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The Efficient Role of Aquatic Plant (Water Hyacinth) in Treating Domestic Wastewater in Continuous System

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Abstract

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In this study, Water Hyacinth *(Eichhornia crassipes)* was used to treat domestic wastewater. Ten organic and inorganic parameters were monitored in three weeks for water purification. The six chemical, biological and physical parameters included Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH_3-N), Total Suspended Solids (TSS) and pH were compared with the Interim National Water Quality Standards, Malaysia River classification (INWQS) and Water Quality Index (WQI). Between 38% to 96% of reduction was observed and water quality has been improved from class III and IV to class II. Analyses for Electricity Conductivity (EC), Salinity, Total Dissolved Solids (TDS) and Ammonium (NH_4) were also investigated. In all parameters, removal efficiency was in range of 13-17th day (optimum 14th day) which was higher than 3 weeks except DO. It reveals the optimum growth rate of water hyacinth has great effect on waste water purification efficiency in continuous system and nutrient removal was successfully achieved.

Key words

Water Hyacinth; Phytoremediation; Wastewater treatment; Removal efficiency; Continuous System

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1. Introduction

Water pollution is not a recent environmental issue, as it had been synonymous with urbanization and modernization along with the dynamic growth in the World's population. In Malaysia, major source of fresh water contributes some 97% of the total water supply including domestic water consumption (Gasim *et al.* 2009). As discussed by (Ling 2010), water pollution is an alarming issue in Malaysia which significantly affects the sustainability of water resources and management. The large quantity of water resources available in the catchment, unfortunately does not guarantee adequate supply to all consumers due to the river pollution. In one of state of Malaysia (Johor), has identified 7,321 wastewater sources which is the highest wastewater sources in the country (1,790: 24.45%) (Afroz, Masud, and Akhtar 2014).

Bioremediation using phytoremediation technique is highly effective to treat different types of wastewater in which comparison to other techniques such as bioaugmentation and bioventing, where phytoremediation is more cost-effective and environmental friendly. Many different types of plants have been used variously in phytoremediation (Roongtanakiat, Tangruangkiat, and Meesat 2007; Baskar, Deeptha, and Rahman 2009; Dipu, Kumar, and Thanga 2011). Much interest in water hyacinth, water lettuce, and vetiver grass recently have indicated that the plants have potential for removal of a wide range of pollutants such as total suspended solids, dissolved solids, electrical conductivity, hardness, biochemical oxygen demand, chemical oxygen demand, nitrogen, phosphorus, heavy metals, and many other contaminants related to wastewater (Gupta, Roy, and Mahindrakar 2012; Rezania *et al*. 2015b).

By referring to the literature, water hyacinth showed greater uptake ability in comparison to other aquatic plants like water lettuce (Ismael *et al.* 2015), water morning glory (lean *et al.* 2014) and *azolla* (Anandha Varun and kalpana 2015). Other researchers discovered that water hyacinth is highly efficient in removing chemical oxygen demand (COD), biological oxygen demand (BOD) and total suspended solids (TSS) (Mitsch, Home, and Naim 2000; Guo *et al*. 2003).

Although, the rapid growth and quick spread of free floating aquatic macrophyte water hyacinth (*Eichhornia crassipes*) cause serious problems for navigation, irrigation, and power generation (Gopal 1987). Hence, Rezania *et al*. (2015a) suggested that water hyacinth is effective in phytoremediation due to its bioremediation capability to remove different types of pollutants from domestic and industrial wastewaters at its optimal growing time. Its growth from the contaminated water is mainly due to its absorption capacity and therefore it is universally used for the treatment of industrial wastewaters because of its higher productivity rate (Dhote and Dixit 2009).

This study is undertaken with the following objectives: 1) to determine the pollutant removal efficiency by water hyacinth based on the optimum growth rate and retention time (21 days) from discharged domestic wastewater to the River, 2) to compare the obtained results of (DO), BOD, COD, (NH_3-N), (TSS) and pH with existing standard of water quality in Malaysia named: the Interim National Water Quality Standards Malaysia River classification (INWQS) and Water Quality Index (WQI), 3) to evaluate the efficiency removal of Electricity Conductivity (EC), salinity, Total Dissolved Solids (TDS), and Ammonium (NH_4) from domestic waste water by water hyacinth.

2. Experimental setup

A pilot experimental system was established near Desa Bakti River, Universiti Teknologi Malaysia (UTM), Skudai, Johor Bahru, in a stabilization pond which is used for the domestic

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wastewater. The fabrication was made to evaluate the efficiency of water hyacinth for the uptake of existing nutrients in the domestic wastewater. The system was comprised of five tanks with the dimension of (48 × 90 × 90 cm) which was interconnected through PVC pipes and is equipped with electric pump which pumps wastewater directly from the stabilization pond. One kilogram of fresh water hyacinth (baby plant = 3 days old) was added into each tank separately (holding capacity 380 Liters) and operated with the wastewater flow of 0.125 L/s. The sampling of wastewater were from two points (inlet and outlet) and last for 21 days with 4 days of interval (6 times) and each test was conducted in triplicates.

3. Analyzed me

thods for wastewater parameters

All ten parameters were investigated in accordance to APHA standards (2005). BOD, COD, NH_3-N, TSS were measured by following methods: BOD_5 was determined using 5-Day BOD test method (APHA, 2005), COD by colorimetric method (5220-D) while Ammoniacal nitrogen (NH_3-N) by using Nessler method (Method: 8038). TSS was determined by using Method No. 2540D. EC, DO, pH and salinity, were measured by portable water meter meanwhile TDS was measured by a TDS meter. NH_4 was measured by “Acidimetric Method”, Method 418D

Two primary methods were employed to classify the river water quality: (WQI) (Table 1 and 2), and (INWQS) (Table 3). The INWQS defined six classes (I, IIA, IIB, III, IV and V) which are referred to the classification of rivers based on the descending order of water quality; Class I is considered the ‘best’ and Class V as the ‘worst’. Percentage removal was calculated based on the equation as below:

$$\frac{Inlet\ pollutant\ removal - outlet\ pollutant\ removal}{Inlet\ pollutant\ removal} \times 100 = \text{ Percent Reduction efficiency}\ .$$

(Akinbile *et al*. 2016)

4. Results and discussion

Table 4 shows the results obtained during 21 days of experiment with 4 days interval. Most of the parameters are in accordance to the (INWQS), which shows the effective treatment of wastewater.

Among the different forms of nitrogen, NH_3-N was found to be removed to a greater extend when compared to other forms of nitrogen (Chen *et al.* 2010). In this study, NH_3-N decreased drastically during 21 days of sampling. The erage of NH_3-N in water inlet was recorded as 0.42 ± 0.29 mg/L in the range of class III which was improved to 0.15 ± 0.20 mg/L in the range of class II. The changes showed 64% efficiency reduction in 3 weeks which was 96% of efficiency based on optimum growth in 2 weeks (Table 4). Akinbile and Yusoff (2012), showed that ammoniacal nitrogen in treatment system with aeration has a high percentage reduction by using water hyacinth (96.12%) compared to *Pistia stratiotes* (91.82%) on the third week. It resulted the addition of DO into the wastewater cause of depletion of CO2 due to photosynthetic activity which can induce a more aerobic environment for this reaction.

In a study by Munavalli and Saler (2009), water hyacinth was effective in COD removal from 30% to 45%. Based on the results in Table 4 and Figure 1, the COD decreased from 39 ± 10 mg/L in inlet to 23 ± 17.5 mg/L in outlet. This reduction improved water quality from class IV to class II by 41% removal efficiency. Meanwhile 78% reduction occurred during optimum growth rate of water hyacinth. Similarly, efficient treatment performance of COD (95%) and NH_3-N (85%) in treating domestic wastewater by water hyacinth was reported by (Rezania *et al.* 2014). Their results were specified in class IIA (INWQS) operating in stable mode with optimum growth rate of 18 days for water hyacinth.

The significant reduction of COD during the growth period is because the crop root mats were fully developed and the filtration capacity of the roots of suspended solids and the absorption of dissolved nutrients were increased (Ghaly, Kamal, and Mahmoud 2005). In a study by Rezania *et al. (*2013), 80% of COD, 75% of TN and 75% of TP were removed during the first week of the experiment. The experiment results showed a 40% of increase in plant biomass after 14 days which calculated as optimum growth of water hyacinth. Table 4 shows the obtained results based on INWQS. Most of the parameters from class III and IV improved to class II which is classified as good in quality of wastewater.

Table 4 and Figure 2 presents BOD removal was recorded 61% and the water quality index improved from class IV to class III from 9 ± 2 mg/L in inlet to 3.5 ± 2.4 mg/L in outlet. Significant BOD removal occurred based on optimum growth rate which was 92%. Costa *et al* (2000) was found 50% of COD, BOD, total nitrogen (TN), and total phosphorous (TP) removed in a hydraulic retention time of 20 days by water hyacinth. Similarly, Kumari and Tripathi (2014) indicated that mixed culture of *Eichhornia crassipes* and *Salvinia natans* was effective for removal of 84.5% of BOD, 83.2% of COD, 26.6% of nitrate-nitrogen, 53.0% of total Kjeldahl nitrogen (TKN) and 56.6% of phosphate-phosphorous (PO_4^{3}-P) in municipal wastewater. According to Vymazal (2007), plant root system acts as proper media for microbial growth providing oxygenic condition in the rhizosphere for microbial degradation of organic pollutants. It is the main reason for higher reduction of BOD and COD in the plant culture in comparison to other parameters.

DO increased by 47% and 23% during 3 weeks and 2 weeks sampling (optimum growth rate) respectively (Figure 2). This increment occurred due to change of DO in inlet from 2.1 ± 1.1 to 3.1±0.8 mg/L, in which improved from class IV to class III in terms of water quality index (Table 4). Similar findings were reported by Akinbile and Yusoff (2012) which DO increased from 3.83 mg/L to 5.23 mg/L by using *Eichhornia crassipes* for wastewater treatment with aeration within the first three weeks of experiment.

As demonstrated in Table 4, a small increase was observed in pH range from 6.95 ± 0.47 to 7.1 ± 0.68 where the water quality index has improved from class II to class I. For microbial activities, the optimum pH values for nitrification process may vary from 6.6 to 8.0. Akinbile and Yusoff (2012) showed in air circulation treatment system (aeration), the rate of pH reduction was higher in phytoremediation treatment with *Eichhornia crassipes* dropped to 4.45 when compared to the treatment by *Pistia stratiotes*, which reduced to 6.24 underlying the efficacy of water hyacinth over water lettuce.

As shown in Figure 3 and Table 4, TSS results showed significant reduction from 58 ± 13.4 mg/L in inlet to 38 ± 22.09 mg/L in outlet by 34% of overall reduction efficiency and 62% of optimum growth rate. Significant improvement occurred for TSS in water index from class III to class II. Loan, Phuong, and Anh (2014) showed that after 21 days, treatment efficiency of water hyacinth was higher than water morning glory (*Ipomoea aquatic*). It was in the range of 37.8% - 53.3% for TSS; 44.4% - 53.4% for COD; 56.7% - 61.4% for PO_4^{3-} and 26.8% - 32.6% for NH_4+, respectively. Valipour, Raman, and Ahn (2015) showed the efficiency of water hyacinth in the

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removal of (COD), (BOD), (TN), (TP), (TSS), (PO_4-P), and NH_3-N was higher than 70% at HRT of 14 hours.

3.1 Removal efficiency of other parameters

Six mentioned parameters showed the overall efficiency was less than reduction efficiency based on optimum growth rate. Similarly, the four factors of TDS, EC, Salinity and NH_4 showed water hyacinth was more effective during its optimum growth rate (Table 5). The obtained results for EC, salinity, TDS and NH_4 are shown in Figure 4.

As reported by Munavalli and Saler (2009), water hyacinth had no significant impact on reducing TDS in dairy wastewater which were shown in removal of inorganic cation and anions. Water hyacinth is not useful in contributing to the conductance yield of wastewater. Similarly, in this study, as showed in Table 5 and Figure 4, TDS reduced from 339 ± 9.5 mg/L to 324 ± 21.5 mg/L a 0.04% overall reduction efficiency and 11% optimum growth rate efficiency in 14 days. Higher TDS reduction (26%) was reported by Moyo, Chapungu, and Mudzengi (2013) in water hyacinth treatment system.

Table 5 shows EC reduced from 501 ± 21 µS/cm to 489 ± 26.3 µS/cm, which has only 0.02% overall efficiency and 11% based on optimum growth rate. Moyo, Chapungu, and Mudzengi (2013) showed that water hyacinth can reduce the electrical conductivity (25%) in polluted river (Shagashe River in Zimbabwe). High level of reduction happened due to high coverage of water surface (95%) by the water hyacinth.

High salinity is a major constraint on water hyacinth growth in coastal regions. In the South America (Orinoco River), water hyacinth survives salinities of 0.13-0.19% w/v and more than 0.34% or 3.41 g/l was fatal for *E. crassipes* (Olivares and Colonnello 2000), whereas in Nigeria salinities below 0.1% w/v have been shown to have no effect on water hyacinth growth (Kola 1988). In this research salinity declined from 0.66 ± 0.18 mg/L to 0.56 ± 0.2 mg/L which has 15% and 44% overall and optimum efficiency respectively. Consequently, low salinity level was not affected plant growth rate and not interfered the nutrient uptake by plant.

As studied by De Casabianca and Laugier (1995), plant yield (water hyacinth) was inversely linked to salinity and varied from 4.2 to 1.1 g d.wt m^{-2} day^{-1} for salinities (NaCl) ranging from 2 to 2.9 g 1 $^{1-}$. From 6 g 1 $^{1-}$ there was no production and plants started to decay and over 8 g 1 $^{1-}$ damage was immutable. As shown in Figure 4 and Table 5, NH_4 increased sharply from 3.22 ± 2.7 mg/L to 6.1 ± 2.5 mg/L, which imposed 89% overall efficiency followed by 95% optimum growth rate efficiency. It shows that the NH_4 is effective parameter in a particular period of water hyacinth growth rate. As discussed by De Casabianca and Laugier (1995), less availability of NH_4^+ in water hyacinth is due to significant conversion of NH_4^+ to NO^{3-} resulting in high amount of NH_4^+ in water. Similarly, Shah *et al.* (2010) proved that treatment performance by water hyacinth in 75% - 100% dye wastewater was in range of 38% to75% for TDS, EC, DO, BOD and COD.

4. Conclusion

Reduction in the most of the parameters like: DO, COD, BOD, (NH_3-N) and TSS by *Eichhornia crassipes* occurred which is due to successful phytoremediation treatment system. In this case, increase of CO_2 levels from photosynthesis and microbial activities have played key role. Based on the results, the water quality has been improved from class IV and III to class II which is due to 38% to 96% of reduction of parameters**.** In this study, highest reduction was in range of 13-17th day of the experiment but optimum was recorded on day 14 in continuous system.

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Meanwhile, Rezania *et al*. (2014) showed the optimum growth rate was in day 12 in batch system (without water flow). The comparison with Interim National Water Quality Standards, Malaysia River classification (INWQS) and Water Quality Index (WQI) classified the water as good condition. EC and salinity showed minor reduction by 11% which was 44% for TDS and great reduction for NH_4 by 95%. All the parameters showed that removal efficiency based on the optimum growth rate was higher than overall removal efficiency in 3 weeks. The results proved that water hyacinth is effective in domestic waste water treatment and the removal efficiency of all parameters was highly related to optimum plant growth rate in different condition. For future studies, the measurement of each unit of nutrient uptake by 1 kg of water hyacinth per 1 m^3 of wastewater is recommended.

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Table 1: Water Quality Index Classification

Parameter	Unit	CLASS				
		Class I	Class II	Class III	Class IV	Class V
Ammoniacal Nitrogen	mg/l	< 0.1	0.1 - 0.3	0.3 - 0.9	0.9 - 2.7	> 2.7
Chemical oxygen demand (COD)	mg/l	10	10 - 25	25 - 50	50 - 100	> 100
Biochemical Oxygen demand (BOD)	mg/l	< 1	1 - 3	3 - 6	6 - 12	> 12
Dissolved Oxygen	mg/l	> 7	5 - 7	3 - 5	1 -- 3	< 1
pH	-----	> 7	6 - 7	5 - 6	< 5	> 5
Total Suspended Solid	mg/l	< 25	25 - 50	50 - 150	150 - 300	> 300

Source: Department of Environment (DOE), 2006

Table 2: WQI-DOE Classification (DOE, 2006)

WQI-DOE Value	Condition
90-100	Very Good
75-90	Good
45-75	Average
20-45	Polluted
0-20	Very Polluted

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Table 3: Interim National River Water Quality Standards River Classification (INWQS)

Class	Uses
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species.
Class IIA	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species.
Class IIB	Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III -- Common of economic value and tolerant species; livestock drinking.
Class IV	Irrigation
Class V	None of the above.

Source: (Zainuddin 2010)

Table 4: Removal percentage of six parameters based on INWQS classification

Parameter	Unit	Results					
		Inlet (Control)	Water Class	Outlet (Average)	Class	Overall efficiency	Efficiency (optimum growth rate*) %
Ammoniacal Nitrogen	mg/L	0.42 ± 0.29	III	0.15 ± 0.20	II	64%	96%
Chemical oxygen demand (COD)	mg/L	39 ± 10	III	23 ± 17.5	II	41%	78%
Biochemical Oxygen demand (BOD)	mg/L	9 ± 2	IV	3.5 ± 2.4	III	61%	92%
**Dissolved Oxygen (DO)	mg/L	2.1 ± 1.1	IV	3.1 ± 0.8	III	47%	23%
**pH	-----	6.95 ± 0.47	II	7.1 ± 0.68	I	0.08%	13%
Total Suspended Solids	mg/L	58 ± 13.4	III	38 ± 22.09	II	34%	62%

Sampling period 21 days

*Optimum growth rate: 14 day (Calculated based on inlet and outlet in day 14)

** Increasing parameter

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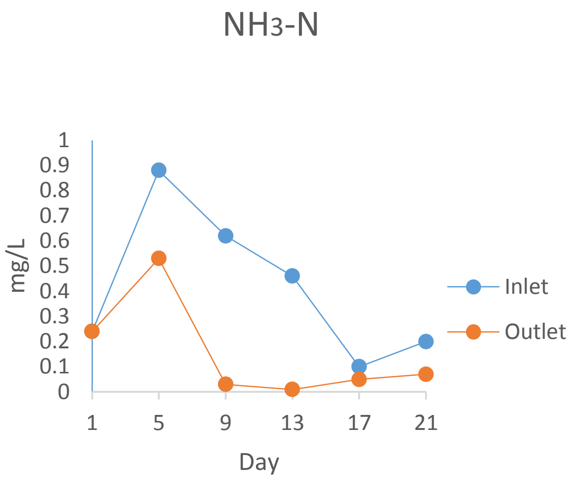
Table 5: Treatment efficiency by water hyacinth

Parameters	Unit	Inlet (Control)	Outlet (Average)	Overall Efficiency %	Efficiency (based on optimum growth rate) %
TDS	mg/L	339 ± 9.5	324 ± 21.5	0.04%	11%
EC	µS/cm*	501 ± 21	489 ± 26.3	0.02%	11%
Salinity	mg/L	0.66 ± 0.18	0.56 ± 0.2	15%	44%
**NH_4	mg/L	3.22 ± 2.7	6.1 ± 2.5	89%	95%

* 1 µS/cm is equivalent to about 0.64 mg of NaCl per kg of water

** Increasing parameter



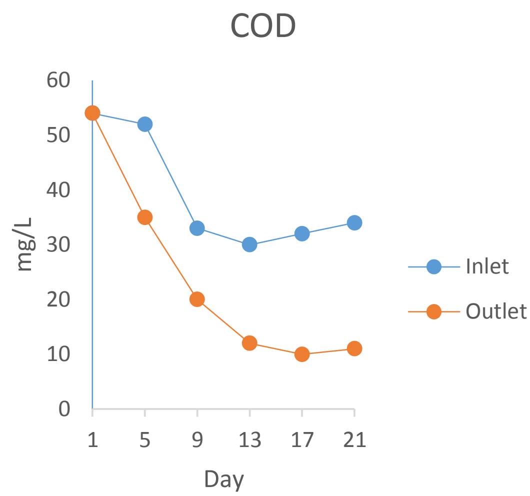


Figure 1: Results obtained for COD and NH_3-N based on INWQS classification

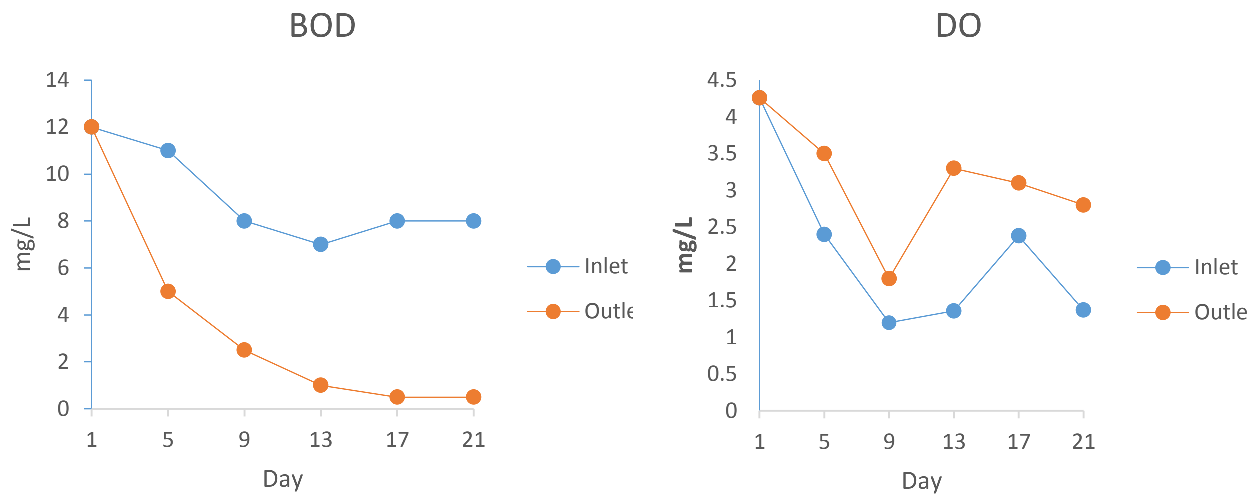


Figure 2: Results obtained for DO and BOD based on INWQS classification

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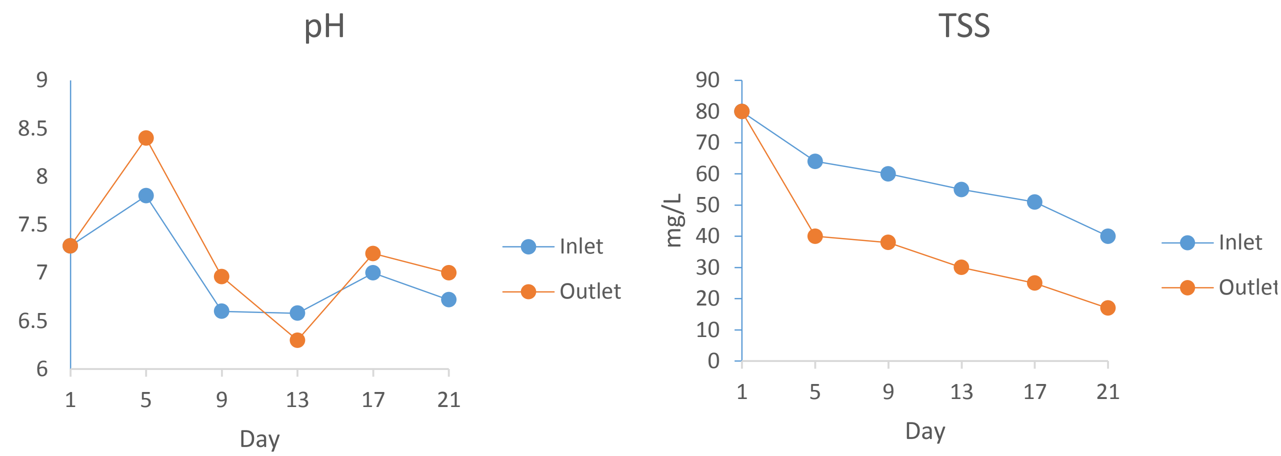

Figure 3: Results obtained for TSS and pH based on INWQS classification

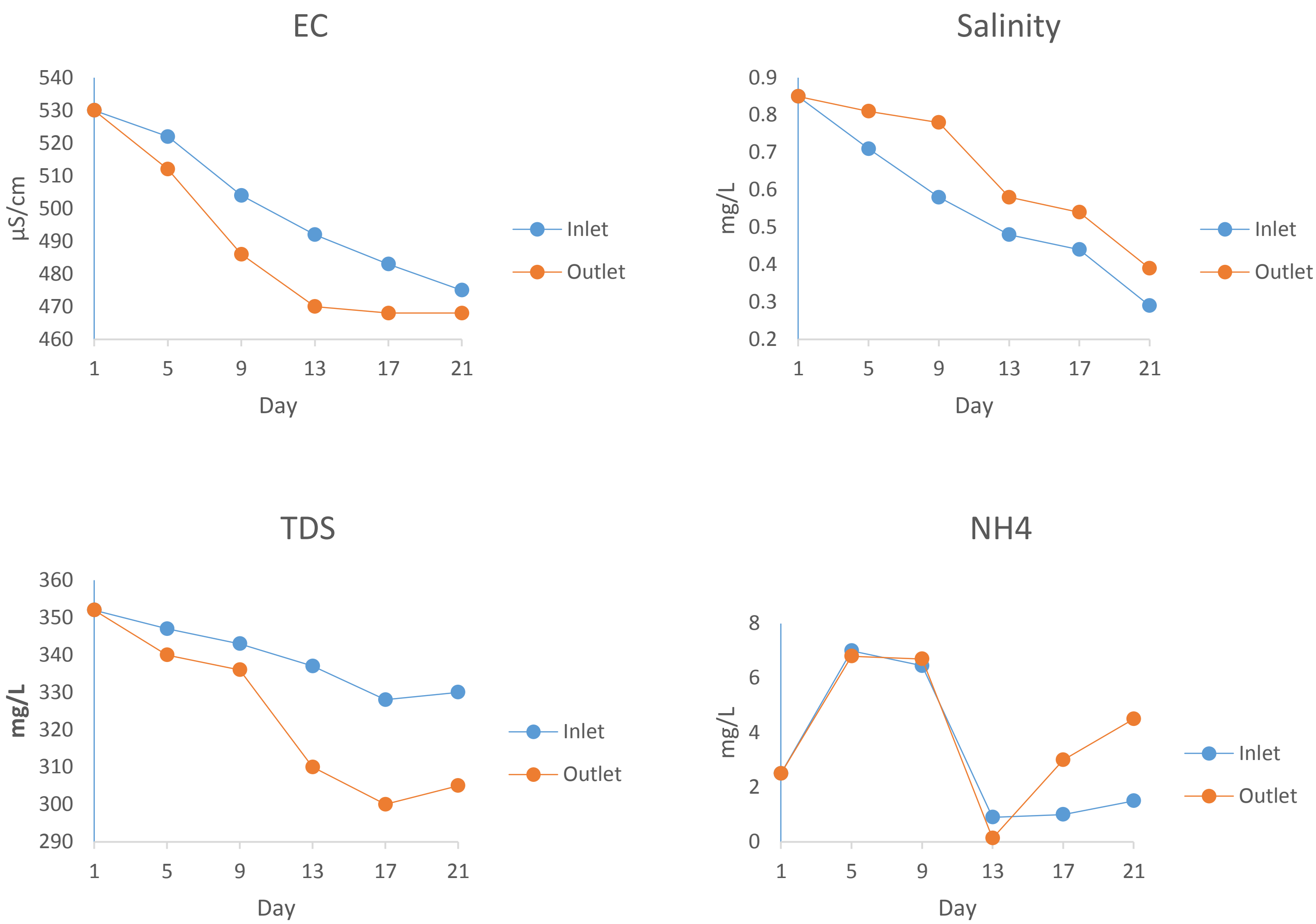

Figure 4: Results obtained for EC, Salinity, TDS and NH_4

