| | | | | | |
|---|---|---|---|---|---|
| 6 | 428.00 | 170.26 | 31.03 | 1.49 | 7.27 |
| 12 | 247.62 | 176.69 | 28.08 | 0.08 | 2.80 |
| 18 | 436.00 | 121.00 | 21.48 | 0.82 | 4.49 |
| 95% range | 157.49 – 583.59 | 95.05-216.92 | 17.08 – 36.64 | -0.61-02.21 | 0.34-9.37 |

# CHAPTER 4

# Results and Discussion

This chapter presents results and discussion obtained from this study. This work assesses the performance of the pilot scale wastewater treatment system employing an activated sludge process followed by a floating aquatic macrophytes constructed wetlands for cafeteria wastewater treatment at three difference HRTs (6,12 and 18 hours).

## 4.1 Characteristics of Raw Wastewater

The wastewater was partially transparent, redolent and the quality was fluctuating with discharge rate from cafeteria as shown in Table 4.1.

Table 4.1 Characteristic of raw wastewater discharge from cafeteria

| **Parameter** | **Range** |
|---|---|
| Temperature ($^0$ C) | 26.0 - 29.6 |
| Electrical Conductivity (µs/cm) | 337 - 548 |
| Total dissolved Solid (mg/L) | 168 - 282 |
| pH | 4.99 - 7.05 |
| Total Suspended Solid (mg/L) | 76.7 - 210 |
| Biological Oxygen Demand (mg/L) | 240 - 496 |

| | | | |
|---|---|---|---|
| Nitrate Nitrogen (mg/L) | 21.73 | - | 44.25 |
| Ammonium Nitrogen (mg/L) | 0.208 | - | 2.08 |
| Ortho –Phosphate (mg/L) | 2.74 | - | 8.71 |

## 4.2 Effect of HRT on Total Suspended Solid Removal Efficiency

Total suspended solid is the dry-weight of particles trapped by a filter. TSS concentration fluctuations under different HRTs are shown in Figure 4.2 (a), (b) and (c). Average TSS concentrations at HRT of 6h resulted 184.3 ±49.2, 140.6±46.3, and 98.8±54.2 mg/L in inlet, outlet of AS system and outlet of FAMCW respectively (Table 4.2). Average TSS concentrations of overall reactor, AS system and FMACW operated at the HRT of 12h were 191.6 ±38.1, 96.0±180.8, and 34.5±108.5 mg/L respectively whereas 126.7±79.9, 19.4±8.2, and 11.2± 14.9 mg/L respectively in reactors operated at the HRT of 18h.

The TSS removal efficiency under different treatment steps are shown in Figure 4.2 (d), (e) and (f). Average TSS removal efficiencies at HRT of 6h resulted in 23.7± 14.3, 30.2± 24.6, and 46.4±27.3 % in inlet, outlet of AS system and outlet of FAMCW respectively (Table 4.2). Average TSS removal efficiencies at AS system were resulted in 23.7± 14.3, 48.3±102.9, and 83.3±21.6 % in HRTs of 6, 12, and 18 h respectively while 30.2± 24.6, 59.2±50.1, and 40.7±64.8 % of removal efficiencies were recorded at FAMCW in HRTs of 6, 12, and 18 h respectively (Table 4.2).

Table 4.2 Average [± (S.D.)($t_{\alpha/2\upsilon}$)] TSS concentrations and removal efficiencies at HRT of 6, 12, and 18 h in different treatment steps

| HRT | Average TSS concentration (mg/L) | | | Average TSS removal efficiency (%) | | |
|---|---|---|---|---|---|---|
| | Inlet | Outlet AS | Outlet FAMCW | AS system | FAMCW | Overall |
| HRT 06 | 184.3 ±49.2 | 140.6±46.3 | 98.8±54.2 | 23.7± 14.3 | 30.2± 24.6 | 46.4±27.3 |
| HRT 12 | 191.6 ±38.1 | 96.0±180.8 | 34.5±108.5 | 48.3±102.9 | 59.2±50.1 | 81.0±64.1 |
| HRT 18 | 126.7±79.9 | 19.4±8.2 | 11.2± 14.9 | 83.3±21.6 | 40.7±64.8 | 91.9±10.7 |

The TSS removal efficiencies under different HRTs are shown in Figure 4.1. Average TSS removal efficiency at the HRT of 18 h (91.9±10.7 %) was significantly higher ($p = 0.007$) than that at the HRT of 6 h (46.4±27.3 %) in overall reactor, and furthermore, the TSS removal efficiency at the HRT of 18 h (83.3±21.6 %) was significantly higher ($p = 0.021$) than that at the HRT of 6 h (23.7±14.3 %) in AS system.

There was no significant difference between the reactor operated at HRTs of 12h and 6h ($p > 0.05$) and 18 h and 12 h ($p > 0.05$) in overall reactor, AS system and FAMCW system.

Results confirmed that HRT of 18 h at AS system provides sufficient time to settle down the particles in secondary clarifier and this assisted that higher TSS removal efficiency in higher HRTs. Lower HRTs alike HRT of 6 h do not provide good enough time to settled down time to settle down the suspended solid matter contain in wastewater. Ling & Lo, (2001) studied on effects of hydraulic retention time and loading rate on brewery wastewater treatment using sequencing batch reactors and found that TSS removal efficiencies increased with HRT.

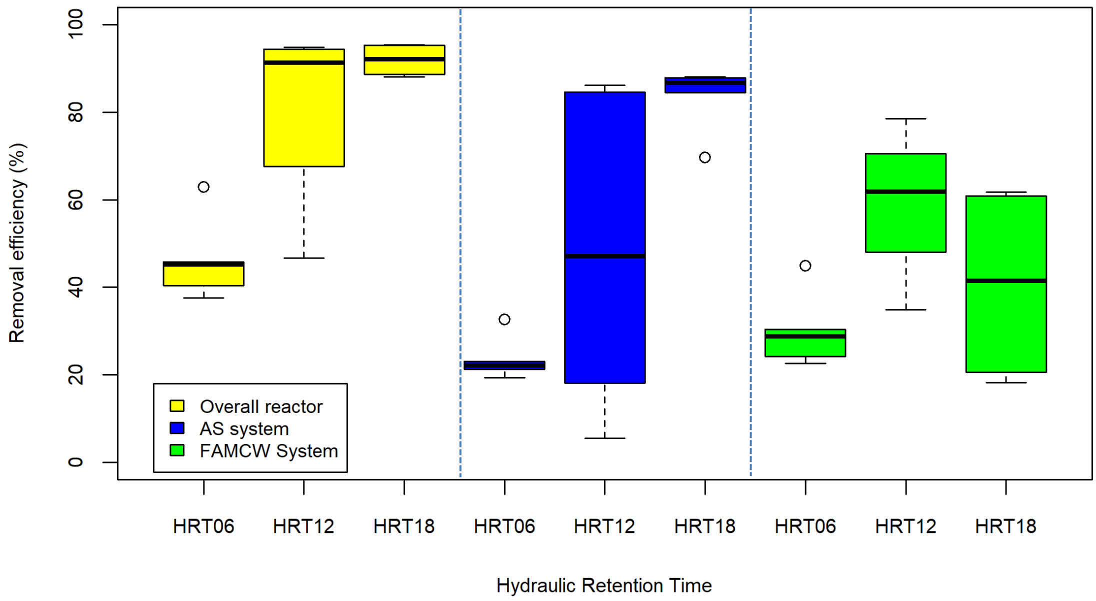
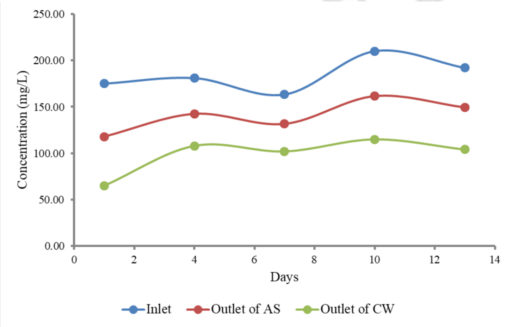
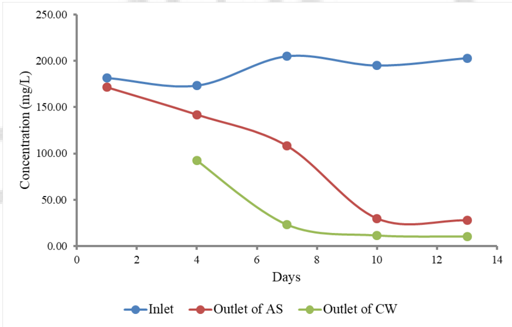


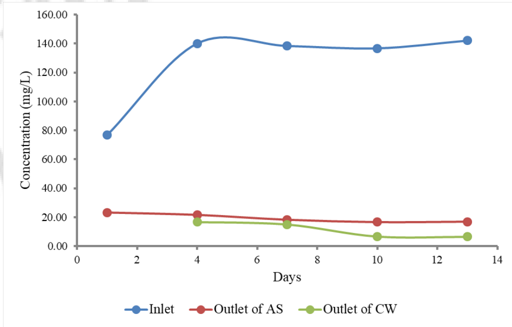

Figure 4.1 TSS removal efficiencies of reactor under HRT of 6, 12, and 18h



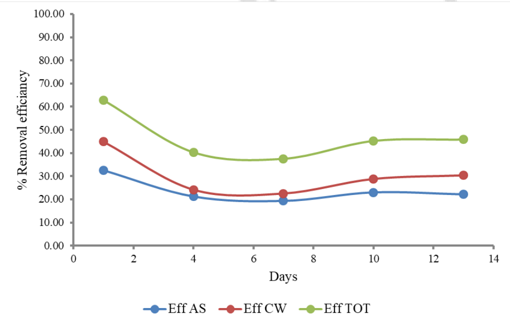

(a) Concentration variation – HRT 06



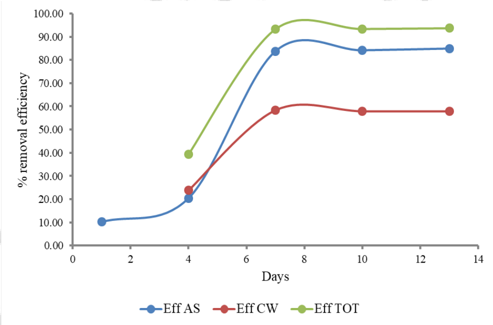

(b) Concentration variation – HRT 12



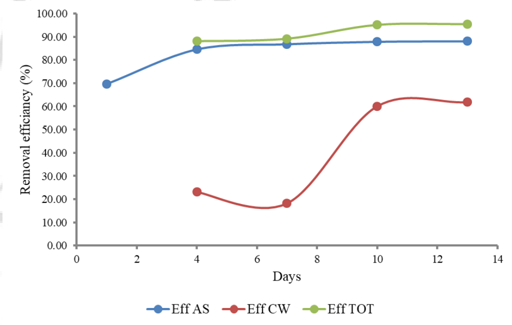

(c) Concentration variation – HRT 18




(d) Removal efficiency – HRT 06




(e) Removal efficiency – HRT 12




(f) Removal efficiency – HRT 18

Figure 4.2 Concentration variation and removal efficiency of total suspended solid

## 4.3 Effect of HRT on Biological Oxygen Demand Removal Efficiency

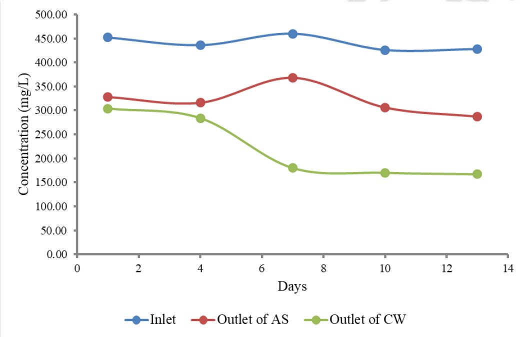
Biological oxygen demand (BOD) is the measured amount of oxygen consumed by aerobic biological organisms in the oxidation process of organic matter present in the wastewater. BOD concentration fluctuations under different HRTs are shown in Figure 4.3 (a), (b) and (c). Average BOD concentrations at HRT of 6h were resulted 440.4±41.6, 321.0±84.0, and 221.0±186.5 mg/L in inlet, outlet of AS system and outlet of FAMCW respectively while 269.2±69.5, 119.6±302.5 and 53.0±198.1 mg/L of average BOD concentrations at HRT of 12h were detected in inlet, outlet of AS system, and outlet of FAMCW respectively. Average BOD concentrations of the reactors operated at HRT of 18h were resulted 464.0±61.3, 55.6±123.6, and 20.0±7.9 mg/L in inlet, outlet of AS system, and outlet of FAMCW respectively (Table 4.3).

The BOD removal efficiency under different treatment steps are shown in Figure 4.3 (d), (e) and (f). Average BOD removal efficiencies at overall reactor were resulted in 49.9±40.9, 79.9±75.0, and 95.6±1.7 % in HRTs of 6, 12, and 18 h respectively. Average BOD removal efficiencies at AS system were detected 27.2±14.3, 56.7±105.4, and 88.3±24.8 % (Table 4.3) in HRTs of 6, 12, and 18 h respectively while 31.0±57.2 ,49.5±47.5, and 42.7±16.5 % of removal efficiencies were recorded at FAMCW in HRTs of 6, 12, and 18 h respectively (Table 4.3). Maximum BOD removal efficiencies at overall reactor were recorded in 95.9, 93.7, and 61.0 % (Table B.3) in HRTs of 18, 12, and 06 h respectively.

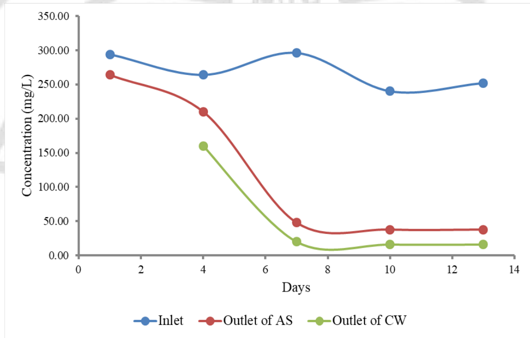
Table 4.3 Average [± (S.D.)($t_{\alpha/2\upsilon}$)] BOD concentrations and removal efficiencies at HRT of 6, 12, and 18 h in different treatment steps

| HRT | Average BOD concentration (mg/L) | | | Average BOD removal efficiency (%) | | |
|---|---|---|---|---|---|---|
| | Inlet | Outlet AS | Outlet FAMCW | AS system | FAMCW | Overall |
| HRT 06 | 440.4±41.6 | 321.0±84.0 | 221.0±186.5 | 27.2±14.3 | 31.0±57.2 | 49.9±40.9 |

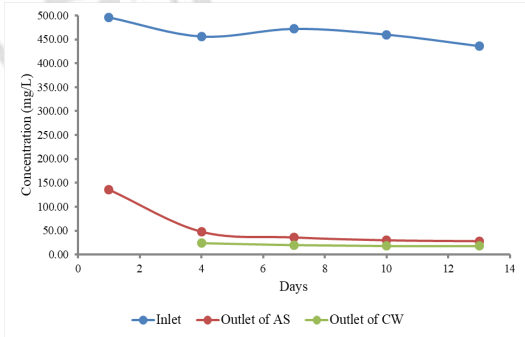
| | | | | | | |
|---|---|---|---|---|---|---|
| HRT 12 | 269.2±69.5 | 119.6±302.5 | 53.0±198.1 | 56.7±105.4 | 49.5±47.5 | 79.9±75.0 |
| HRT 18 | 464.0±61.3 | 55.6±126.6 | 20.0±7.9 | 88.3±24.8 | 42.7±16.5 | 95.6±1.7 |



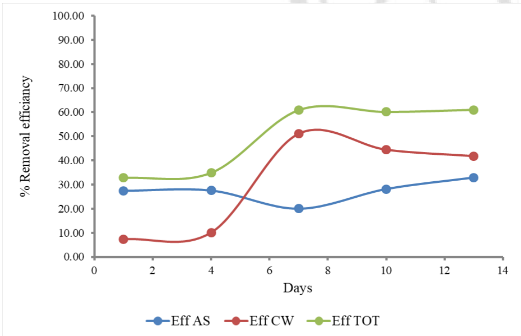

(a) Concentration variation – HRT 06



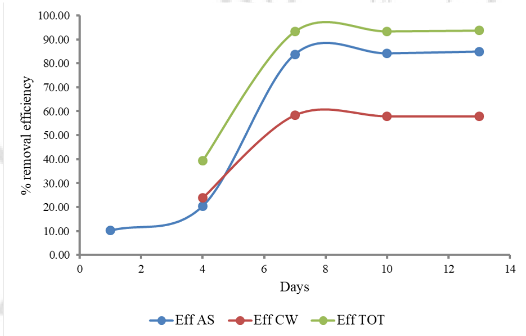

(b) Concentration variation – HRT 12



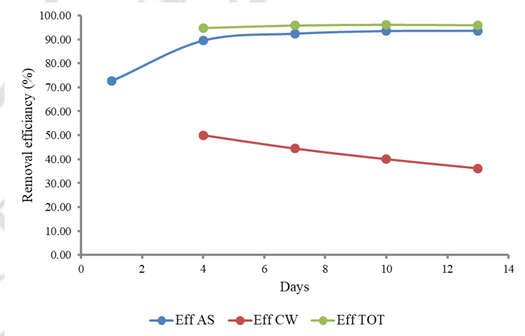

(c) Concentration variation – HRT 18




(d) Removal efficiency – HRT 06




(e) Removal efficiency – HRT 12

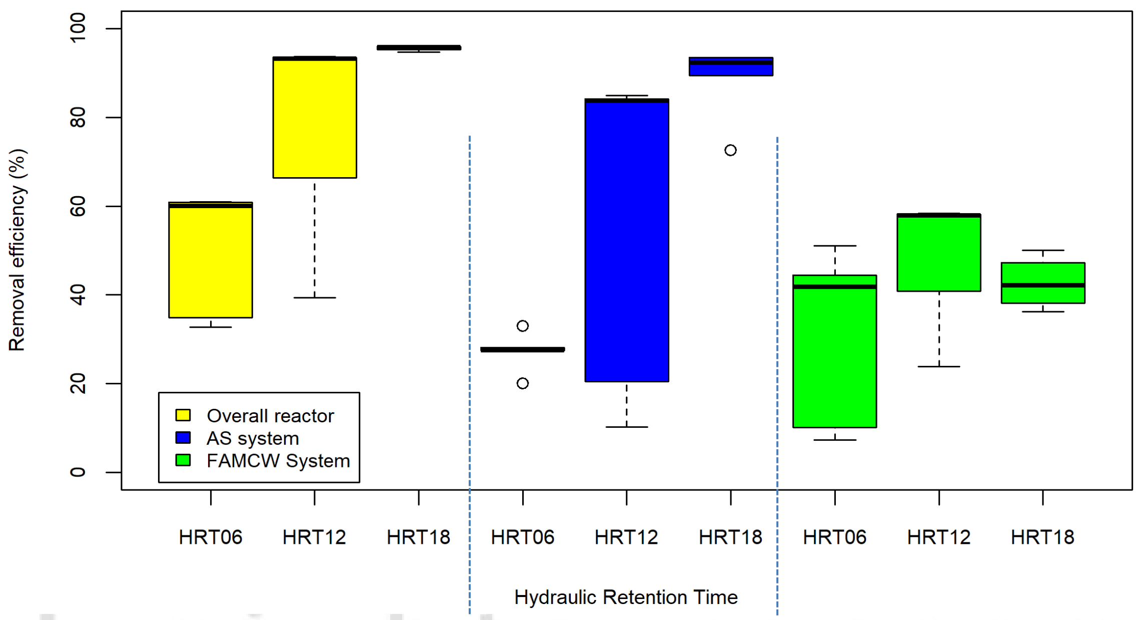



(f) Removal efficiency – HRT 18

Figure 4.3 Concentration variation and removal efficiency of biological oxygen demand

The BOD removal efficiencies under different HRTs are shown in Figure 4.4. The average BOD removal efficiency at the HRT of 18 h (95.6±1.7 %) was significantly higher ($p<0.05$) than that at the HRT of 6 h (49.9±40.9 %) in overall reactor, and furthermore, the BOD removal efficiency at the HRT of 18 h (88.3±24.8 %) was significantly higher ($p<0.05$) than that at the HRT of 6 h (27.2±14.3 %) in AS system. There was no significant difference between the reactor operated at HRTs of 12 h and 6 h ($p > 0.05$) and 18 h and 12 h ($p > 0.05$) in each treatment steps.

It was observed that the greatest portion of the BOD was removed in the AS system under HRT of 18 h (88.3 %) while FAMCW removed (42.7 %). Higher HRTs provide sufficient time for microorganisms to degrade the organic matter contain in wastewater than lower HRTs and it results in high BOD removal efficiency at HRT of 18 h. Previous study illustrated that some bacteria were washed out of up flow anaerobic sludge blanket reactor while the HRT was less




than 12 h, and the BOD removal decreased with the decrease in HRT (Wang et al., 2015). Results revealed that the shorter HRTs operated the lower removal efficiencies of BOD achieved. It also confirmed that FAMCW not effectively remove the BOD compared to AS system.

Figure 4.4 BOD removal efficiencies of reactor under HRT of 6, 12, and 18h

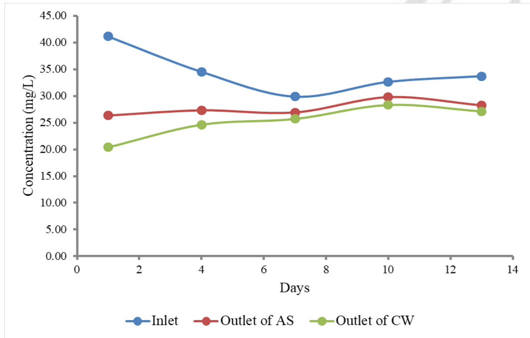
**4.4 Effect of HRT on Nitrate Nitrogen Removal Efficiency**

Biological nitrogen removal is typically achieved by autotrophic nitrification under aerobic conditions followed by heterotrophic denitrification under anoxic conditions (Metcalf et al., 2003), (Grady et al., 2011). Nitrate nitrogen ($NO_3$-N) concentration fluctuations under different HRTs are shown in Figure 4.5 (a), (b) and (c). Average $NO_3$ - N concentrations at HRT of 6h were resulted 34.4±11.6, 27.7±3.7, and 25.2±8.5 mg/L in inlet, outlet of AS system and outlet of FAMCW respectively while 31.7±19.7, 19.5±17.8, and 13.8±10.4 mg/L of average $NO_3^-$ - N concentrations ware detected in inlet, outlet of AS system, and outlet of FAMCW respectively under system operated at HRT of 12h. Averages $NO_3$-N concentrations of the reactors operate at HRT of 18h were resulted 23.3±3.7, 9.6±1.2, and 5.5±4.0 mg/L in inlet, outlet of AS system, and outlet of FAMCW respectively (Table 4.4).

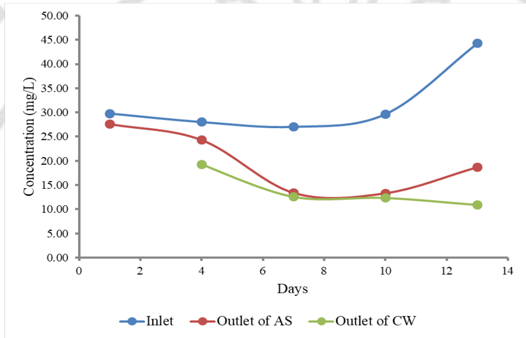
The $NO_3$-N removal efficiency under different treatment steps are shown in Figure 4.3 (d), (e) and (f). Average $NO_3$ - N removal efficiencies at HRT of 6h resulted in 18.3±30.5, 9.2±21.8, and 25.2±42.8 % in inlet, outlet of AS system and outlet of FAMCW respectively. Average $NO_3$-N removal efficiencies at AS system were resulted in 18.3±30.5, 36.±67.7, 58.9±1.4% (Table 4.4) in HRTs of 6, 12, and 18 h respectively while 9.2±21.8, 19.0±45.9, and 42.1±43.5% of removal efficiencies were recorded at FAMCW in HRTs of 6, 12, and 18 h respectively (Table 4.4). Maximum $NO_3$-N removal efficiencies at overall reactor was recorded in 82.9, 75.4, and 50.4 % in HRTs of 18, 12, and 6 h respectively (Table B.4).

Table 4.4 Average [± (S.D.)($t_{\alpha/2\upsilon}$)] $NO_3$ - N concentrations and removal efficiencies at HRT of 6, 12, and 18 h in different treatment steps

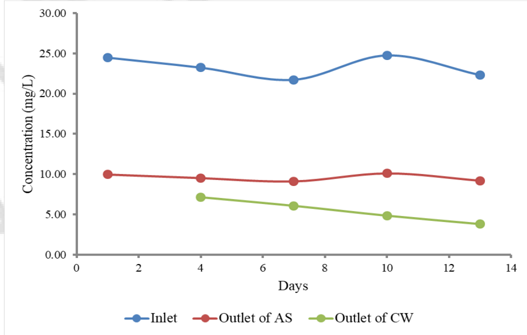
| | Average $NO_3$ - N concentration (mg/L) | | | Average $NO_3$ - N removal efficiency (%) | | |
|---|---|---|---|---|---|---|
| HRT | Inlet | Outlet AS | Outlet FAMCW | AS system | FAMCW | Overall |
| HRT 06 | 34.4±11.6 | 27.7±3.7 | 25.2±8.5 | 18.3±30.5 | 9.2±21.8 | 25.2±42.8 |
| HRT 12 | 31.7±19.7 | 19.5±17.8 | 13.8±10.4 | 36.8±67.7 | 19.0±45.9 | 54.6±50.5 |
| HRT 18 | 23.3±3.7 | 9.6±1.2 | 5.5±4.0 | 58.9±1.4 | 42.1±43.5 | 76.1±18.1 |



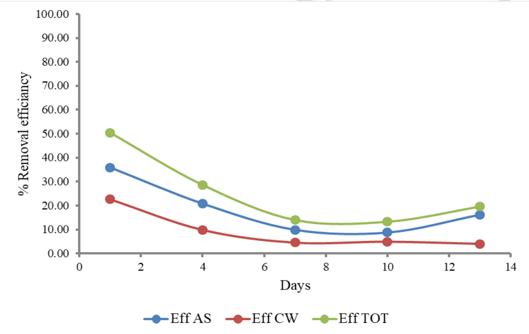

(a) Concentration variation – HRT 06



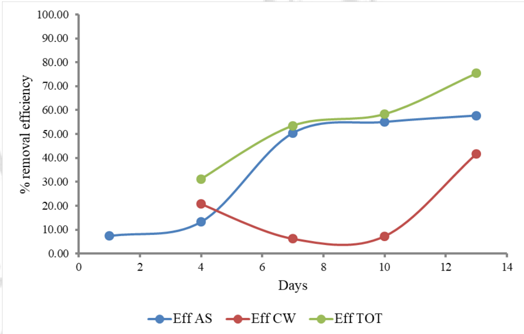

(b) Concentration variation – HRT 12



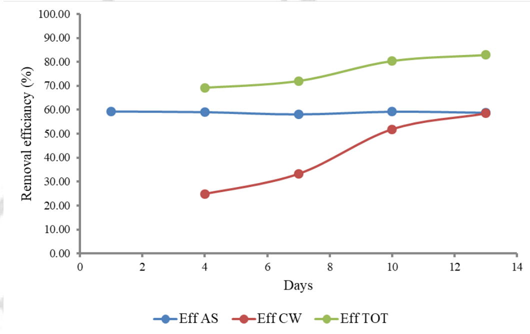

(c) Concentration variation – HRT 18




(d) Removal efficiency – HRT 06




(e) Removal efficiency – HRT 12




(f) Removal efficiency – HRT 18

Figure 4.5 Concentration variation and removal efficiency of nitrate nitrogen

The $NO_3$-N removal efficiencies under different HRTs are shown in Figure 4.6. Average $NO_3$-N removal efficiency at HRT of 06 h (25.2±42.8%) was significantly lower (p =0.008) than that at the HRT of 18 h (76.1±18.1%) in overall reactor, and moreover, average $NO_3$-N removal efficiency at the HRT of 06 h (18.3±30.5%) was significantly lower (p =0.008) than that at the HRT of 18 h (58.9±1.4%) in AS system. Similar result was shown in the FAMCW, average $NO_3$-N removal efficiency at the HRT of 06 h (9.2±21.8%) was significantly lower (p =0.022) than that at the HRT of 18 h (42.1±43.5%). Furthermore, average $NO_3$-N removal efficiency at the HRT of 18 h (58.9±1.4%) was significantly higher ($p<0.05$) than that at the HRT of 6 h (36.8±67.7%) in AS system. No significant differences were observed between HRT of 12 and 18 h ($p > 0.05$) except AS system and HRT of 06 and 12h ($p > 0.05$) in each treatment steps.

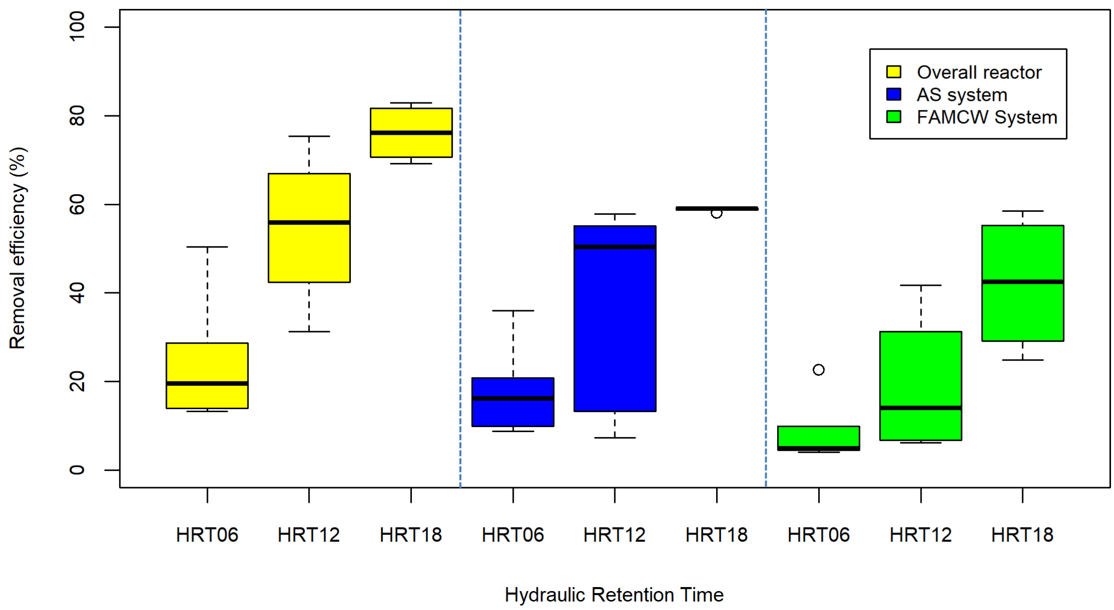



Figure 4.6 $NO_3$ -N removal efficiencies of reactor under HRT of 6, 12, and 18h

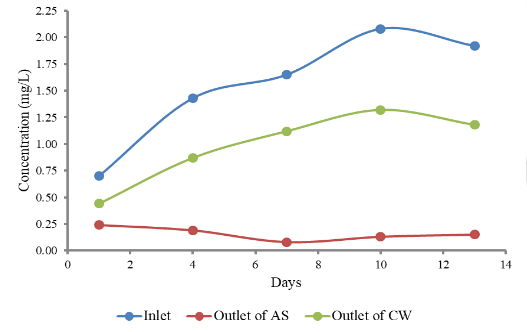
Insufficient nitrification process occurred in lower HRT due to short retention time for growth of nitrifying bacteria and results indicate that higher HRTs were enhanced the $NO_3$-N removal efficiency than lower HRTs. However, when the influent $NO_3$-N concentration was too high, the impact of HRT on denitrification was weakened (Moussavi et al, 2015).

The uptake of nitrate by macrophytes transforms inorganic nitrogen forms into organic compounds, as construction component for cells and tissues (Vymazal, 1994). Water hyacinth sucked up the $NO_3$-N in the wastewater as well. Long retention time of influent triggered $NO_3$-N uptake by water hyacinth and resulted higher $NO_3$-N removal efficiency in FAMCW system under HRT of 18 h than HRT of 6 and 12 h.

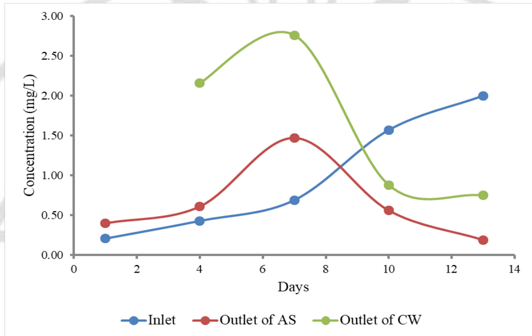
**4.5 Effect of HRT on Ammonium Nitrogen Removal Efficiency**

Ammonium nitrogen ($NH_4$-N) is a significant contaminant which contain in many type of wastewater and excessive discharge $NH_4$-N lead eutrophication in water bodies (Kinidi L et al., 2017). $NH_4$-N concentration fluctuations under different HRTs are shown in Figure 4.7 (a), (b) and (c). Average $NH_4$-N concentrations at HRT of 6h were resulted 1.6±1.5, 0.2±0.2, and 1.0±1.0 mg/L in inlet, outlet of AS system and outlet of FAMCW respectively while 1.0±2.1, 0.6±1.4, and 1.6±2.7 mg/L of average $NH_4$-N concentrations ware detected in inlet, outlet of AS system, and outlet of FAMCW respectively under system operated at HRT of 12h. Averages $NH_4$-N concentrations of the reactors operate at HRT of 18h were resulted 0.9±0.4, 0.2±0.2, and 0.1±0.2 mg/L in inlet, outlet of AS system, and outlet of FAMCW respectively (Table 4.5).

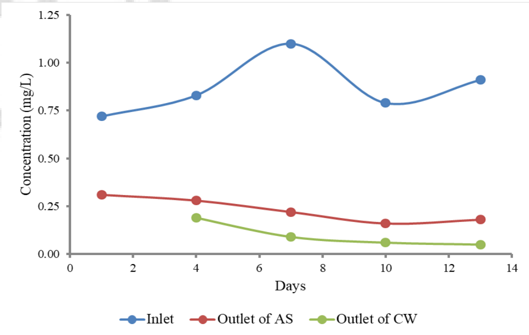
The $NH_4$-N removal efficiency under different treatment steps are shown in Figure 4.7 (d), (e) and (f). Average $NH_4$-N removal efficiencies at HRT of 6h resulted in 86.7±33.8, -668.7±1316.2, and 36.7±7.7 % in inlet, outlet of AS system and outlet of FAMCW respectively. Average $NH_4$ - N removal efficiencies of the reactor operate at HRT of 12h noticed -18.5±254.7, -173.4±118.4, and -149.0±658.9 % while 72.6±29.4, 56.5±47.6, and 89.0±22.2% in inlet, outlet of AS system and outlet of FAMCW respectively (Table 4.5). Highest Average $NH_4$ - N efficiency was recorded in HRT of 18h while lowest efficiency recorded at HRT of 12h. Furthermore, minus average removal efficiency was recorded in HRT of 12h at each treatment steps and it was abnormal with other results.



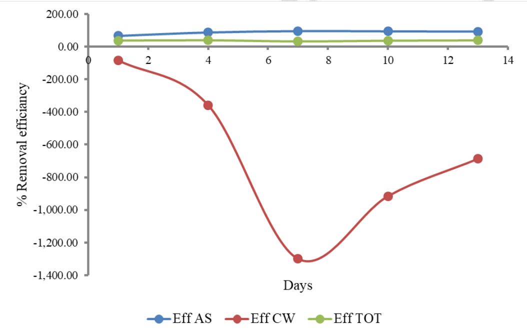

(a) Concentration variation – HRT 06



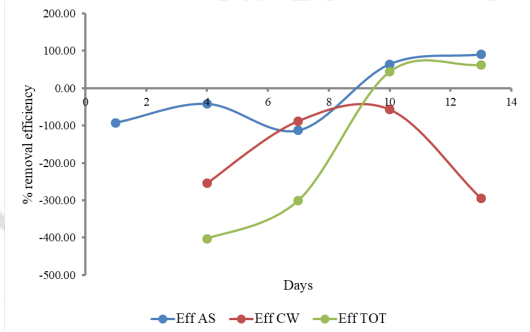

(b) Concentration variation – HRT 12



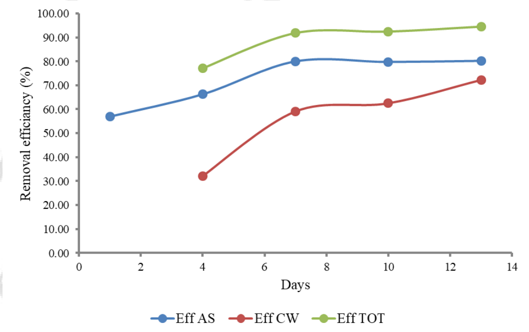

(c) Concentration variation – HRT 18




(d) Removal efficiency – HRT 06




(e) Removal efficiency – HRT 12




(f) Removal efficiency – HRT 18

Figure 4.7 Concentration variation and removal efficiency of ammonium nitrogen

Table 4.5 Average [± (S.D.)($t_{\alpha/2\upsilon}$)] $NH_4$ - N concentrations and removal efficiencies at HRT of 6, 12, and 18 h in different treatment steps

| HRT | Average $NH_4$ - N concentration (mg/L) | | | Average $NH_4$- N removal efficiency (%) | | |
|---|---|---|---|---|---|---|
| | Inlet | Outlet AS | Outlet FAMCW | AS system | FAMCW | Overall |
| HRT 06 | 1.6±1.5 | 0.2±0.2 | 1.0±1.0 | 86.7±33.8 | -668.7±1316.2 | 36.7±7.7 |
| HRT 12 | 1.0±2.1 | 0.6±1.4 | 1.6±2.7 | -18.5±254.7 | -173.4±118.4 | -149.0±658.9 |
| HRT 18 | 0.9±0.4 | 0.2±0.2 | 0.1±0.2 | 72.6±29.4 | 56.5±47.6 | 89.0±22.2 |

The $NH_4$ - N efficiencies under different HRTs are shown in Figure 4.8. The average $NH_4$ -N removal efficiency of the overall reactor operated at HRT of 18 h (89.0±22.2 %) was significantly higher (p = 0.038) than that at the HRT of 6 h (36.7±7.7%) whereas removal efficiency at HRT of 12 h (-149.0±658.9%) was significantly lower (p = 0.027) than that at HRT of 18 h (89.0±22.2 %).

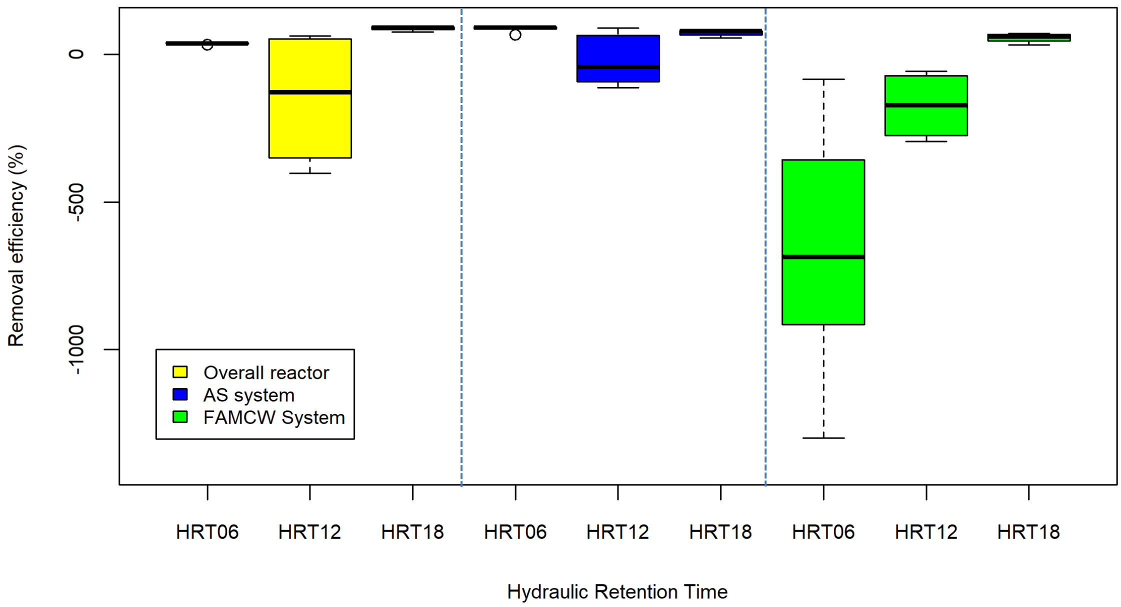



Figure 4.8 $NO_3^-$ -N removal efficiencies of reactor under HRT of 6, 12, and 18h

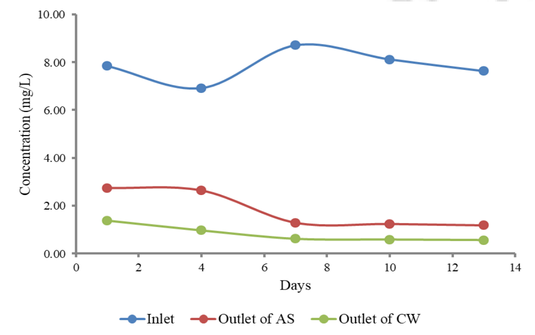
Furthermore, the $NH_4$-N removal efficiency at the HRT of 6 h (86.7±33.8 %) was significantly higher (p = 0.032) than that at the HRT of 12 h (-18.5±254.7%) in AS system while removal efficiency at HRT of 6 (-668.7±1316.2 %) significantly lower (p= 0.007) than that at the HRT of 18 h (56.5±47.6 %) in FAMCW system. There was no significant difference between the operation at HRTs of 12 h and 6 h ($p>0.05$) in FAMCW system and overall reactor while 18 h and 12 h ($p > 0.05$) in AS and FAMCW systems treatment steps.

Limiting amounts of dissolved oxygen (< 2 mg/L) inhibit nitrification and cause nitrite accumulation or nitrous and nitric oxide production (Goreau et al., 1980). Dissolve oxygen (DO) concentration in FAMCW was ranged 1-2 mg/L. Nitrification was deteriorated due to the low dissolve oxygen level and FAMCW recorded higher $NH_4$-N concentration than AS system in HRTs of 6 and 12 h due to the DO shortage. Expanding of FAMCW surface area or use of aeration can enhance ammonia nitrogen removal in constructed wetlands (Jamieson et al, 2003).

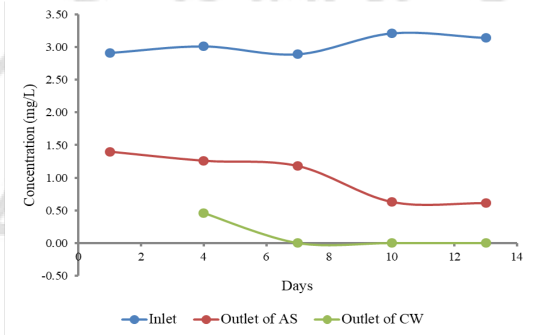
### 4.6 Effect of HRT on Ortho Phosphate Removal Efficiency

Phosphorous is one of the major nutrients contributing in the increased eutrophication of lakes and natural waters (Dodds & Smith, 2016). Ortho phosphate (O-$PO_4$) concentration fluctuations under different HRTs are shown in Figure 4.9 (a), (b) and (c). Average O-$PO_4$ concentrations at HRT of 6h were resulted 7.8±1.8, 1.8±2.2, and 0.8±1.0 mg/L in inlet, outlet of AS system and outlet of FAMCW respectively while 3.0±0.4, 1.0±1.0, and 0.1±0.6 mg/L of average O-$PO_4$ concentrations ware detected in inlet, outlet of AS system, and outlet of FAMCW respectively under system operated at HRT of 12h. Averages O-$PO_4$ concentrations of the reactors operate at HRT of 18h were resulted 4.5±5.5, 2.5±4.1, and 0.5±1.5 mg/L in inlet, outlet of AS system, and outlet of FAMCW respectively (Table 4.6).

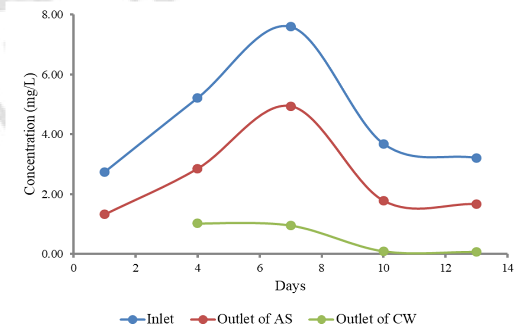
The O-$PO_4$ removal efficiency under different treatment steps are shown in Figure 4.9 (d), (e) and (f). Average O-$PO_4$ removal efficiencies at HRT of 6h resulted in 76.3±32.7, 53.8±14.9, and 89.3±13.4 % in inlet, outlet of AS system and outlet of FAMCW respectively. Average O-$PO_4$ removal efficiencies of the reactor operate at HRT of 12 h noticed 66.0±37.4, 90.9±50.7, and 96.2±21.2 % while 46.3±19.3, 83.9±41.2, and 90.8±23.4 % at HRT of 18 h in inlet, outlet of AS system and outlet of FAMCW respectively. Average O-$PO_4^{3-}$ removal efficiency at HRT of 06, 12, and 18 h was noticed almost similar values (Table 4.6).



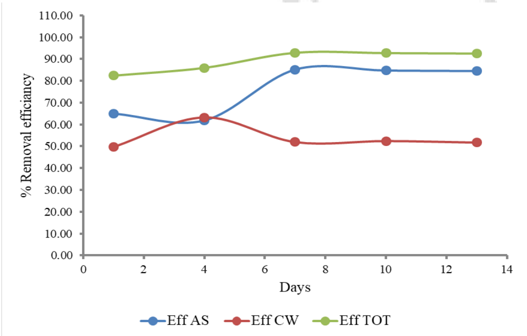

(a) Concentration variation – HRT 06



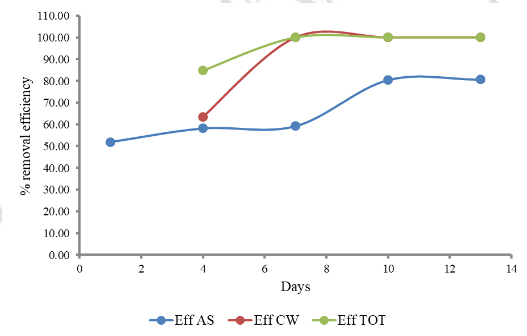

(b) Concentration variation – HRT 12



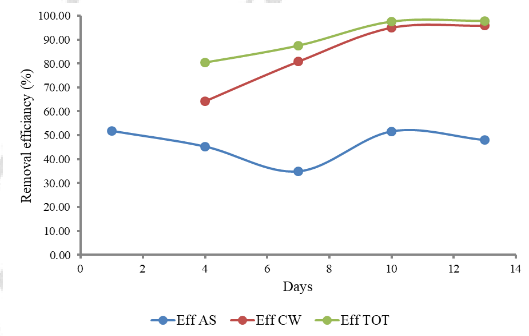

(c) Concentration variation – HRT 18




(d) Removal efficiency – HRT 06




(e) Removal efficiency – HRT 12




(f) Removal efficiency – HRT 18

Figure 4.9 Concentration variation and removal efficiency of ortho phosphate

Table 4.6 Average [± (S.D.)($t_{\alpha/2\upsilon}$)] O-$PO_4$ concentrations and removal efficiencies at HRT of 6, 12, and 18 h in different treatment steps

| HRT | Average O-$PO_4$ concentration (mg/L) | | | Average O-$PO_4$ removal efficiency (%) | | |
|---|---|---|---|---|---|---|
| | Inlet | Outlet AS | Outlet FAMCW | AS system | FAMCW | Overall |
| HRT 06 | 7.8±1.8 | 1.8±2.2 | 0.8±1.0 | 76.3±32.7 | 53.8±14.9 | 89.3±13.4 |
| HRT 12 | 3.0±0.4 | 1.0±1.0 | 0.1±0.6 | 66.0±37.4 | 90.9±50.7 | 96.2±21.2 |
| HRT 18 | 4.5±5.5 | 2.5±4.1 | 0.5±1.5 | 46.3±19.3 | 83.9±41.2 | 90.8±23.4 |

The O-$PO_4$ efficiencies under different HRTs are shown in Figure 4.10. O-$PO_4$ removal efficiency of the FMACW operated at the HRT of 12 h (90.9±50.7%) was significantly higher (p=0.011) than that at the HRT of 06 h (53.8±14.9%). Results showed that higher HRTs facilitate sufficient time to take up the O-$PO_4$ in effluent at FAMCW system and it caused to higher removal efficiencies of O-$PO_4$. There was no significant difference (p >0.05) detected between the reactor operated at HRTs of 12 and 6 h and HRTs of 12 and 18 h in AS system.

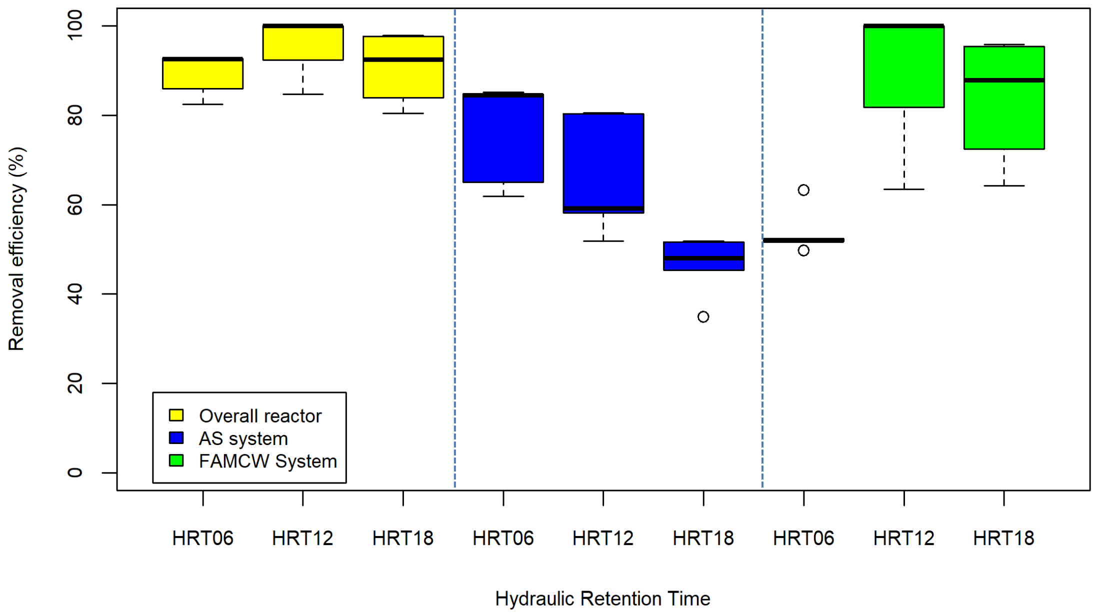



Figure 4.10 O -$PO_4$ removal efficiencies of reactor under HRT of 6, 12, and 18h

Average O-$PO_4^{3-}$ removal efficiency of AS system operated at the HRT of 06 h (76.3±32.7%) was significantly higher (p = 0.003) than that at HRT of 18 h

(46.3±19.3%). Lopez et al., (2009) found that long HRT (greater than 12 h) affected intracellular carbon storage polymers and caused a reduction in the rate of aerobic phosphorus removal and conclude that lower HRTs enhance the $O\text{-}PO_4$ removal efficiency in AS system. However, there was no significant difference ($p > 0.05$) observed among the overall reactor operated at HRTs of 6, 12, and 18 h. Because FAMCW system removed almost all remain $O\text{-}PO_4$ in effluent.

Dunn's (Dunn, 1964) multiple comparison test results and adjusted p-values using Benjamini-Hochberg method (Benjamini & Hochberg, 1995) were shown in Table 4.7 and those p values used to found the significant different among HRTs.

Table 4.7 Paired comparison of HRTs in each treatment step

| Parameter | Comparison | p value | | |
|---|---|---|---|---|
| | | ASP | FAMCW | Overall |
| BOD | HRT06 - HRT12 | 0.524 | 0.105 | 0.063 |
| | HRT06 - HRT18 | 0.032* | 0.701 | 0.020* |
| | HRT12 - HRT18 | 0.084 | 0.153 | 0.525 |
| TSS | HRT06 - HRT12 | 0.479 | 0.262 | 0.22 |
| | HRT06 - HRT18 | 0.021* | 0.679 | 0.007* |
| | HRT12 - HRT18 | 0.071 | 0.328 | 0.126 |
| $NO_3-N$ | HRT06 - HRT12 | 0.524 | 0.292 | 0.122 |
| | HRT06 - HRT18 | 0.008* | 0.022* | 0.008* |
| | HRT12 - HRT18 | 0.029* | 0.184 | 0.237 |
| $NH_4$ -N | HRT06 - HRT12 | 0.032* | 0.227 | 1.000 |
| | HRT06 - HRT18 | 0.206 | 0.007* | 0.038* |
| | HRT12 - HRT18 | 0.288 | 0.126 | 0.027* |
| $O\text{-}PO_4$ | HRT06 - HRT12 | 0.229 | 0.011* | 0.282 |
| | HRT06 - HRT18 | 0.003* | 0.051 | 0.743 |
| | HRT12 - HRT18 | 0.060 | 0.465 | 0.301 |

*statistically significantly difference in 95% confidence level

## 4.7 Relative growth rate of water hyacinth

The water hyacinth is a perennial, mat forming, floating aquatic plant of wide distribution in tropical, subtropical, and warm temperate regions throughout the world (Penfound & Earle, 1948). It grows rapidly in polluted waters making it an ideal candidate for large-scale application for nutrient removal and water purification (Reddy & Sutton, 1984). Relative growth rates (RGRs) of the water hyacinth in different HRTs (Figure 4.11.) were 0.0168, 0.0265, and 0.0150 $d^{-1}$ in HRTs of 6, 12, and 18 h in for 6-, 12- and 18-h HRTs, (Table 4. 8) respectively. At 18-h HRT where the highest removal efficiency, found had low growth rates for water hyacinth as well. Advantage of HRT of 18 was the decreased harvesting times during operation due to the low growth rate of *Eichhornia* sp.

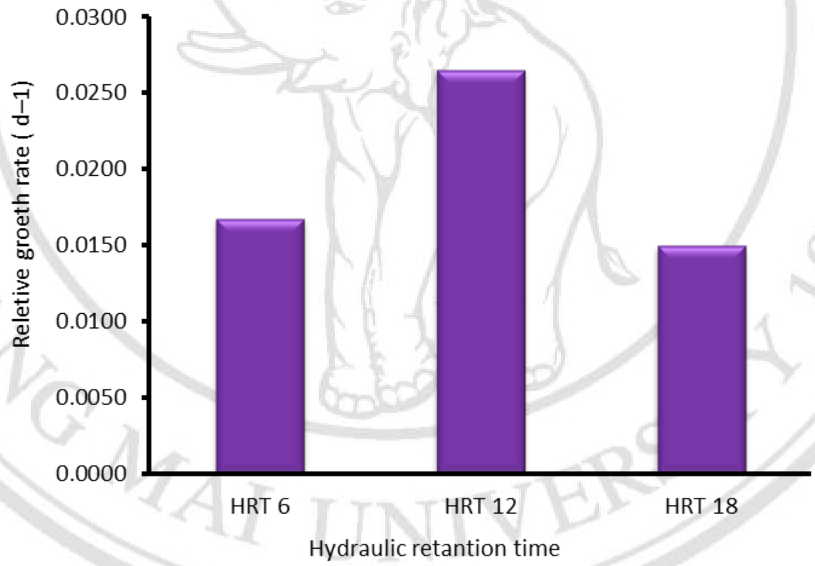



Figure 4.11 Relative growth rates of water hyacinth grown with wastewater from cafeteria for 13 days under HRT of 6, 12, and 18 h

(a). HRT 6 – Day 01

(b). HRT 6 – Day 13

(c). HRT 12 – Day 01

(d). HRT 12 – Day 13

(e). HRT 18 – Day 01

(f). HRT 18 – Day 13

Figure 4.12 Growth difference of water hyacinth in HRT of 6, 12, and 18h

Table 4.8 Fresh & dry weight, growth rate and relative growth rates of water hyacinth in HRT of 6, 12, and 18h

| HRT | HRT 6 | HRT 12 | HRT 18 |
|---|---|---|---|
| Fresh weight (g)– Day 01 | 423.3 | 419.3 | 421.9 |
| Fresh weight (g)– Day 13 | 526.3 | 591.6 | 512.5 |
| Dry weight (g)– Day 01 | 23.88 | 23.34 | 24.53 |
| Dry weight (g)– Day 13 | 29.69 | 32.93 | 29.80 |
| FW/DW ratio | 17.73 | 17.96 | 17.20 |
| Growth rate (g $d^{-1}$) | 0.45 | 0.74 | 0.41 |
| RGR ($d^{-1}$) | 0.016 | 0.026 | 0.015 |

The plant is dense in growth and increases very rapidly at 12-h HRT comparing with 6- and 18- h HRT. Leaf color is more green and bright in 12-h HRT (Figure 4. 12(d)). Because 12-h HRT provide sufficient time to uptake the nutrient from wastewater. Some necrosis observed in 6-h HRT and unfruitful growth of water hyacinth was observed (Figure 4. 12(b)). Lowest growth rate was observed in 18- h HRT, because excess amount of nutrients was treated from the AS system and lesser amount of nutrient entered to the FAMCW. Still 18- h HRT provides sufficient time to assimilate the nutrient, but inadequate nutrient concentrations affected to lower plant growth. However, No leaf necrosis observed in 18- h HRT.

Water hyacinth, the worst aquatic weed was found to be highly impossible to eradicate from the water ways, though its quest for nutrients has given a possible way for its usage in phytoremediation. In the last few years great interest has been shown for the research of water hyacinth as a good candidate for pollutant removal or even as a bioindicator for heavy metals in aquatic ecosystems (Priya & Selvan, 2017).

## 4.8 Multiple statistical correlation between concentration and removal efficiency

### 4.8.1 Multiple statistical correlation at 6 h HRT

In this study, the wastewater quality was monitored and the pollutant removal efficiencies were obtained at different HRT. Results showed that the inlet concentrations of wastewater and physical characteristics had a positive or negative correlation with pollutant removal efficiencies. Table 4.9 shows multiple correlations between physicochemical parameters and pollutant removal efficiencies at 6 h HRT in AS – FAMCW reactor.

It can be observed that wastewater temperature had a strong positive correlation with BOD and O-$PO_4$ removal efficiencies (r = 0.87 and 0.96 respectively). Activities of microorganism functioned on the organic matter and phosphorus accumulating microorganisms (PAOs) ware increased with temperature and higher temperature provide favorable condition to degrade the organic matters. $NO_3$-N removal efficiencies showed strong negative correlation with temperature (r = -0.98). Study of Guo et al., (2013) found that, the overall nitrogen removal efficiencies were controlled by denitrification at low temperatures. pH had strong positive correlation (r = 0.71) with O-$PO_4$ removal while $NO_3$-N removal shows strong negative correlation (r = -0.72) with pH. Because form of O-$PO_4$ dominated in aqueous solution at most basic pH (Pan et al., 2017) Nevertheless, Microbial activity is inhibited at pH above 9 and at pH below 6.0, the pH of wastewater desires to remain between 6 and 9 (Ko et al., 2006). EC shows strong positive correlation (r = 0.92 and 0.86 respectively) with TSS and $NO_3$-N removal while BOD and O-$PO_4$ shows strong negative correlation (r = -0.70 and -0.79 respectively). TDS concentration shows strong positive correlation (r = 0.92) with TSS removal. Inlet $NO_3$-N concentration had strong positive correlation with $NO_3$-N removal and strong negative correlation with BOD removal while inlet $NH_4$-N concentration had strong positive and negative correlation with BOD and $NO_3$-N removal efficiencies respectively (r = 0.85 and -0.94 respectively). Inlet $NH_4$-N had strong positive and inlet $NO_3$-N had strong negative correlation (r = 0.82 and -0.98 respectively) with O-$PO_4$ removal efficiencies at HRT 6.

Table 4.9 Multiple correlation analysis between physicochemical parameters and pollutant removal efficiencies at 6 h HRT

| | Correlation | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T_IN | pH_IN | EC_IN | TDS_IN | TSS_IN | BOD_IN | NO3_IN | NH4_IN | PO4_IN | RE_TSS | RE_BOD | RE_NO3 | RE_NH4 | RE_PO4 |
| T_IN | 1.00 | | | | | | | | | | | | | |
| pH_IN | 0.79 | 1.00 | | | | | | | | | | | | |
| EC_IN | -0.88 | -0.95 | 1.00 | | | | | | | | | | | |
| TDS_IN | -0.85 | -0.97 | 0.99 | 1.00 | | | | | | | | | | |
| TSS_IN | 0.25 | -0.39 | 0.19 | 0.27 | 1.00 | | | | | | | | | |
| BOD_IN | -0.31 | 0.28 | -0.14 | -0.17 | -0.91 | 1.00 | | | | | | | | |
| NO3_IN | -0.96 | -0.86 | 0.97 | 0.94 | -0.06 | 0.09 | 1.00 | | | | | | | |
| NH4_IN | 0.93 | 0.51 | -0.66 | -0.61 | 0.59 | -0.61 | -0.82 | 1.00 | | | | | | |
| PO4_IN | 0.32 | 0.45 | -0.46 | -0.39 | -0.21 | 0.50 | -0.40 | 0.19 | 1.00 | | | | | |
| RE_TSS | -0.86 | -0.81 | 0.92 | 0.92 | 0.03 | 0.11 | 0.93 | -0.70 | -0.09 | 1.00 | | | | |
| RE_BOD | 0.87 | 0.66 | -0.70 | -0.65 | 0.31 | -0.23 | -0.78 | 0.85 | 0.62 | -0.53 | 1.00 | | | |
| RE_NO3 | -0.98 | -0.72 | 0.86 | 0.81 | -0.33 | 0.32 | 0.96 | -0.94 | -0.37 | 0.84 | -0.87 | 1.00 | | |
| RE_NH4 | -0.32 | -0.61 | 0.62 | 0.58 | 0.48 | -0.70 | 0.50 | -0.09 | -0.92 | 0.29 | -0.47 | 0.37 | 1.00 | |
| RE_PO4 | 0.96 | 0.71 | -0.79 | -0.74 | 0.33 | -0.29 | -0.88 | 0.92 | 0.51 | -0.69 | 0.98 | -0.96 | -0.41 | 1.00 |

IN = Inlet, RE = Removal Efficiency

Table 4.10 Multiple correlation analysis between physicochemical parameters and pollutant removal efficiencies at 12 h HRT

| | Correlation | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T_IN | pH_IN | EC_IN | TDS_IN | TSS_IN | BOD_IN | NO3_IN | NH4_IN | PO4_IN | RE_TSS | RE_BOD | RE_NO3 | RE_NH4 | RE_PO4 |
| T_IN | 1.00 | | | | | | | | | | | | | |
| pH_IN | 0.99 | 1.00 | | | | | | | | | | | | |
| EC_IN | -0.81 | -0.88 | 1.00 | | | | | | | | | | | |
| TDS_IN | -0.78 | -0.85 | 1.00 | 1.00 | | | | | | | | | | |
| TSS_IN | 0.77 | 0.75 | -0.42 | -0.35 | 1.00 | | | | | | | | | |
| BOD_IN | -0.39 | -0.47 | 0.54 | 0.56 | -0.06 | 1.00 | | | | | | | | |
| NO3_IN | 0.07 | 0.17 | -0.14 | -0.11 | 0.41 | -0.44 | 1.00 | | | | | | | |
| NH4_IN | 0.63 | 0.70 | -0.56 | -0.53 | 0.65 | -0.76 | 0.75 | 1.00 | | | | | | |
| PO4_IN | 0.44 | 0.51 | -0.48 | -0.49 | 0.20 | -0.98 | 0.49 | 0.84 | 1.00 | | | | | |
| RE_TSS | 0.86 | 0.94 | -0.61 | 0.75 | 0.93 | -0.14 | 0.42 | 0.75 | 0.35 | 1.00 | | | | |
| RE_BOD | 0.90 | 0.96 | -0.69 | 0.76 | 0.95 | -0.03 | 0.35 | 0.68 | 0.25 | 0.99 | 1.00 | | | |
| RE_NO3 | 0.55 | 0.68 | -0.24 | 0.87 | 0.84 | -0.28 | 0.78 | 0.91 | 0.46 | 0.90 | 0.86 | 1.00 | | |
| RE_NH4 | 0.48 | 0.60 | -0.04 | 0.51 | 0.55 | -0.70 | 0.68 | 0.98 | 0.83 | 0.79 | 0.71 | 0.87 | 1.00 | |
| RE_PO4 | 0.90 | 0.96 | -0.69 | 0.75 | 0.95 | -0.03 | 0.35 | 0.67 | 0.25 | 0.99 | 1.00 | 0.86 | 0.71 | 1.00 |

IN = Inlet, RE = Removal Efficiency

Table 4.11 Multiple correlation analysis between physicochemical parameters and pollutant removal efficiencies at 18 h HRT

| | Correlation | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T_IN | pH_IN | EC_IN | TDS_IN | TSS_IN | BOD_IN | NO3_IN | NH4_IN | PO4_IN | RE_TSS | RE_BOD | RE_NO3 | RE_NH4 | RE_PO4 |
| T_IN | 1.00 | | | | | | | | | | | | | |
| pH_IN | 0.63 | 1.00 | | | | | | | | | | | | |
| EC_IN | 0.26 | 0.30 | 1.00 | | | | | | | | | | | |
| TDS_IN | 0.40 | 0.26 | 0.97 | 1.00 | | | | | | | | | | |
| TSS_IN | -0.05 | 0.03 | 0.81 | 0.71 | 1.00 | | | | | | | | | |
| BOD_IN | 0.00 | -0.12 | -0.44 | -0.32 | -0.84 | 1.00 | | | | | | | | |
| NO3_IN | 0.20 | 0.73 | -0.25 | -0.29 | -0.53 | 0.41 | 1.00 | | | | | | | |
| NH4_IN | 0.04 | -0.53 | 0.55 | 0.63 | 0.58 | -0.27 | -0.90 | 1.00 | | | | | | |
| PO4_IN | -0.27 | -0.54 | 0.59 | 0.62 | 0.48 | 0.01 | -0.66 | 0.84 | 1.00 | | | | | |
| RE_TSS | 0.80 | 0.72 | 0.02 | 0.07 | 0.04 | -0.58 | 0.38 | -0.38 | -0.81 | 1.00 | | | | |
| RE_BOD | 0.99 | 0.54 | 0.49 | 0.63 | -0.32 | -0.03 | 0.11 | 0.17 | -0.25 | 0.77 | 1.00 | | | |
| RE_NO3 | 0.79 | 0.62 | -0.05 | 0.04 | 0.14 | -0.63 | 0.25 | -0.27 | -0.77 | 0.99 | 0.78 | 1.00 | | |
| RE_NH4 | 0.93 | 0.33 | 0.31 | 0.51 | -0.09 | -0.14 | -0.13 | 0.33 | -0.20 | 0.73 | 0.96 | 0.78 | 1.00 | |
| RE_PO4 | 0.91 | 0.67 | 0.16 | 0.26 | -0.05 | -0.44 | 0.26 | -0.18 | -0.65 | 0.97 | 0.90 | 0.98 | 0.87 | 1.00 |

IN = Inlet, RE = Removal Efficiency

### 4.8.2 Multiple statistical correlation at 12 h HRT

Table 4.10 shown multiple correlations between physicochemical parameters and pollutant removal efficiencies at 12 h HRT in AS – FAMCW reactor. Slightly difference correlation trend shown in HRT 12 comparing with HRT 06 and temperature had a strong positive correlation with BOD and O-$PO_4$ removal efficiencies (r = 0.90, and 0.90 respectively). Inlet pH, showed similar trend as temperature and had strong positive correlation with BOD and O-$PO_4$ removal efficiencies (r = 0.94 and 0.96). Inlet $NO_3$-N and $NH_4$-N concentrations showed strong positive correlation with $NO_3$-N and $NH_4$-N removal efficiencies (r = 0.71, 0.68 and 0.91, 098 respectively).

### 4.8.3 Multiple statistical correlation at 18 h HRT

Table 4.11 shown multiple correlations between physicochemical parameters and pollutant removal efficiencies at 18 h HRT in AS – FAMCW reactor. It observed that temperature had a strong positive correlation with BOD, $NO_3$-N, $NH_4$-N, and O-$PO_4$ removal efficiencies (r = 0.99, 0.79, 0.93 and 0.91 respectively). Inlet pH had strong positive correlation with *o*-$PO_4$ efficiencies ( r = 0.67)

Summarized that, temperature and pH showed strong positive correlation with BOD and O-$PO_4$ removal efficiencies in each HRT (Figure 4.13, Figure 4.14, Figure 4.15 and Figure 4.17 respectively).

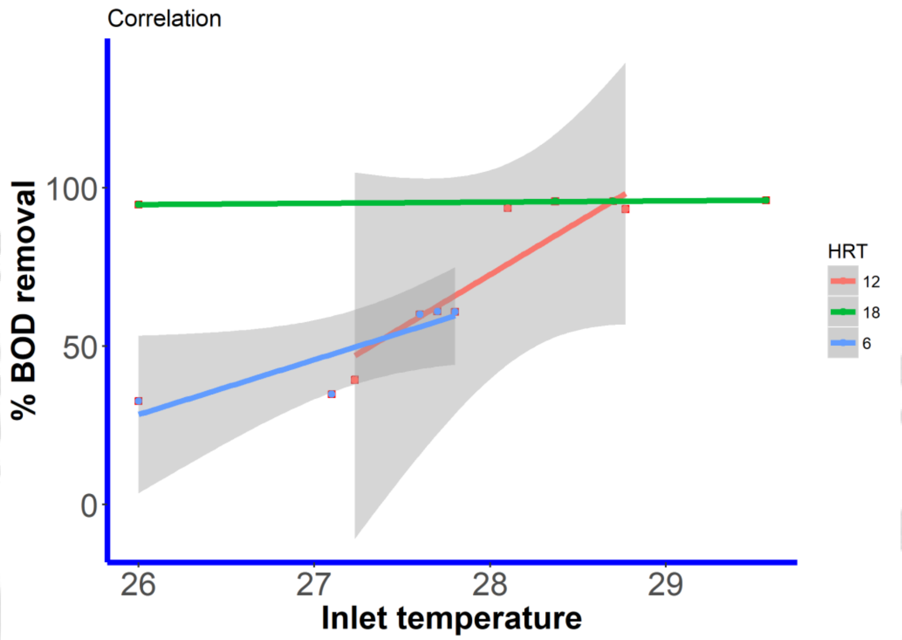



Figure 4.13 Correlation between inlet temperature and BOD removal efficiencies at HRT of 6, 12, and 18h

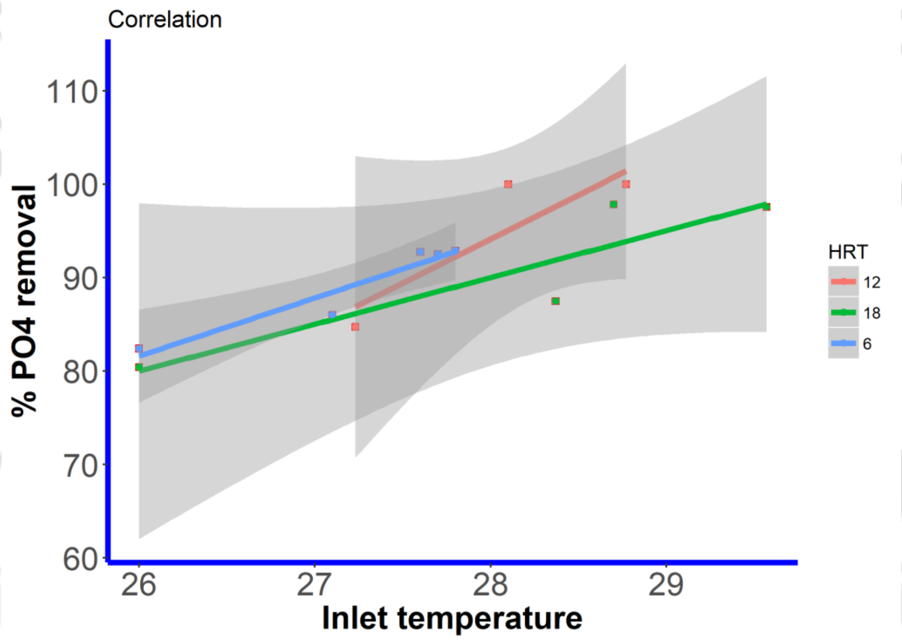



Figure 4.14 Correlation between inlet temperature and O-$PO_4$ removal efficiencies at HRT of 6, 12, and 18h

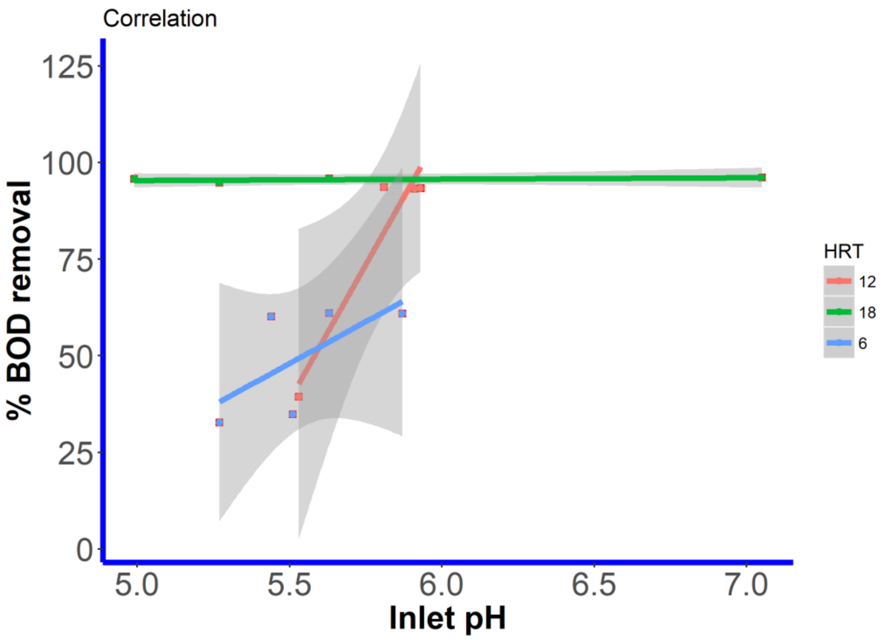



Figure 4.15 Correlation between inlet pH and BOD removal efficiencies at HRT of 6, 12, and 18h

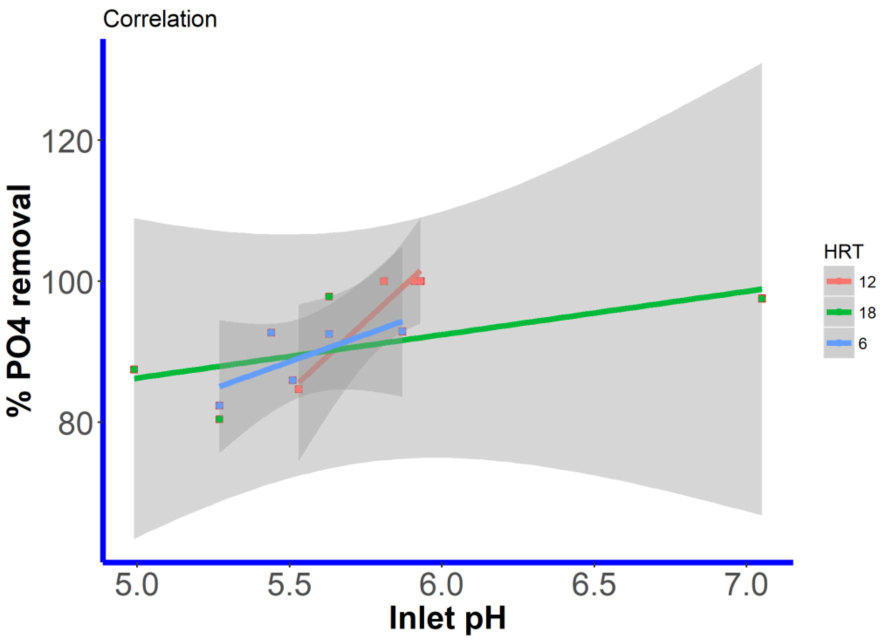



Figure 4.16 Correlation between inlet pH and O-$PO_4$ removal efficiencies at HRT of 6, 12, and 18h

## 4.9 Principle component analysis

The idea of principal components analysis (PCA) is to find a small number of linear combinations of the variables to capture most of the variation in the data frame as a whole. Principal components analysis finds a set of orthogonal standardized linear combinations, which together explain all of the variation in the original data (Crawley, 2012). PCA is applying to extract the significant information from a multivariate data table and to present this information as a set of few new variables called principal components (PC). PCA is a useful and common statistical technique for finding patterns in data of high dimension and reduce input variables complexity when we have a huge volume of information and want to have a better interpretation of variables (Oliveira et al, 2002)

Table 4.12 Wastewater quality parameters associated with PCA and abbreviations

| Parameter | Abbreviation |
|---|---|
| Inlet temperature | TI |
| Inlet pH | pHI |
| Inlet EC | ECI |
| Inlet TDS | TDI |
| Inlet BOD | BOI |
| Inlet TSS | TSI |
| Inlet N- $NO_3$ | NOI |
| Inlet N-$NH_4$ | NHI |
| Inlet o- $PO_4$ | POI |
| AS system temperature | TA |
| AS system pH | pHA |
| AS system EC | ECA |
| AS system TDS | TDA |
| AS system BOD | BOA |
| AS system TSS | TSA |
| AS system N-$NO_3$ | NOA |

Table 4.12 (Continued)

| Parameter | Abbreviation |
|---|---|
| AS system N-$NH_4$ | NHA |
| AS system O-$PO_4$ | POA |
| FAMCW temperature | TC |
| FAMCW pH | pHC |
| FAMCW EC | ECC |
| FAMCW TDS | TDC |
| FAMCW BOD | BOC |
| FAMCW TSS | TSC |
| FAMCW N-$NO_3$ | NOC |
| FAMCW N-$NH_4$ | NHC |
| FAMCW O-$PO_4$ | POC |

Table 4.13 Importance of components at 6 H HRT

| | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Standard deviation | 4.293 | 2.436 | 1.262 | 1.019 | 5.288e-15 |
| Proportion of Variance | 0.682 | 0.219 | 0.059 | 0.038 | 0.000e+00 |
| Cumulative Proportion | 0.682 | 0.902 | 0.961 | 1.000 | 1.000e+00 |

First and second principal components of HRT 06 (PC1 and PC2) explain 68.2% and 21.9% of the total variation, respectively. Cumulative proportion of PC1 and PC2 are 90.2% of the total variation as shown in Table 4.13. Figure 4.17 showed the relative importance of PC and Figure 4.18 showed the correlation between a variable and the PCs at HRT 6. All variable ware positioned close to the circumference of the correlation circle except POI (Inlet O-$PO_4$ concentration), explain that almost all variable showed good representation of the variable on the PC. It confirmed that those PC's good enough to explain the variability of parameters under HRT 6.

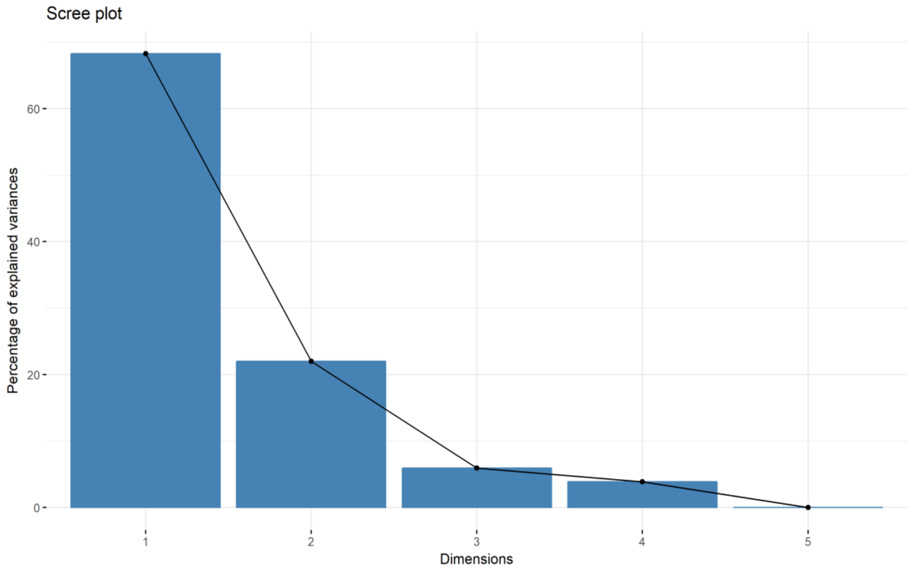



Figure 4.17  Relative importance of the principal components at HRT 6

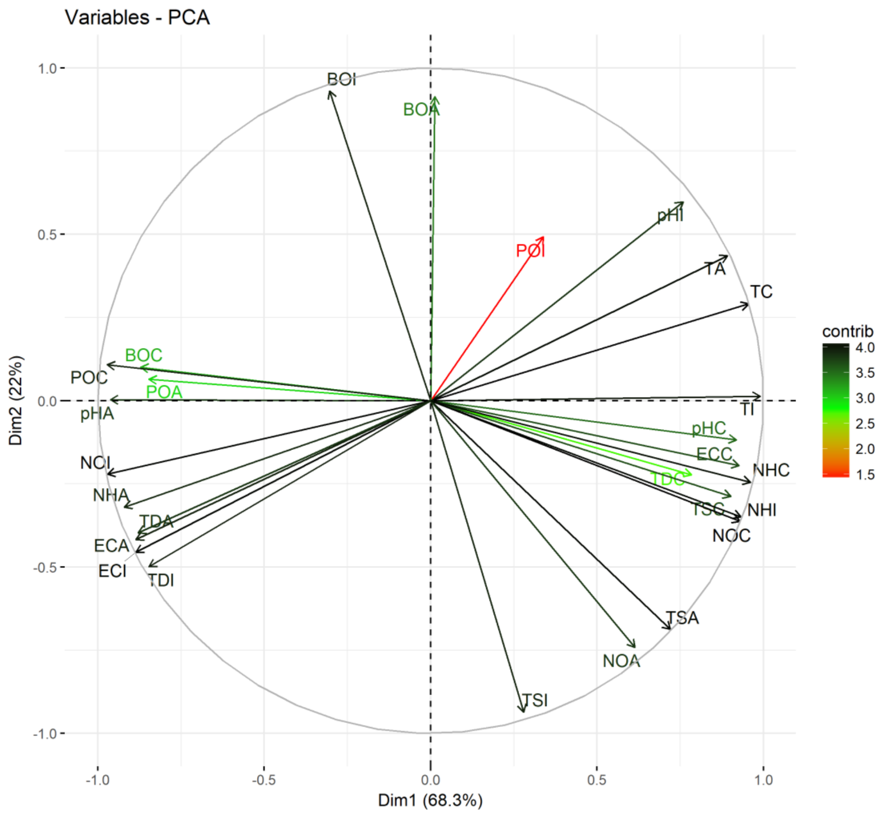



Figure 4.18  Correlation circle between a variable and a PC at  HRT 6

Table 4.14 Importance of components at 12 H HRT

| | PC1 | PC2 | PC3 | PC4 |
|---|---|---|---|---|
| Standard deviation | 3.7715 | 3.1891 | 1.61406 | 7.431e-15 |
| Proportion of Variance | 0.5268 | 0.3767 | 0.09649 | 0.000e+00 |
| Cumulative Proportion | 0.5268 | 0.9035 | 1.00000 | 1.000e+00 |

First and second principal components of HRT 12 (PC1 and PC2) explain 52.6% and 37.6% of the total variation, respectively. Cumulative proportion of PC1 and PC2 are 90.3% of the total variation as shown in Table 4.14. Figure 4. 19 showed the relative importance of PC and Figure 4.20 showed the correlation between a variable and the PCs at HRT 12.

Similar trend shown as HRT 6 and most of the variables ware positioned close to the circumference of the correlation circle except NOI and TDI (Inlet N-$NO_3$ and Inlet TDS concentrations respectively), explain that almost all variable showed good representation of the variable on the PC. It confirmed that those PC's good enough to explain the variability of parameters under HRT 12.

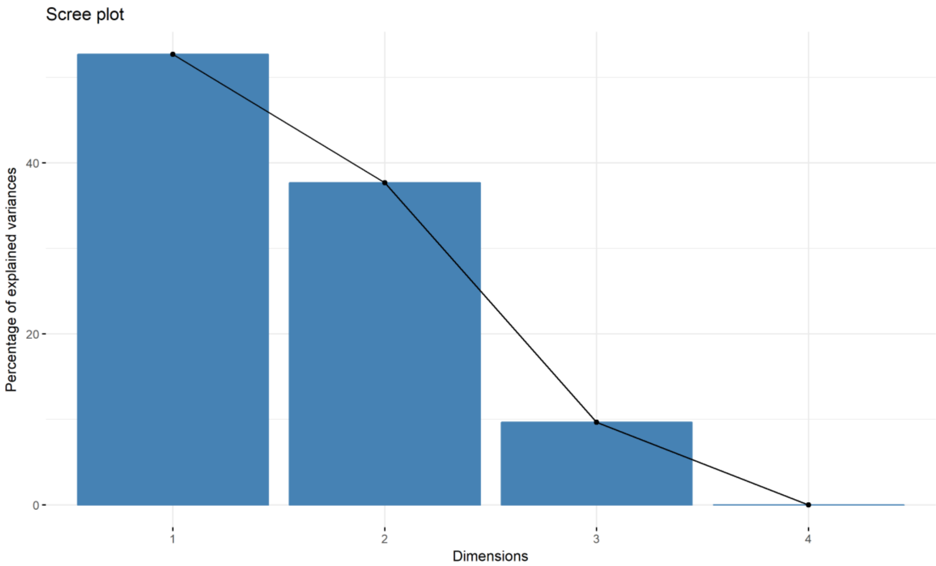



Figure 4.19 Relative importance of the principal components at HRT 12

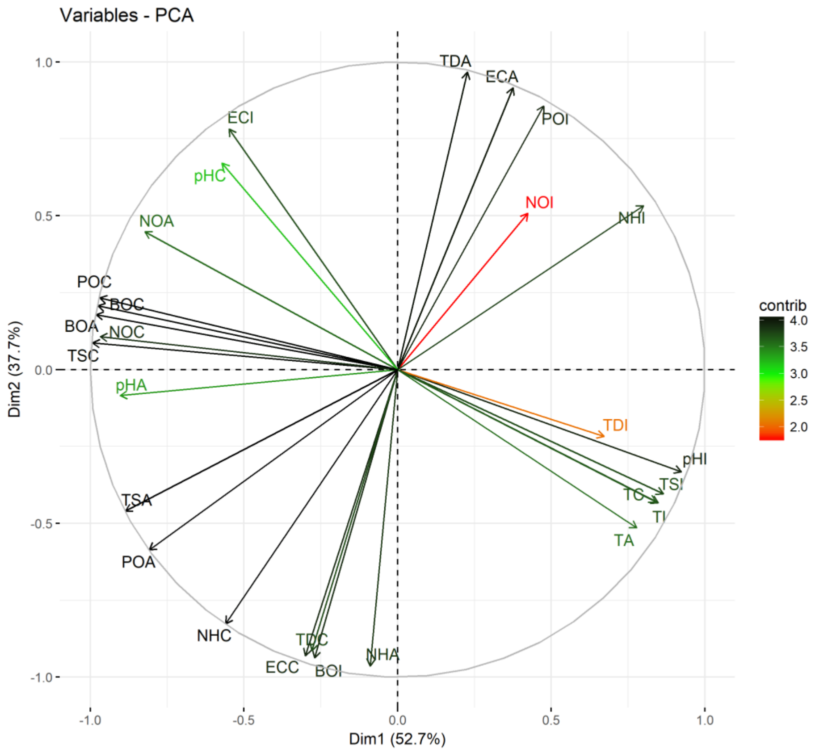



Figure 4.20 Correlation circle between a variable and a PC at HRT 12

Table 4. 15 Importance of components at 18 H HRT

| | PC1 | PC2 | PC3 | PC4 |
|---|---|---|---|---|
| Standard deviation | 3.783 | 2.8563 | 2.1286 | 2.991e-15 |
| Proportion of Variance | 0.530 | 0.3022 | 0.1678 | 0.000e+00 |
| Cumulative Proportion | 0.530 | 0.8322 | 1.0000 | 1.000e+00 |

First and second principal components of HRT 18 (PC1 and PC2) explain 53.0% and 30.2% of the total variation, respectively. Cumulative proportion of PC1 and PC2 are 83.2% of the total variation as shown in Table 4.15. Figure 4.21 showed the relative importance of PC and Figure 4.22 showed the correlation between a variable and the PCs at HRT 12. Similar as HRT 6 and 12, most of the variables ware positioned close to the circumference of the correlation circle except TSI, NOA and ECI (Inlet TSS, AS N-$NO_3$, and Inlet EC), explain that almost all variable showed good representation of the variable on the PC.

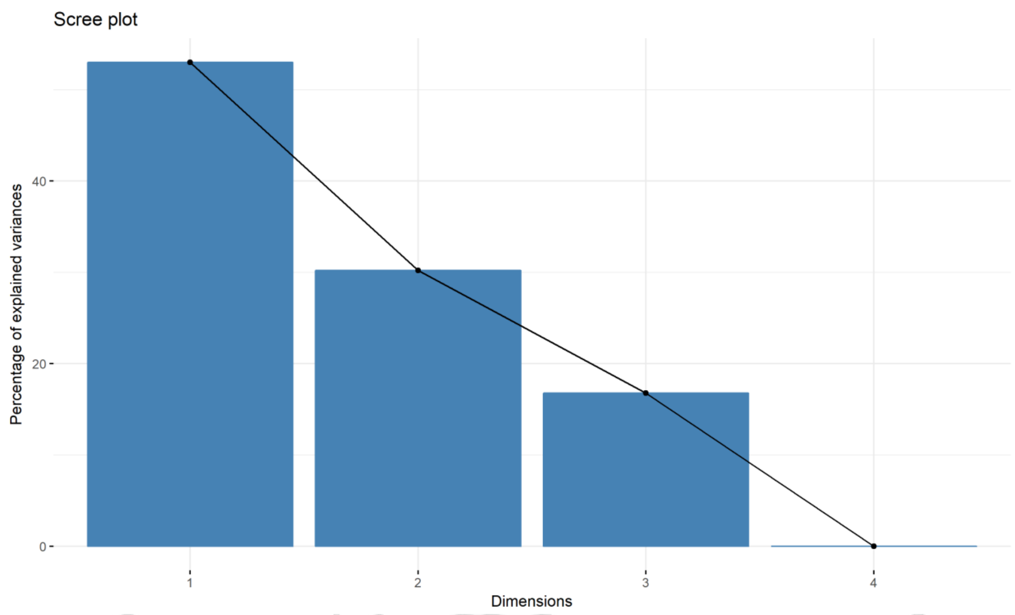



Figure 4.21 Relative importance of the principal components at HRT 18

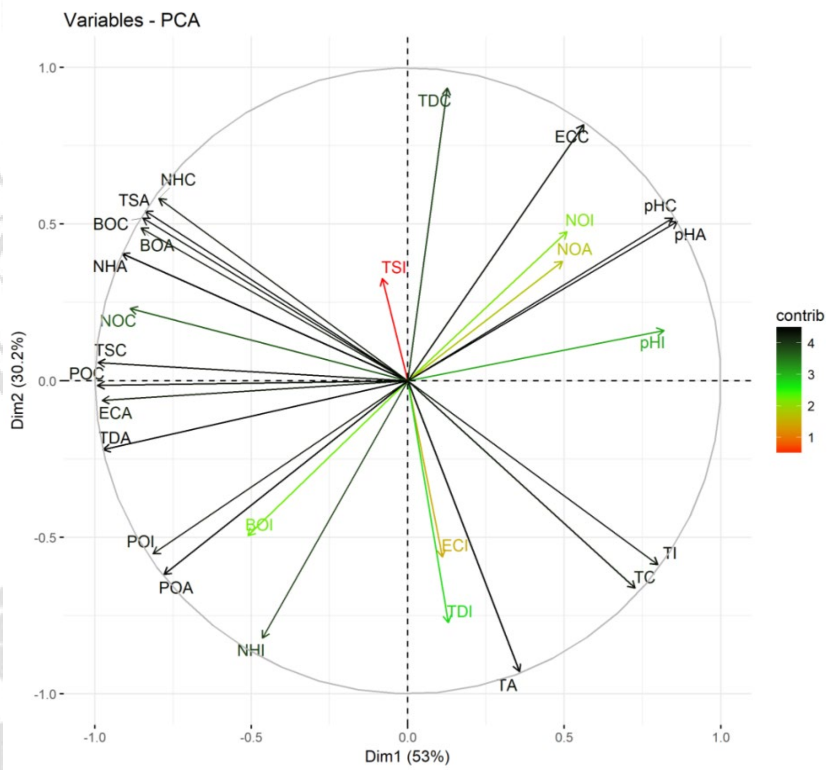



Figure 4.22 Correlation circle between a variable and a PC at HRT 18

Concluded that, all variables except few variables were perfectly represented by PC and PCA can used to explain the correlation between the variable in this study.

Biplot generated from PCA was used to explain the correlation between the variables. In addition, PC 1 and PC 2 of each HRT were represented more than 80% of cumulative variance and good enough to explain the correlation as well.

The directions of the arrows show the relative loadings of the variable on the first and second principal components. Figure 4.23 shows the biplot of variables under HRT 06.

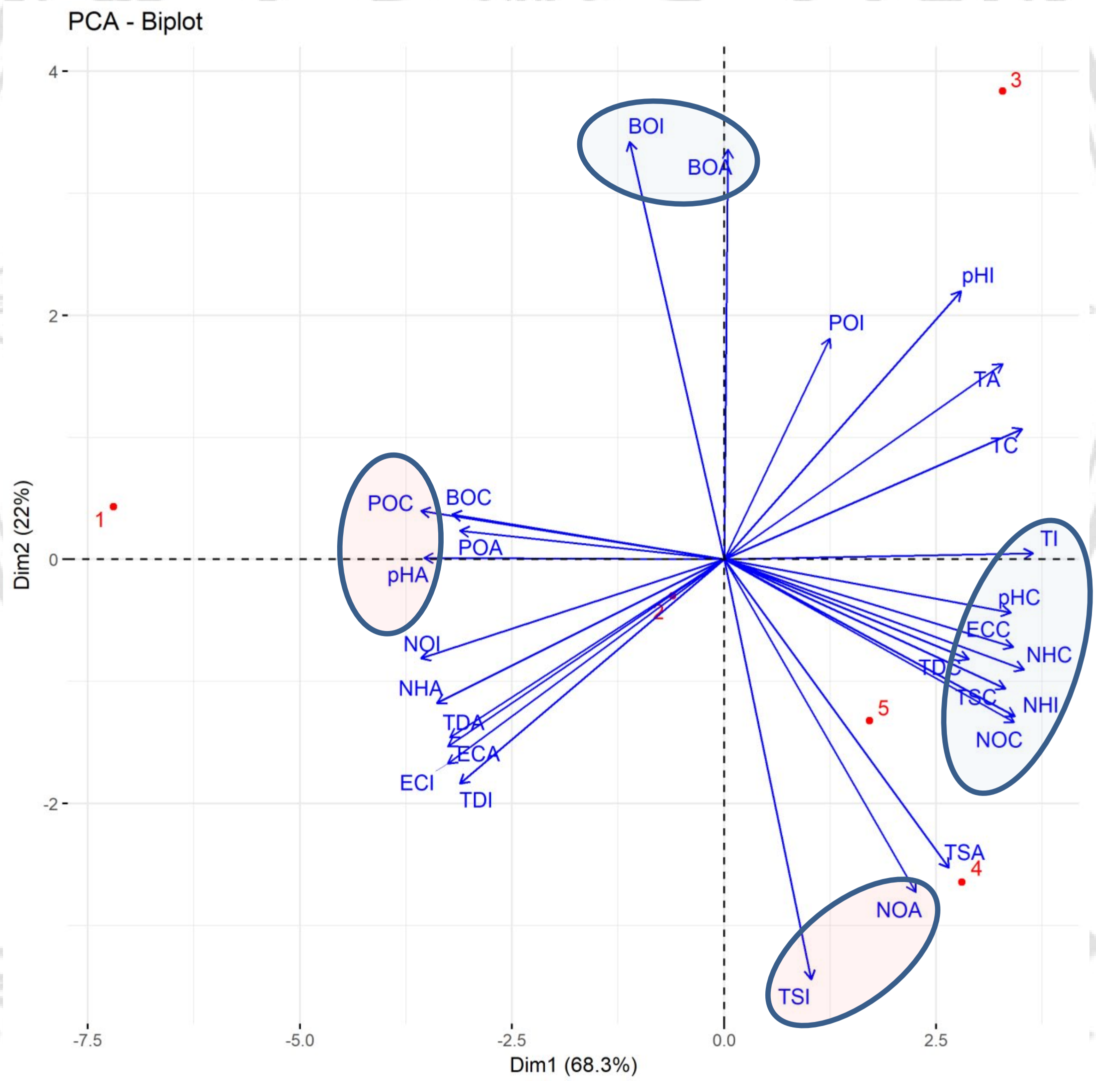



Figure 4.23 PCA Biplot of variables at HRT 06



The first PC is strongly correlated with eight of the original variables. The PC increases with increasing inlet temperature and $NH_4$–N concentration, FAMCW temperature, pH, EC, TSS, $NO_3$−N and $NH_4$–N concentrations. This was suggested that those eight criteria vary together. If one increases, then the remaining ones tend to as well. In fact, could state that based on the correlation of 0.231 (Table C 1) that, this PC is primarily a measure of the inlet temperature. In contrast, first PC negatively correlated with pH of AS system and o-$PO_4$ concentration at FAMCW. Second PC positively correlated with BOD concentration at inlet and AS system and negatively correlated with inlet TSS concentration and $NO_3$–N at AS system (Table C 1).

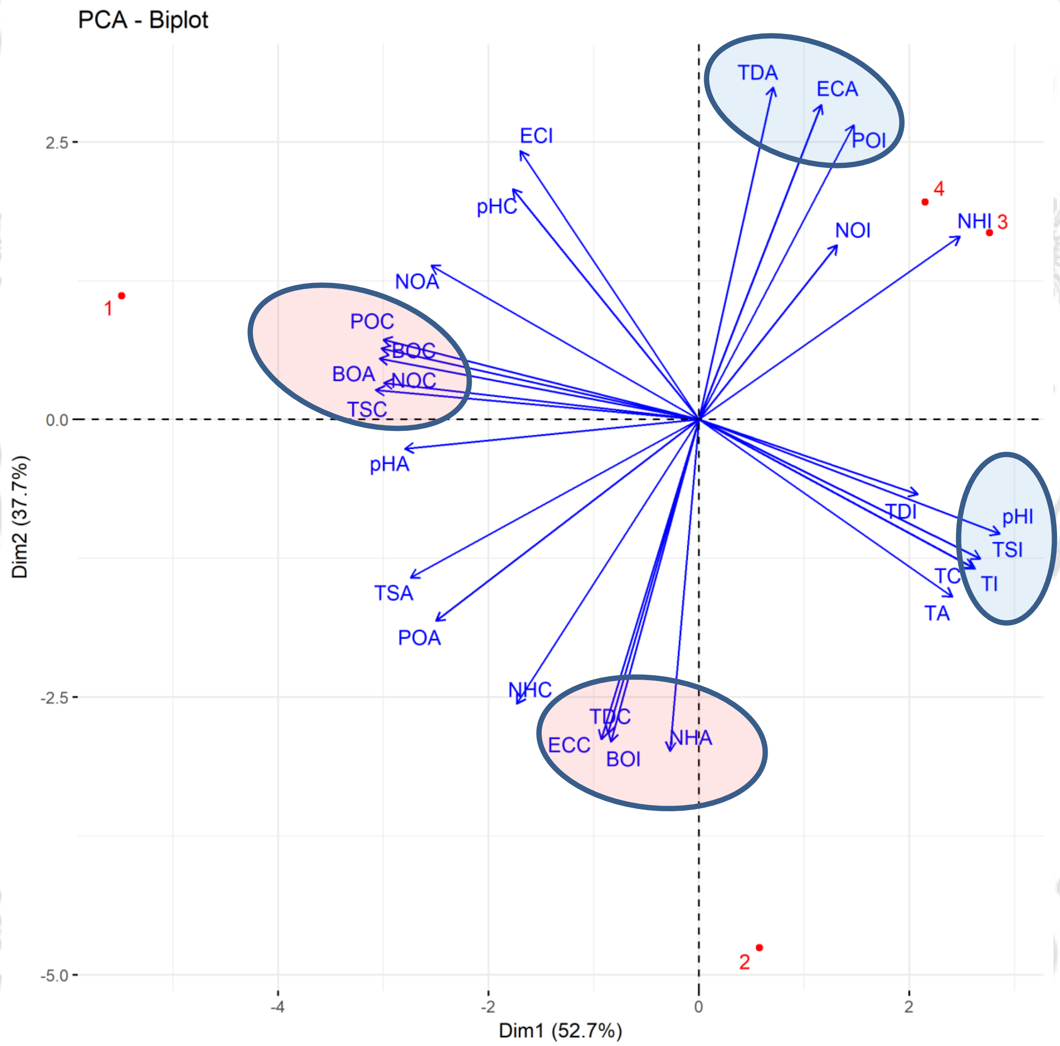



Figure 4.24 PCA Biplot of variables at HRT 12

Figure 4. 24 shows the biplot of variables under HRT 12. The first PC is strongly correlated with inlet temperature, pH and TSS concentration while negatively correlated with BOD concentration in AS system and BOD, $NO_3$–N and TDS, O-$PO_4$

concentration at FAMCW. Based on the correlation of 0.245 (Table C. 2) that, PC1 is primarily a measure of the inlet pH. PC2 positively correlated with O-$PO_4$ concentration at inlet and EC and TDS concentration in AS system. PC2 negatively correlated with BOD concentration in inlet, $NH_4$–N concentration in AS system and EC and TDS concentration at FAMCW system (Table C. 2).

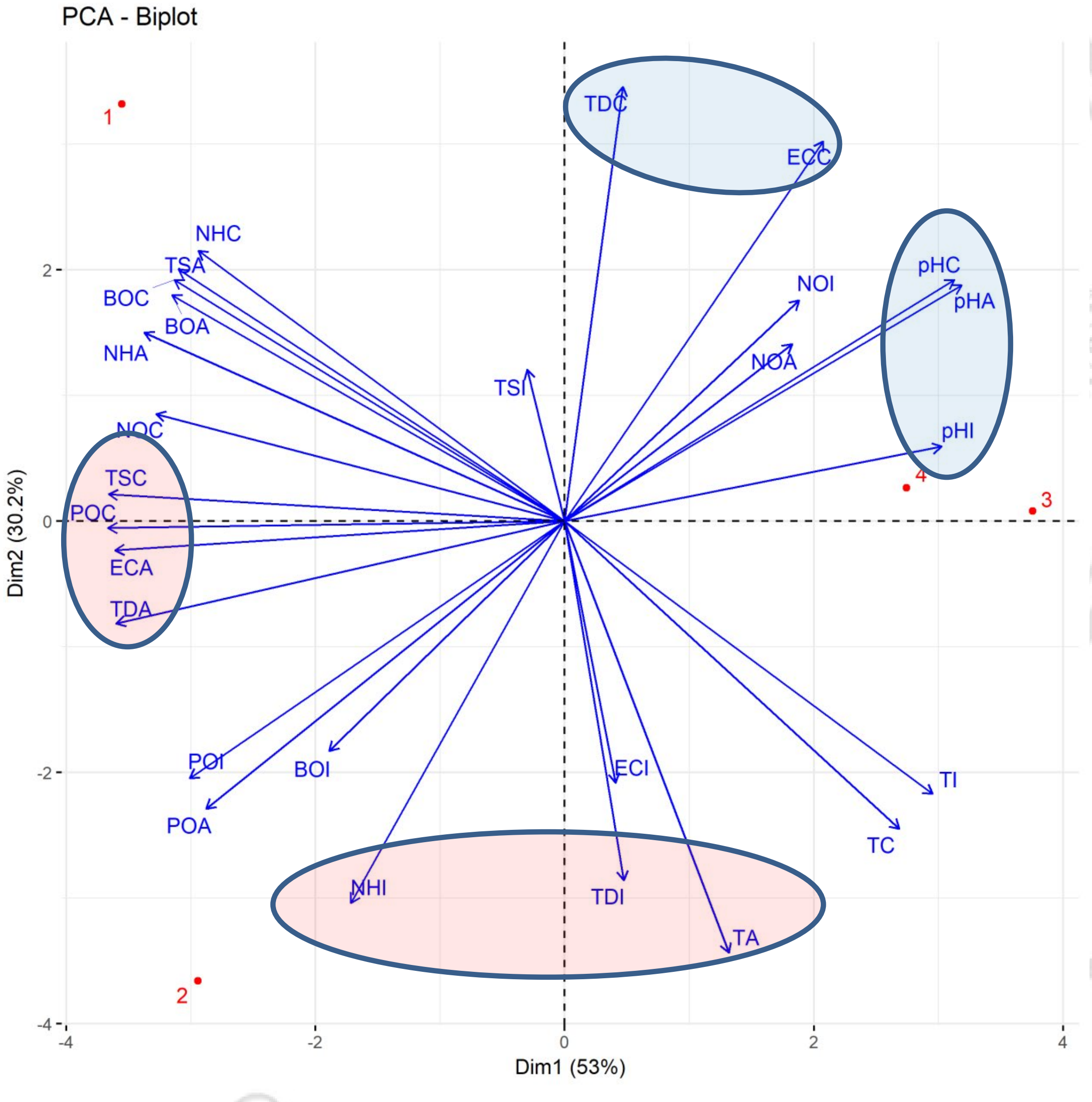



Figure 4.25 PCA Biplot of variables at HRT 18

Figure 4. 25 shows the biplot of variables under HRT 18. The PC1 is positively correlated with pH of inlet, AS and FAMCW units while negatively correlated with EC and TDS in AS system and TSS and o-$PO_4$ concentration at FAMCW. Based on the correlation of 0.225 and 0.228 (Table C. 3) that, PC1 is primarily a measure of the pH at

AS and FAMCW units respectively. PC2 positively correlated with EC and TDS in FAMCW and negatively correlated with TDS, $NH_4$–N concentration in inlet and temperature in AS system (Table C. 3).

### 4.10 Mathematical Modeling of Activated Sludge Unit

Biodegradation of organic matter plays a key role in activated sludge process to treat the wastewater. A mathematical model was developed in order to describe the degradation coefficient and order of decay in organic matter and nutrients.

The law of conservation of mass says that when chemical reactions take place, matter neither created nor destroyed (Masters, 1991). A mass balance is an accounting of a material for a specific system boundary.

As shown in the Figure 4.26 flow and concentration of BOD from the feed tank to the aeration tank express $Q_{in}$, $u_{in}$ : Flow and concentration of BOD exiting the aeration tank. $Q_{out}$: $u_{out}$;

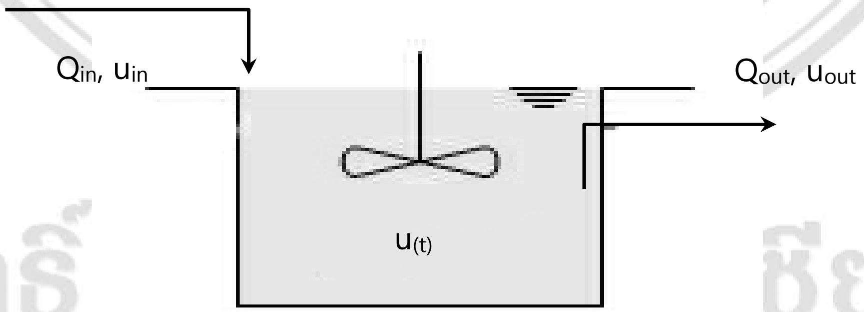



Figure 4.26 The aeration tank process of activated sludge diagram



From mass balance equation,

$$m_{in} - m_{out} \pm m_{rxn} = \frac{d}{dt}[BOD] \qquad \text{Eq.4. 1}$$

$$m_{in} = Q_{in}u_{in}, \quad m_{out} = Q_{out}u_{out}$$ Eq.4. 2

$$m_{rxn} = \frac{du}{dt} = -ku^n$$ Eq.4. 3

$$\frac{\forall du}{dt} = -k\forall u^n$$ Eq.4. 4

$$\frac{du}{dt} = \frac{Q}{\forall}.u_{in} - \frac{Q}{\forall}.u - ku^n$$ Eq.4. 5

Differential equation for BOD removal,

$$\frac{du}{dt} = \frac{1}{\theta}.u_{in} - \frac{1}{\theta}.u - ku^n$$ Eq.4. 6

where's,

Q = flow rate

u = biochemical oxygen demand

∀= reactor volume

k = degradation coefficiant

n = order of decay

θ = hydraulic retention time

Stating from Eq.4.1 and derive differential equation for calculate the BOD degradation coefficient and order of the degradation as showed in Eq. 4.6. This equation cannot solve manually and $4^{th}$ Order Runge – Kutta equation (Eq.4.7) used to performed the mathematical model and Eq.4.6 substituted to $4^{th}$ order runge – kutta equation. $K_1$, $K_2$, $K_3$, and $K_4$ constants were calculated using Eq.4. 8, Eq.4. 9, Eq.4. 10, and Eq.4. 11 respectively.

$$u_{n+1} = u_n + \frac{\Delta t}{6}(K_1 + 2K_2 + 2K_3 + K_4) \qquad \text{Eq.4. 7}$$

Where,

$$K_1 = f(t_n, u_n) \qquad \text{Eq.4. 8}$$

$$K_2 = f(t_n + \frac{\Delta t}{2}, u_n + \frac{K_1}{2}\Delta t) \qquad \text{Eq.4. 9}$$

$$K_3 = f(t_n + \frac{\Delta t}{2}, u_n + \frac{K_2}{2}\Delta t) \qquad \text{Eq.4. 10}$$

$$K_4 = f(t_n + \Delta t, u_n + K_3\,\Delta t) \qquad \text{Eq.4. 11}$$

The model was run under different Δt values as shown in the Table 4.16 in order to determine the suitable Δt value for each HRT. Δt =1 take long time to run the process and Δt = 8 take short time to run the process. Then Δt =3 chose as best Δt value for this process.

Table 4.16 Order of decay and degradation coefficient of BOD in different Δt

| Pollutant | | HRT (θ) = 6 | | HRT (θ) = 12 | | HRT (θ) = 18 | |
|---|---|---|---|---|---|---|---|
| | Δt | k | n | k | n | k | n |
| BOD | 8 | 18.792 | 0.000 | 11.000 | 0.000 | 17.500 | 0.080 |
| | 6 | 0.050 | 1.040 | 0.130 | 1.280 | 23.250 | 0.000 |
| | 3 | 0.110 | 0.900 | 0.100 | 0.700 | 16.060 | 0.100 |
| | 2 | 0.110 | 0.900 | 0.110 | 1.000 | 16.060 | 0.100 |
| | 1 | 0.118 | 0.890 | 0.123 | 1.100 | 14.340 | 0.090 |

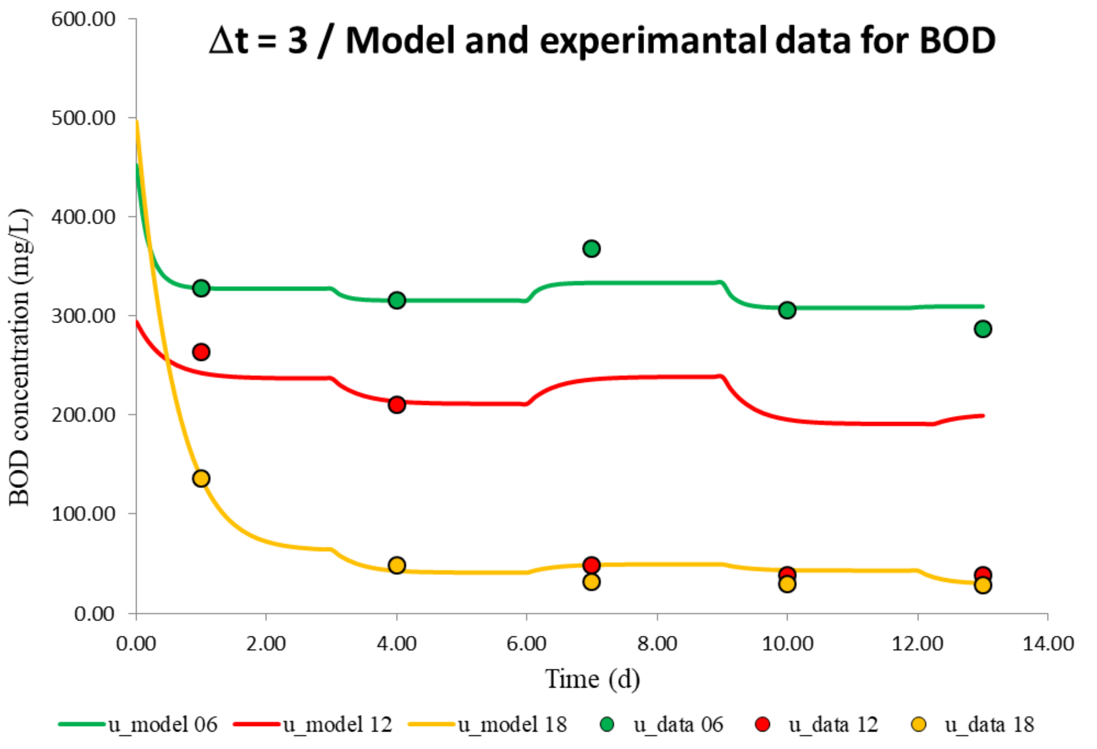



Figure 4.27 Experimental and model data for BOD degradation in AS system

Table 4.17 Order of decay and degradation coefficient of BOD at Δt =3

| HRT | Order of BOD decay (mg $L^{-1}$ $d^{-1}$) | Degradation coefficient for BOD |
|---|---|---|
| 06 | 0.9 ≈ 1.0 | 0.1 $d^{-1}$ |
| 12 | 0.7 ≈ 1.0 | 0.1 $d^{-1}$ |
| 18 | 0.1≈ 0.0 | 16.0 mg $L^{-1}$ $d^{-1}$ |

Table 4.17 shows the order of BOD decay and reaction order of BOD removal in different Δt under different HRTs. Results showed that first order process take place at HRT 06 & 12 and zero order process take place at HRT 18. Process does not depend on the number of microorganism cell at first order reaction and process depends on the number of cells at zero order reaction. It can concluded that BOD degradation at HRT 18 depend on microbial cell

number and BOD degradation at HRT 12 and 6 independent from microbial cell number.

Figure 4. 27 showed the experimental data and model data plot at $\Delta t = 3$. It clearly showed that 6 and 18 -h HRT experimental data perfectly fit mathematical model and 12-h HRT experimental data fit with the model data at start and deviate in end. It was expected that BOD degradation at 12-h HRT 12h was mix order reaction. It clearly indicates that BOD concentration was rapidly decreased at 18-h HRT. Because microorganism had sufficient time to degrade the organic matter contain in the wastewater at 18- h HRT than 06 and 12 h HRTs. Rapid BOD removal caused to higher BOD rate constant at 18 h HRT.

Organic matters consist with different chemical composition in nature. Not all-organic matter will have same degradation rate. Simple sugar and starches ware rapidly degraded and resulted large BOD rate constant, however, complex organic matter degrades slowly and resulted low BOD rate constant. Cafeteria wastewater largely consists with simple organic matter such as starch and simple sugars. 18 –h HRT showed relatively very high level of BOD rate constant with 12 and 06 h HRTs.