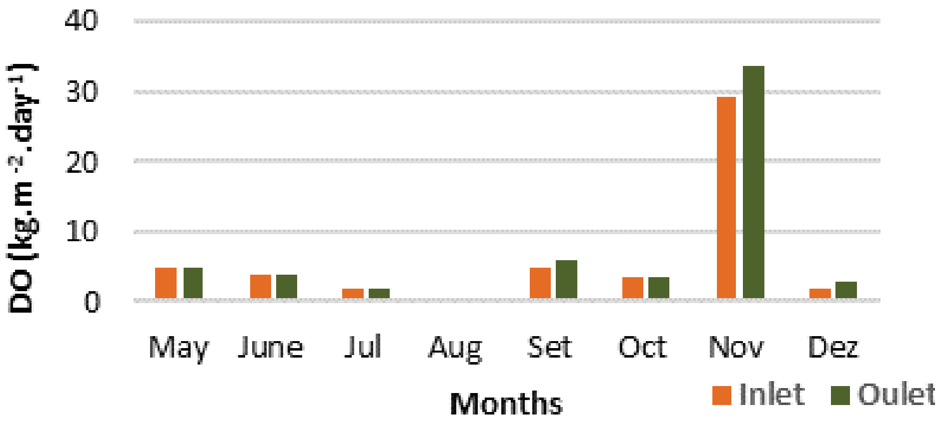

Figure 5: Representation of dissolved oxygen, DO, loads at inlet and outlet of FB obtained along the monitored period.

Dissolved oxygen (OD) is an important indicator of the ecological status of the bodies of water and in FBs interferes in some pollutant removal mechanisms [7].

The DO level depends largely on the mass loads applied. So, it can be observed that the OD loads were low with the exception in the month of November in which an unexpected increase occurred. This was due to the great rainfall that occurred in this month that promoted the great oxygenation of the water masses. In any case, it seems that exists a trend of a gradual increase in values of OD at the exit of FB compared to the inlet. In fact, *Vetiver zizinioides*, with their long roots can improve the levels of oxygen of water [11].

The inflow of organic matter, monitored by the parameter chemical organic demand, COD, (Fig.6) shows that it is always high (ranged between 8.8-150 kg.m^{2}.day^{-1}), with November month standing out remarkably due to the precipitation conditions recorded. The FB allowed significant load removals rates and the average of removal rate obtained was 44%.

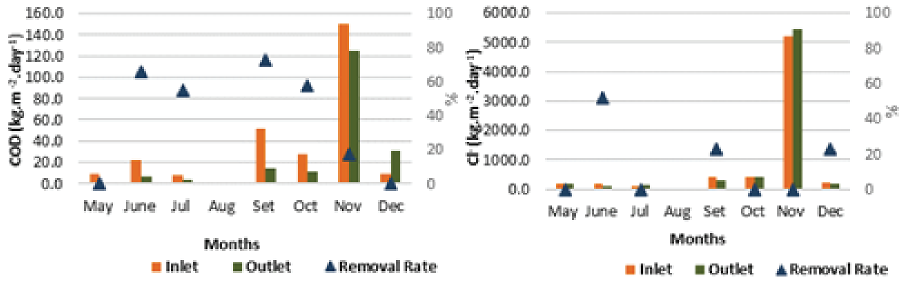

Figure 6: Representation of load rates of chemical organic matter, COD, and chlorides (Cl^-) at inlet and outlet of FB obtained along the monitored period and removal rates obtained.

The continuous use of waters with high salt content (e.g. Cl^-), can lead to soil salinization, making it impossible for agricultural use. Depending on the salt content, the salinity of the water may also affect the availability of water to crops, and may restrict its use [15]. The inflow loads of chlorides are very high (ranged between 98-5227 kg.m^2.day^{-1}), (Fig. 6), and the treatment by FB allowed an average removal rate of 15%.

The evolution of the nutrients phosphorus and nitrogen measured by total phosphorous parameter (TP) and total nitrogen (TN) during the monitoring period is presented in Fig.7.

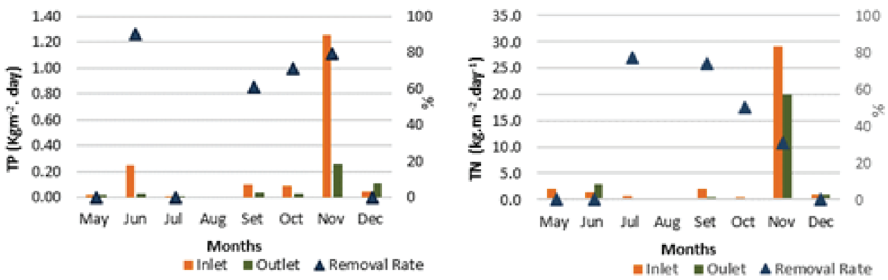

Figure 7: Representation of load rates of total phosphorus (TP) and total nitrogen (TN) at inlet and outlet of FB obtained along the monitorization period and removal rates obtained.

The low levels of these two macro nutrients are characteristic of Roxo stream [3]. Phosphorus constitutes an important limiting factor of eutrophication processes and even in low concentrations could foster the growth of algae, causing problems of eutrophication.

The inflows range of load rate were 0.01 -1.30 kg.m^2.day^{-1} and outflows were 0.01-0.26 kg.m^2.day^{-1}. The FB system showed capacity to remove this parameter, reaching the average of removal efficiency of 43%. This result is in line with those referred in [11] that indicates, for treatments with *Vetiver zizinioides*, high removal load rates.

For total nitrogen, (TN), the inflows are lows too and FB has showed a capacity to reach an average of removal efficiency of 33%.

4. Conclusions

The influent pollutants to the river are very closely related to the hydrological behaviour;

The main results obtained had shown that the average removal rates obtained were: (i)TN=33%; (ii)TP=43%; (iii) COD=44% and (iv) Cl-=15%;

Ecw presents always high values. The FB treatment promotes a slighted decrease of ECw, but not enough to avoid the slight-moderate risk of salinity;

DO level increased slightly and the pH remained neutral;

The capacity of removal of the treatment with FB seems to be not dependent of the concentration of the pollutants and

Although the study carried out was short-lived, the results suggest that the use of FB may constitute a long-term, ecological and economical system for the treatment of the Roxo stream water. Further work is needed to consolidate the results, to determining hydraulic and kinetic parameters relevant to the possible dissemination of this technology.

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