The Significant Variables of Effluent Constructed Wetlands Treated Domestic Wastewater by Statistical Tests

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Abstract. Domestic wastewater was treated by vertical flow constructed wetlands under different set-up designs and operation conditions. These conditions include different aggregate diameters, contact time, resting time, and chemical oxygen demand. The physical and chemical measurements of effluents were obtained. These measurements are Chemical oxygen demand; Biochemical oxygen demand; Ammonia-Nitrogen; Nitrate-Nitrogen; Ortho-Phosphate-Phosphorous; Suspended solids; Turbidity and pH. This research aims to find out which variables are significantly effective by using ANOVA with POST HOC tests. The results showed Chemical oxygen demand; Biochemical oxygen demand, Ammonia-Nitrogen, Nitrate-Nitrogen, Ortho-Phosphate-Phosphorous, and Suspended Solids have significantly effective (P<0.05).

1. Introduction

Many researchers reported that constructed wetlands have efficiency in treating many types of wastewater, such as textile wastewater [1-3], domestic wastewater [4,5], urban runoff, animal wastewater, and mine drainage [6-8]. Furthermore, many researchers investigated the significant differences in each design and operation variables for using constructed wetlands to treat wastewater [4,5,9]; They used different statistical methods such as the Mann-Whitney U test ANOVA. ANOVA analysis has been employed to explore the differences of such parameters water quality specifically [10,11]. An ANOVA test is a way to determine if experimental data are significant. It helps the researchers to reject the null hypothesis or accept the alternate theory [10].

Al-isawi et al. [9] worked on treated domestic wastewater contaminated by hydrocarbon by vertical flow constructed wetlands located in Newton Building of The University of Salford, Greater Manchester, UK, through the period between 26 June 2012 and 10 June 2014 (six seasons). This wetlands system consists of different design set-up parameters and operational variables, as shown in Table 1. They used the Mann-Whitney test to determine the significant differences for such water quality parameters for all wetlands filter. The results showed no significant difference in COD removal for Wetlands 1-6 and a significant difference in SS for all Wetlands. At the same time, there is no significant difference for all wetlands in the case of nutrients [8]. This research aims to investigate the water seasonal outflow water quality parameters by using statistical approaches.
Table 1 Comparison of the experimental vertical flow wetland set-up [9].

| Wetland filters | Aggregate diameter (mm) | Contact time (h) | Resting time (h) | Chemical oxygen demand (mg/l) |
|-----------------|-------------------------|-----------------|-----------------|------------------------------|
| Filter 1 and 2  | 20                      | 72              | 48              | 139.3                        |
| Filter 3 and 4  | 10                      | 72              | 48              | 139.3                        |
| Filter 5 and 6  | 10                      | 72              | 48              | 283.1                        |
| Filter 7        | 10                      | 36              | 48              | 139.3                        |
| Filter 8        | 10                      | 36              | 24              | 139.3                        |

2. Methodology

2.1. Samples collection

The vertical flow constructed wetlands used to treat domestic wastewater located within a greenhouse on the Newton Building roof, University of Salford, Greater Manchester, UK, as shown in Table 2 [9].

Table 2 Comparison of seasonal inflow and outflow water quality parameters (26 June 2012–10 June 2014) measured in mg/L [9].

| Parameters | Autumn 2012 | Winter 2012/2013 | Spring 2013 | Autumn 2013 | Winter 2013/2014 | Spring 2014 |
|------------|-------------|------------------|-------------|-------------|------------------|-------------|
| Inflow COD | 261.0       | 230.3            | 186.0       | 352.5       | 200.7            | 245.3       |
| BOD        | 108.6       | 118.0            | 221.2       | 167.1       | 104.3            | 105.8       |
| NH4-N      | 65.0        | 46.0             | 69.4        | 32.2        | 41.4             | 23.0        |
| NO3-N      | 6.7         | 12.0             | 5.2         | 0.8         | 5.7              | 1.6         |
| PO4-P      | 18.71       | 17.81            | 17.81       | 14.85       | 16.37            | 13.62       |
| SS         | 125.7       | 158.5            | 379.9       | 166.6       | 147.5            | 122.6       |
| Outflow COD | 57.1        | 64.5             | 82.5        | 240.5       | 72.0             | 65.6        |
| Filter 1 BOD | 42.7       | 23.0             | 54.2        | 28.3        | 18.3             | 26.3        |
| NH4-N      | 9.4         | 11.8             | 25.1        | 14.9        | 4.5              | 2.7         |
| NO3-N      | 1.2         | 4.0              | 0.7         | 0.4         | 0.5              | 0.42        |
| PO4-P      | 2.46        | 2.46             | 5.41        | 6.93        | 1.92             | 2.99        |
| SS         | 4.5         | 4.2              | 12.1        | 12.9        | 14.7             | 5.8         |
| Outflow COD | 57.1        | 64.5             | 82.5        | 86.4        | 24.9             | 19.8        |
| Filter 2 BOD | 42.7       | 23.0             | 54.2        | 18.3        | 9.4              | 12.7        |
| NH4-N      | 9.4         | 11.8             | 25.1        | 12.0        | 3.9              | 3.2         |
| NO3-N      | 1.2         | 4.0              | 0.7         | 3.6         | 2.9              | 2.8         |
| PO4-P      | 2.46        | 2.46             | 5.41        | 4.1         | 3.08             | 2.44        |
| SS         | 4.5         | 4.2              | 12.1        | 6.1         | 9.6              | 5.5         |
| Outflow COD | 51.6        | 59.4             | 69.2        | 181.7       | 83.1             | 72.5        |
| Filter 3 BOD | 35.6       | 19.4             | 54.4        | 33.6        | 22.3             | 17.9        |
| NH4-N      | 7.0         | 8.2              | 20.0        | 9.9         | 2.9              | 1.73        |
| NO3-N      | 2.0         | 5.1              | 3.0         | 0.37        | 0.42             | 0.42        |
| PO4-P      | 2.26        | 2.23             | 2.49        | 6.65        | 1.79             | 2.25        |
| SS         | 4.3         | 3.7              | 5.9         | 12.3        | 16.0             | 7.6         |
| Outflow COD | 51.6        | 59.4             | 69.2        | 81.4        | 81.6             | 13.59       |
| Filter 4 BOD | 35.6       | 19.4             | 54.4        | 18.9        | 8.0              | 8.8         |
| NH4-N      | 7.0         | 8.2              | 20.0        | 8.9         | 3.5              | 1.89        |
| NO3-N      | 2.0         | 5.1              | 3.0         | 4.3         | 3.2              | 1.2         |
| PO4-P      | 2.26        | 2.23             | 2.49        | 3.76        | 3.36             | 2.13        |
Table 2 continued

| Parameters | Autumn 2012 | Winter 2012/2013 | Spring 2013 | Autumn 2013 | Winter 2013/2014 | Spring 2014 |
|------------|-------------|------------------|-------------|-------------|------------------|-------------|
| Outflow    |             |                  |             |             |                  |             |
| COD        | 77.8        | 80.1             | 108.4       | 356.0       | 112.2            | 65.7        |
| BOD        | 49.0        | 26.5             | 76.4        | 37.9        | 19.5             | 10.8        |
| NH4-N      | 21.5        | 22.88            | 46.2        | 26.87       | 8.12             | 10.45       |
| NO3-N      | 5.9         | 7.1              | 6.9         | 0.7         | 1.0              | 1.4         |
| PO4-P      | 4.1         | 3.62             | 3.67        | 10.65       | 3.01             | 2.42        |
| SS         | 5.2         | 4.7              | 9.6         | 19.2        | 14.8             | 6.5         |
| Filter 5   |             |                  |             |             |                  |             |
| COD        | 77.8        | 80.1             | 108.4       | 107.6       | 29.5             | 19.2        |
| BOD        | 49.0        | 26.5             | 76.4        | 27.6        | 8.7              | 11.7        |
| NH4-N      | 21.5        | 22.88            | 46.2        | 23.0        | 11.7             | 3.2         |
| NO3-N      | 5.9         | 7.1              | 6.9         | 9.3         | 2.2              | 5.5         |
| PO4-P      | 4.1         | 3.62             | 3.67        | 8.12        | 3.07             | 2.75        |
| SS         | 5.2         | 4.7              | 9.6         | 10.0        | 7.8              | 7.1         |
| Filter 6   |             |                  |             |             |                  |             |
| COD        | 52.4        | 62.6             | 64.2        | 82.5        | 19.4             | 19.9        |
| BOD        | 40.4        | 19.4             | 28.1        | 18.1        | 10.1             | 12.7        |
| NH4-N      | 7.8         | 7.0              | 12.8        | 7.3         | 1.4              | 5.1         |
| NO3-N      | 4.3         | 6.3              | 15.8        | 2.5         | 4.2              | 3.1         |
| PO4-P      | 2.89        | 2.71             | 2.73        | 5.26        | 2.86             | 2.05        |
| SS         | 6.3         | 4.8              | 5.6         | 5.2         | 1.0              | 1.56        |
| Filter 7   |             |                  |             |             |                  |             |
| COD        | 60.0        | 62.7             | 75.0        | 174.4       | 18.85            | 40.0        |
| BOD        | 39.6        | 17.8             | 26.9        | 19.6        | 9.8              | 13.7        |
| NH4-N      | 9.4         | 8.6              | 23.1        | 6.5         | 1.2              | 1.6         |
| NO3-N      | 4.9         | 5.4              | 9.0         | 5.6         | 3.1              | 3.1         |
| PO4-P      | 3.08        | 2.72             | 2.83        | 4.74        | 3.32             | 2.47        |
| SS         | 5.0         | 4.8              | 7.9         | 4.5         | 1.1              | 3.9         |

1Chemical oxygen demand, 2Biochemical oxygen demand, 3Ammonia-Nitrogen, 4Nitrate-Nitrogen, 5Ortho-Phosphate-Phosphorous, 6Suspended solids

2.2. Data analysis
In this research, ANOVA analysis was used to test the differences in water seasonal outflow water quality parameters among general seasons. Also, the Post Hoc approach was utilized to investigate the differences of each parameter between every two seasons to get more in-depth insight. Both analyses were performed using the SPSS package [12-14].

3. Results and discussions
Table 3 summarizes the ANOVA tables of all parameters studied in this research (COD, BOD, NH4-N, NO3-N, PO4-P, and SS). This table reports only the P-Value of each table, where each parameter has its ANOVA Table. From Table 3, it is clear that there is a significant difference (p<0.05) in average levels of all parameters among seasons (Autumn 2012, Winter 2012/2013, Spring 2013, Autumn 2013, Winter 2013/2014, and Spring 2014), which are demonstrated in Table 2.

Table 3 P-Value for each parameter, related to Table 2

| Parameters | P-Value |
|------------|---------|
| COD        | 0.000   |
| BOD        | 0.000   |
| NH4-N      | 0.000   |
| NO3-N      | 0.044   |
| PO4-P      | 0.000   |
| SS         | 0.005   |
After revealing significant differences among seasons for all parameters, it is better to use Post Hoc tests to get more detailed results. Tables 4 – 6 represent those results. Table 4 shows significant differences in COD levels (P <0.05) between season 4 and 1,2,3,5 and 6, whereas the differences are not significant between other seasons. On the other hand, BOD levels have shown significant differences (P <0.05) between season 1 and all different seasons. Similarly, season 2 has shown the same results against all other seasons.

Table 4 P-value (from Post Hoc test) for the COD and BOD

| Season | COD       | BOD       |
|--------|-----------|-----------|
|        | 1         | 2         | 3         | 4         | 5         | 6         | 1         | 2         | 3         | 4         | 5         | 6         |
| 1      | 0.780     | 0.330     | 0.000     | 0.80      | 0.34      | 0.000     | 0.018     | 0.001     | 0.000     | 0.000     | 0.000     | 0.000     |
| 2      | 0.481     | 0.000     | 0.608     | 0.228     | 0.000     | 0.460     | 0.067     | 0.130     | 0.000     | 0.000     | 0.000     | 0.000     |
| 3      | 0.001     | 0.227     | 0.600     | 0.000     | 0.012     | 0.027     | 0.484     | 0.739     | 0.000     | 0.000     | 0.000     | 0.000     |
| 4      | 0.000     | 0.000     | 0.000     | 0.016     | 0.008     | 0.014     | 0.015     | 0.015     | 0.408     | 0.429     | 0.970     | 0.072     |
| 5      | 0.799     | 0.484     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |
| 6      |           |           |           |           |           |           |           |           |           |           |           |           |

Table 5 shows that, for the NH4-N and NO3-N variables, there are significant differences (P <0.05) between several seasons, such as season 3 and all other seasons, etc., while there are no significant differences (P >0.05) between different seasons. Furthermore, Table 6 has shown some significant differences (P <0.05) such as season 4, in the case of PO4-P, and all other seasons. In the case of SS, the results showed some significant differences (P <0.05) such as season 3 and seasons 1 and 2, while there are no significant differences (P >0.05) between season 3 and seasons 4, 5 and 6. At the same time, there are no significant differences (P >0.05) of PO4-P and SS levels between seasons.

Table 5 P-Value (from Post Hoc test) for the NH4-N and NO3-N

| season | NH4-N     | NO3-N     |
|--------|-----------|-----------|
|        | 1         | 2         | 3         | 4         | 5         | 6         | 1         | 2         | 3         | 4         | 5         | 6         |
| 1      | 0.773     | 0.000     | 0.572     | 0.059     | 0.34      | 0.139     | 0.100     | 0.955     | 0.377     | 0.397     | 0.906     | 0.203     |
| 2      | 0.000     | 0.782     | 0.031     | 0.017     | 0.865     | 0.125     | 0.021     | 0.023     | 0.484     | 0.000     | 0.000     | 0.000     |
| 3      | 0.000     | 0.000     | 0.000     | 0.016     | 0.008     | 0.090     | 0.014     | 0.015     | 0.000     | 0.799     | 0.484     | 0.000     |
| 4      | 0.016     | 0.008     | 0.189     | 0.057     | 0.488     | 0.691     | 0.072     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |
| 5      | 0.799     | 0.484     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |
| 6      |           |           |           |           |           |           |           |           |           |           |           |           |

Table 6 P-Value for (from Post Hoc test) the PO4-P and SS

| season | PO4-P     | SS        |
|--------|-----------|-----------|
|        | 1         | 2         | 3         | 4         | 5         | 6         | 1         | 2         | 3         | 4         | 5         | 6         |
| 1      | 0.906     | 0.203     | 0.000     | 0.966     | 0.512     | 0.745     | 0.038     | 0.007     | 0.015     | 0.769     | 0.540     | 0.030     |
| 2      | 0.165     | 0.000     | 0.939     | 0.591     | 0.000     | 0.018     | 0.000     | 0.006     | 0.536     | 0.000     | 0.000     | 0.000     |
| 3      | 0.000     | 0.189     | 0.057     | 0.488     | 0.691     | 0.072     | 0.767     | 0.015     | 0.030     | 0.000     | 0.000     | 0.000     |
| 4      | 0.000     | 0.000     | 0.000     | 0.767     | 0.015     | 0.030     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |
| 5      | 0.540     | 0.030     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |
| 6      |           |           |           |           |           |           |           |           |           |           |           |           |
4. Conclusions

This paper has presented a methodology using the ANOVA and POST Hoc test to determine which physical and chemical measurements are significantly useful. The results showed Chemical oxygen demand; Biochemical oxygen demand, Ammonia-Nitrogen, Nitrate-Nitrogen, Ortho-Phosphate-Phosphorous, and Suspended Solids have significantly effective (P<0.05).

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