Assessment on biochemical oxygen demand (BOD) removal using treatment train system for agricultural run-off

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Abstract. Agricultural runoff is non-point source pollution that is unpredictable and difficult to control. Best Management Practices (BMPs) and Low Impact Development (LID) has been utilized as a method to manage agricultural runoff. Treatment train systems are LID-BMPs arranged in a series that aims to treat and manage agricultural runoff. This study focuses on the use of treatment train systems to reduce the concentration of BOD in agricultural runoff. A treatment train system was set up with three varying configurations to evaluate the efficiency of BOD removal. The three configurations consisted of no vegetation set which acts as the control, vegetated set, and vegetated set with the saturated zone. All three configurations showed good final removal rates of BOD at 56% for the control and 75% and 85% for both vegetated sets without and with the saturated zone. The control is classified as Class III according to Water Quality Standards, while both vegetated set without and with saturated zone had classified both sets as Class II and I, respectively. The performance of the treatment train system was compared to the use of a single bioretention system.

1. Introduction

Agricultural runoff is a non-point source of water pollution where water flows from agricultural land use and ultimately reaches bodies of water such as streams and lakes or be absorbed into the Earth. The source of contamination stems from fertilizers, sediments, pesticides, and waste coming from croplands and live-stock operations [1]. The use of inputs such as fertilizers and phosphorus not only help crops flourish, but once it is washed off by the rain, the agricultural runoff carries the input as well and when it reaches water bodies such as rivers and lakes, it acts as a catalyst to the growth of algae which leads to a phenomenon called an algal bloom. Unfortunately, the funding required to treat the occurrence of algal bloom is very costly [2]. The occurrence of algal bloom creates areas in the water body where there is no oxygen present due to all the oxygen content in the water being consumed by algae and releasing carbon dioxide. The lack of oxygen leads organisms such as bacteria and fish to suffocate and die. The algae also block sunlight from reaching the bottom of the water body which leads to vegetation not being able to perform photosynthesis.
According to Wiens [1], non-point sources of water pollution are becoming more of a concern as point sources are easier to control. Being a non-point source, control over where and when it occurs becomes more difficult because of its random and unpredictable nature. However, the consequences it brings is not something to dismiss as the impact it brings towards the ecosystem may be devastating if not controlled. Wiens [1] mentions that agricultural land use and water systems are linked due to the hydrologic cycle that occurs, where both land use and water systems are affected by each other. This leads to water bodies such as rivers containing relatively high levels of bacterial contamination from the agricultural watersheds. For example, Bryan’s 1976 study (as cited in [1]) stated that runoff coming from dairy farms containing manure had shown an increase in fecal coliform levels, which in turn would lead to high concentrations of BOD.

The Department of Irrigation and Drainage of Malaysia (DID) has prepared an Urban Stormwater Management Manual that includes standards and practices that should be followed for all matters related to water management. One of the indicators that can be used to characterize pollutants for runoff is biochemical oxygen demand (BOD). A high BOD value would indicate a high amount of organic pollution in a body of water which has the potential to disrupt the local ecosystem. Agricultural runoff from plantations contains all sorts of pollutants such as pesticides and fertilizers that have seeped into the soil. Treatment train systems are introduced to act as a filter to remove BOD in the runoff. This study aims to evaluate the performance of BOD removal using a treatment train system for BOD removal for agricultural runoff treatment.

2. Materials and method

2.1. Site sampling

Samples were obtained from a nearby palm oil plantation located at Jalan Felcra Nasaruddin for characterization and use as a benchmark. The BOD concentrations in the samples were determined accordingly. Two types of samples were collected, which were from the palm oil water channel and the river where the water channels flow into. Samples were taken from three different locations along the water channel and three more locations along the river as shown in figure 1. Based on the finding from the characterization study, the pollutant source can be used as a benchmark to determine the performance of the treatment train system in reducing the BOD value of the synthetic runoff used.

![Figure 1. Six (6) sampling points from palm oil plantation to the river](image-url)
2.2. Treatment train setup

Figures 2 and 3 demonstrate how a series of three bioretention columns were set up. Three alternative column arrangements were employed, each with its own set of configurations, as follows:

a.) No vegetation with 300mm soil depth (control)
b.) Vegetation with 300mm soil depth
c.) Vegetation with 300mm soil depth and saturated zone.

The bioretention column consisted of a ponding zone, soil media, sand layer, and gravel layer. A Ti plant (Cordyline fruticosa) was planted in the ponding zone for columns with vegetation as a replacement to the Red Hot Chinese Hibiscus plants that were planted prior because it was found that the plants were wilting. The soil media was made up of a mixture of 60 percent sand, 30 percent topsoil, and 10 percent compost. While the soil media layer was 300mm deep, the sand layer was 95mm deep, and the gravel layer was 100mm deep. The water tank holds 150L of synthetic runoff acting as the influent. The system was regulated by valves, which allow the influent to flow via column 1, where it will eventually flow to columns 2 and 3. The outlets of each column simulate a free falling of the runoff which helps aerate the runoff to allow for more supply of oxygen to the runoff.

![Treatment train setup diagram](image)

**Figure 2.** (a) Treatment train system setup: layout of treatment train; (b) Arrangement of bioretention columns in series
2.3. Preparation of Synthetic Agricultural Runoff

In this work, the synthetic agricultural runoff was used to overcome the drawback of using actual agricultural runoff, which would require multiple trips to obtain large volumes of the agricultural runoff that would act as an influent on the system. The synthetic runoff was prepared with measurements according to table 1 which includes the measurements scaled according to the 60-gallon water tank (227 liters) that was used. The calculations were based on the characterization study and compared to previous research.

The synthetic runoff was prepared by measuring each chemical constituent using a weighing scale with a tolerance of 0.01g. The chemical constituents were then put into a beaker and mixed with tap water. The synthetic runoff was then carefully poured slowly into the water tank while being constantly stirred. The synthetic runoff was prepared prior for every run, as it begins to be contaminated with algae after 3 to 4 days.

2.4. Sampling and BOD testing

About 150 mL of each sample was filled into BOD bottles. The dissolved oxygen of each BOD bottle was measured with the calibrated DO meter and the results were recorded accordingly. A sufficient amount of distilled water was added up to half of the b BOD bottle's neck, and a stopper was inserted to prevent air bubbles in each of the prepared sample bottles. The BOD bottles were capped off, covered with aluminium foil, and labeled immediately to prevent evaporation. The BOD bottles were then kept in the incubator for five days at a temperature of 20°C. After 5 days of the incubation period, the remaining dissolved oxygen was measured and recorded, respectively. Since no bacterial seed was added throughout the research, the BOD was determined using equations (1), (2), and (3).

\[
\text{BOD}_5 = (\text{DO}_{\text{initial}} - \text{DO}_{\text{final}}) \times \text{Dilution factor}
\]  

(1)
Dilution factor = \frac{\text{Bottle volume}}{\text{Sample Volume}} \quad (2)

The removal rate of BOD can be calculated as,

\text{Removal rate (\%)} = \left( \frac{\text{BOD}_{\text{influent}} - \text{BOD}_{\text{effluent}}}{\text{BOD}_{\text{influent}}} \right) \times 100\% \quad (3)

3. Results and discussion

3.1. Characterization of Agricultural Runoff

The BOD\textsubscript{5} values of water samples taken from the Felcra Nasaruddin palm oil plantation are displayed in figure 4. Samples A1, A2, and A3 were obtained from the palm oil water channel, while samples B1, B2, and B3 were collected from the river into which the water channels flow. It was found that the BOD\textsubscript{5} values for agricultural runoff from the palm oil water channel were determined to be in an average of 12.08mg/L. On the other hand, the BOD\textsubscript{5} values for the main river were in an average of 5.48mg/L, which is lower than the BOD\textsubscript{5} values for agricultural runoff from the palm oil water channel. This result was considered acceptable and in agreement with the finding reported by other studies [3, 4, 5, 6, and 7]. Moreover, the more it goes downstream showing lower in BOD\textsubscript{5} values since the constituents being diluted [3].

![Figure 4. BOD concentration for agricultural runoff from palm oil plantation](image)

3.2. Biochemical Oxygen Demand (BOD) Analysis

In this study, five runs of experiments were conducted with the three trial runs to get used to the process and improving the system. Each run takes five days from the start of the run to the measurement of BOD of the samples. Each run would necessitate the preparation of a new synthetic runoff due to the high possibility of algae accumulation in the water tank after two days, which would affect the results. The first three runs helped determine the appropriate volume of sample to be used, and the fourth run helped identify any problems in collecting samples from the vegetated set with the saturated zone. From the fourth run, it was found that running the synthetic runoff through the vegetated set with the saturated zone required a minimum of two hours and constant monitoring, as leaving the saturated zone inside the column configurations lead to the vegetation wilting. Despite the fact that five runs were carried out, only the fifth yielded promising and acceptable data that could be used for further investigation. Figure 5 shows the average BOD\textsubscript{5} measurements from the five runs. It can be seen that certain BOD readings cannot be accepted due to several issues such as the presence of bubbles in the bottle, a remaining DO reading of less than 1mg/L, a small difference between final DO and initial DO (excluding the final effluents), and unable to collect the sample due to time constraints.
Figure 5. BOD concentration before and after treatment using treatment train.

Figure 6 exhibits the reduction of the BOD measurements when the agricultural runoff passes through each bioretention configuration. Moreover, each column configuration shows an initial BOD reduction of greater than 82%. It was found that the control set shows mean BOD removal rate of 52%, while the vegetated sets shows slightly better which mean BOD removal rates with 75% and 85% for Set A and B, respectively. Out of the three configurations, the vegetated set with saturated zone shows the best performance with an 88% initial removal rate and 98% final removal rate. Though the vegetated set with the saturated zone requires higher maintenance and monitoring, as leaving the saturated zone in the setup causes the vegetation to wilt. From the results, the control set can be classified as Class II according to Water Quality Standards, while both vegetated set without and with saturated zone can be classified as Class I. If each set was to consider the first column as a single bioretention system, all three configurations would be classified as Class IV, which shows that the arrangement of bioretention systems in a series contributes greatly in removing BOD of agricultural runoff. The reduction of the BOD measurements can be attributed to the soil media as it filters the pollutants present in the runoff. In addition to that, the cascading discharge of each column configuration assisted in aerating the runoff as it cascades into the next column.

Figure 6. BOD reduction (%) using treatment train.
4. Conclusion
Agricultural runoff from a nearby palm oil plantation was characterized and used as a benchmark for the synthetic runoff and it was found that the samples collected from the palm oil water channel had an average BOD$_5$ reading of 12.08mg/L and the main river had a lower average reading at 5.48mg/L.

The three configurations showed high final BOD removal rates at 96% for the control, and 98% for both vegetated sets without and with saturated zone and the control set was classified as Class II according to Water Quality Standards, while the two vegetated sets without and with saturated zone were classified as Class I. Based on the results, it can be attributed to the cascading flow of discharge as well as soil media in filtering the pollutants. Lastly, the effectiveness of BOD removal in treatment train system was compared to a single bioretention system. When only the first bioretention cell was taken into consideration, the control set had the lowest BOD$_5$ removal rate of 52%, the vegetated set with 300 mm soil depth had a greater BOD$_5$ removal rate of 75% compared to the control set, while the highest removal rates is 85% with the presence of saturated zone. This would classify all three sets as Class IV, so it can be said that treatment train systems exhibit better performances in BOD removal compared to single bioretention systems.

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