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Constructed Wetland to Treat Tapioca Starch Wastewater in Indonesia

D. Kurniadie*, D. Wijaya[1], D. Widayat, U. Umiyati and Iskandar[2]

Department of Agronomy, Faculty of Agriculture, Padjadjaran University, Bandung, Indonesia
[1]School of Graduate Student, Padjadjaran University, Bandung, Indonesia
[2]Department of Fishery, Faculty of Fishery and Sea Technology, Padjadjaran University, Bandung, Indonesia
✉ denny.kurniadie@gmail.com

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Abstract: The tapioca wastewater normally is discharged directly into the surface water without treatment processes causing pollution and harmful to the surface water. A constructed wetland to treat wastewater from tapioca starch factory has been built in tapioca factory Sumedang Regency, Indonesia, in December 2015. Every nine days, water samples from both influent and effluent were taken and analysed for COD, BOD_5, O_2, cyanide and total settleable solids. The objective of this study was to find out whether combination of pre-treatment and constructed wetland planted with *Phragmiteskarka* can meet the discharge requirements corresponding to 150 mg l^{-1} biochemical oxygen demand (BOD_5), 300 mg l^{-1} chemical oxygen demand (COD), 100 mg l^{-1} TSS and 0.3 mg l^{-1} cyanide according to Indonesian standard for tapioca industry.The results of this experiment from period from July 2016 to March 2017 showed that the treatment efficiency of BOD_5, COD and total settleable solids were 99.07%, 98.99% and 92.54% respectively, whereas the average concentration in effluent was 17 mg $l^{-1}$for BOD_5, COD was 22 mg $l^{-1}$and total settleable solids was 51 mg l^{-1}. The overall results show that BOD_5 and COD concentration in effluent were already far lower than the Indonesian standard for tapioca factory wastewater.

Key words: Constructed wetland, phragmites karka, tapioca wastewater.

Introduction

Cassava is a native plant from South America which has important source of carbohydrates for human consumption especially in the tropical countries. Most people in the tropics use cassava as a major source of calories (Dufour, 1989). Cassava contain 94% carbohydrate and low content of protein and vitamin. Cassava belong to the third largest source of carbohydrates for human consumption in the world (Ghihime et al., 2015). Tapioca starch production has an important role in increasing economic sector in Indonesia. Tapioca starch processing produce not only tapioca flour but also by-products such as solid waste, gas and wastewater. The total wastewater produced per ton of tapioca starch was 12-15 m^3 (Kamaraj et al., 1996; Fettig et al., 2013). According to Bengtsson and Treit (1994) tapioca wastewater usually has high content of organic material such as chemical oxygen demand (COD) up to 25,000 mg l^{-1}, TSS up to 3000-15,000 mg l^{-1} and also high cyanide content up to 10-15 mg l^{-1}.

Problem related to tapioca wastewater became serious in Indonesia. Kiravanich (1977) reported that tapioca wastewater can cause serious pollution problem in many Asian countries. The tapioca wastewater can harm aquatic organisms in many public waters and river. According to Rajbhandari and Annachhatre (2004) tapioca starch wastewater has high cyanide content up

*Corresponding Author

to 10-15 mg l^{-1}, which is very toxic to many aquatic life as low as 0.3 mg l^{-1}. Suspended solids present in wastewater can settle on the streambed and spoil fish breeding areas in the stream. High biochemical oxygen demand (BOD) in the tapioca wastewater will reduce oxygen content in receiving public water (Rajbhandari and Annachhatre, 2004).

In Indonesia most of cassava processing occurs in small facilities that discharge this effluent without any treatment to the surrounding, thus creating water pollution in rivers and ground water and reducing oxygen level due to high content of organic compounds. According to Sanches et al. (2017), untreated effluent of cassava wastewater can harm the fauna of the river due to high content of cyanide. Water pollution caused by agriculture industries, such as tapioca starch production can cause negative impacts to many public waters in Indonesia. Those wastewater (around 75%) was generally directly discharged into rivers causing many environmental pollution problem such as eutrophication and diarrheal diseases, such as cholera, typhoid, dysentery and hepatitis (Buttler et al., 1990; Denny, 1997; Kurniadie, 2011). Furthermore Kurniadie (2011) stated that around 30% of wastewater in Indonesia comes from agricultural wastewater, animal husbandry wastewater and others. According to Kurniadie and Kunze (2000), the cost of building wastewater treatment facilities in Indonesia was very expensive, so treatment of wastewater before entering the river or other public waters in Indonesia is still less done.

According to Vymazal (2010), constructed wetlands are natural ecosystems which is simple, safe, cheap, eco-friendly, environmentally friendly and has been developed to remove pollutants from wastewater. This artificial wetland mimic the treatment that occurs in natural wetlands by relying on heterotrophic microorganisms, aquatic plants and a combination of naturally occurring biological, chemical and physical processes. This system will be the treatment alternative to conventional wastewater treatment in Indonesia which is expensive due to high technology. This system will be suitable for Indonesian condition due to simple in technology, environmentally friendly, using local materials and almost free maintenance (Kurniadie, 2011).

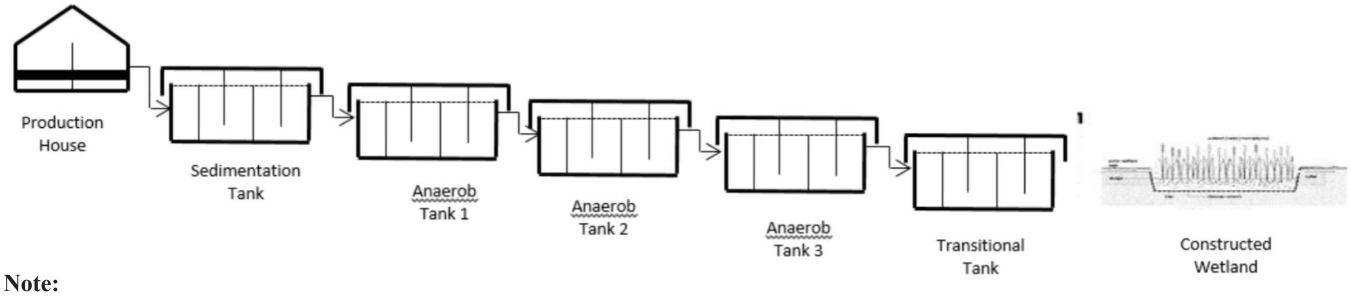
Constructed wetlands (CWs) have been used as secondary treatment for domestic wastewater, industrial and agricultural wastewater (Sayadi et al., 2012). This system has been widely used in various countries such as America, Germany, Australia, England, China, India and Czech as an alternative wastewater treatment especially for isolated areas where wastewater pipe installation is not available yet (Kurniadie, 2011). According to Cooper and Boon (1987) the efficiency of this system to reduce wastewater contaminants was already high. Geller (1997) stated that constructed wetlands (CWs) can reduce 99% BOD_5, COD (95-99%), total N (71-97%) and total P (97-99%). According to Vymazal (1996) this system can decrease 77-98% BOD_5, COD (59-91%) and SS (77-99%). Kurniadie and Kunze (2000) stated that constructed wetland to treat house wastewater by using *Phragmiteskarka* in Sumedang, Indonesia can reduce BOD_5 98.94%, COD 96.76%, PO_4-P 91.92%, total nitrogen 53.71% and more than 98% for *E. coli* bacteria.

The objective of this study was to find out whether combination of pre-treatment and constructed wetland planted with *Phragmiteskarka* can meet the discharge requirements corresponding to 150 mg l^{-1} biochemical oxygen demand (BOD_5), 300 mg l^{-1} chemical oxygen demand (COD), 100 mg l^{-1} TSS and 0.3 mg l^{-1} cyanide according to Indonesian standard for tapioca industry (Ministry of Environment Republic of Indonesia, 2014).

Materials and Methods

A constructed wetland (5.6 m long, 3.6 m wide and 0.8 m deep) to treat wastewater from tapioca starch factory has been built in Sumedang Regency in December 2015. The constructed wetland is a subsurface flow constructed wetland (16.12 m^3, vertical flow, continuous feeding and drainage system spread over the whole bed area), planted with *Phragmites karka* at a density 16 plants per m^2. The wastewater was mechanically pre-treated in a sedimentation tank (1 m^3), three anaerobe tanks (3 × 1 m^3) and transition/aerobe tank (1 m^3) then flowed into the filter bed via polyethylene pipe (12 m long) by gravity (Figure 1).The filter bed was sealed with clay soil and polyethylene membrane. The filter bed was built from multi layers with sand as the main media. Small size of gravel (8-16 mm) was used in the first top layer (10 cm), followed by 10 cm of bigger size of gravel (16-32 mm). River sand was used as the main layer (40 cm deep), followed by 10 cm of small size of gravel (8-16 mm) and finally, at the bottom, 10 cm larger size of gravel (16-32 mm) (Figure 2). The treated water was collected in a drain at the bottom of the filter.

Samples of water both from influent and effluent of anaerobe tank 3, effluent of transitional tank and effluent of wetland were taken every nine days for period of eight months (July 2016 until March 2017) and analysed in the wastewater Laboratory of PDAM



Note:
1 unit of sedimentation tank—vol: 1 m³, detention time: 1 day
3 units of anaerobe tanks—vol: 3 m³, detention time: 3 days
1 unit transitional/aerobe tank—vol: 1 m^3, detention time: 1 day
Constructed wetland—vol: 16.12 m^3, detention time: 4 days

Figure 1: Layout of a vertical flow constructed wetland system for starch tapioca factory. Wastewater is pre-treated in sedimentation tank, anaerobic tanks and transitional tank.

Bandung, Indonesia, for COD, BOD_5, cyanide, O_2 and total settleable solids. The total detention time was nine days.

Before Treatment

The initial concentration of tapioca starch wastewater (BOD_5, COD and TSS) was usually higher than the Indonesian standard value for discharge into public water. Table 1 shows that the BOD_5, COD, and TSS concentrations of tapioca starch wastewater were 2472.94 mg l^{-1}, 4000.86 mg l^{-1} and 739.53 mg l^{-1} respectively, which were still higher than the Indonesian standard value for tapioca starch industry (200 mg l^{-1}, 300 mg l^{-1} and 150 mg l^{-1}), but the cyanide concentration (0.144 mg l^{-1}) was lower than the Indonesian standard value, which is 0.3 mg l^{-1}.

Pre-treatment

Pre-treatment always be coupled with additional waste management strategies. Pre-treatment are important to the constructed wetlands' performance. The accumulation of solids shortens the effective life of a constructed wetland, so pre-treatment strategy was required. Septic tanks and sedimentation tanks can remove solids and ideally release only liquid effluent for treatment within the wetlands. According to Biddlestone et al. (1991) using mechanical aeration device and a sedimentation tank was recommended for pre-treatment subsurface vertical flow wetlands. The pre-treatment of this study use sedimentation tank, three anaerobe tanks and transition tank.

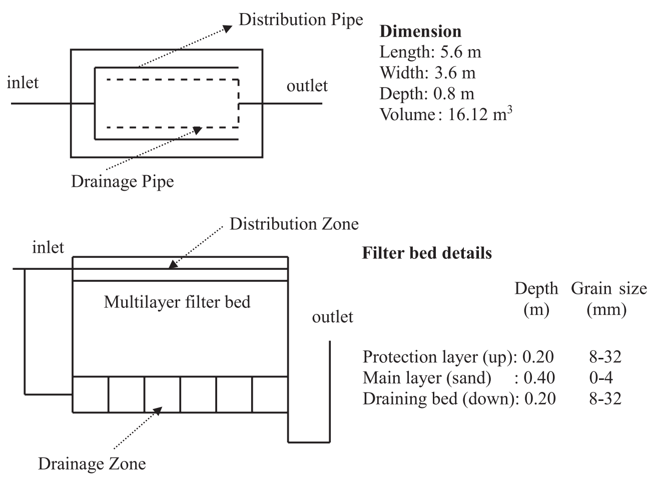


Figure 2: Schematic of filter bed in constructed wetland.

Table 1: The comparison of the parameters of influent quality with Indonesian standard value for discharge

Chemical parameters	*Influent of tapioca starch wastewater (mg l^{-1})*	*Maximum value of Indonesian standard (mg l^{-1})**
BOD_5	2472.94	150
COD	4000.86	300
TSS	739.53	100
Cyanide (CN)	0.144	0.3

* The Ministry of Environment Regulation No 5 year 2014 about wastewater effluent quality standard of tapioca industry.

Sedimentation Tank

Sedimentation tank (volume 1 m^3) was designed to separate the solid and liquid materials from tapioca starch wastewater. The solid materials will be settled on the bottom of the sedimentation bed by gravity. The liquid materials will flow through an effluent pipe to anaerobe tank (Figure 3).

Anaerobe Tank

Anaerobe tank consist of three tanks in parallel and each tank has volume 1 m^3. Each tank was filled up with 30 litre of activated sludge. In this tank, methane gas is produced due to anaerobe process responsible for reducing organic pollutants such as BOD_5 and COD. The anaerobe process will compose five layers namely gas layer, bubble layer, clear layer, active sludge layer and sludge decomposition layer (Figure 3). Clear layer that contains clear water will flow through effluent pipe to transition tank. The sludge decomposition layer was taken out two times a week.

Transitional Tank

Transitional tank (volume 1 m^3) was built to increase oxygen content of tapioca wastewater and decrease anaerobe microorganism in wastewater. Transition tank

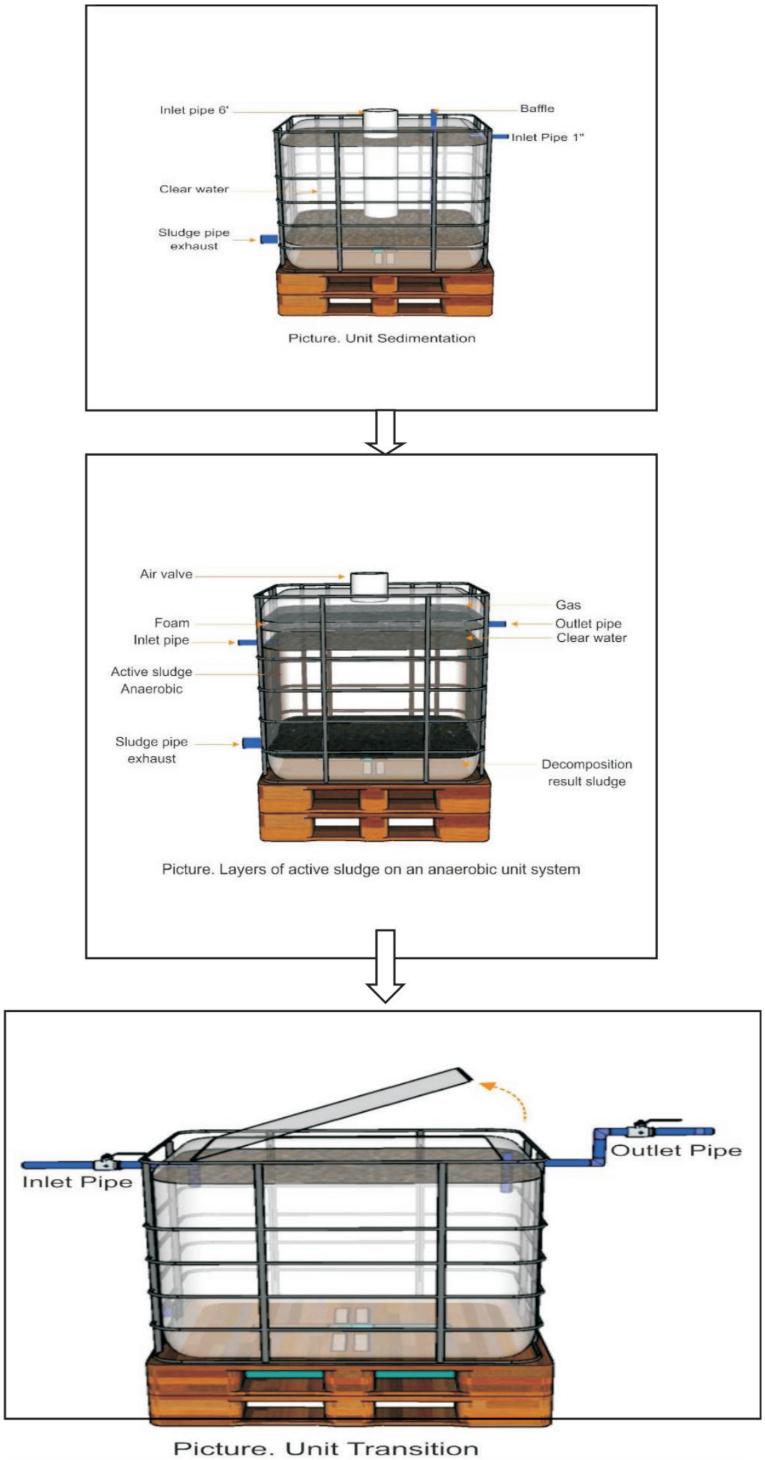


Figure 3: Sedimentation tank, anaerobe tank and transitional tank.

was set up by opening the cover of the tank and let the oxygen from the air diffuse in to the tank (Figure 3).

This constructed wetland to treat tapioca starch wastewater has been operated for fourteen months, but its treatment efficiency was already high. During this study period (July 2016–March 2017), the average of removal percentage from pre-treatment (anaerobe tanks) were 80.94% for COD, 78.27% for BOD_5, cyanide 33.38% and 77.97% for Total Settleable Solids (TSS), whereas the removal percentage in transitional/aerob tank was 46.32% for COD, 41.73% for BOD_5, cyanide 9.49% and 26.12% for TSS (Table 1). The whole removal percentage from pre-treatment was 89.76% for COD, 87.33% for BOD_5, 39.58% for cyanide and 83.72% for TSS (Table 2).

During period of analysis (March 2016 until July 2017), the average of BOD_5, COD and TSS concentrations in inlet of anaerob tank of constructed wetland was 2472.94 mg l^{-1} for BOD_5, 4000.86 mg l^{-1} for COD, cyanide 0.19 mg l^{-1} and 739.53 mg l^{-1} for TSS, whereas the concentration of BOD_5, COD, cyanide and TSS in outlet of transitional tank or inlet of constructed wetland was decreased to 313.25 mg l^{-1}, 409.34 mg l^{-1}, 0.087 mg l^{-1} and 120 mg l^{-1} for BOD_5, COD, Cyanide and TSS respectively (Table 2, Figure 4). This pre-treatment process has high removal percentage (87.33% for BOD_5, 89.76 for COD, 39.58% for cyanide and 83.72% for TSS). These concentrations of BOD_5, COD and TSS in outlet of transitional tank still exceeded the Indonesian standard for tapioca factory wastewater 150 mg l^{-1} for BOD_5, 300 mg l^{-1} for COD and 100 mg l^{-1} for TSS (Ministry of Environment, Republic Indonesia, 2014).

The average concentrations of BOD_5, COD, cyanide and TSS in outlet of constructed wetland were 53.67 mg l^{-1} for BOD_5, 56.81 mg l^{-1} for COD, 0.065 mg l^{-1} for cyanide and 51 mg l^{-1} for TSS. These average concentrations of BOD_5, COD, cyanide and TSS were lower than the Indonesian standard for tapioca factory wastewater 150 mg l^{-1} for BOD_5, 300 mg $l^{-1}$for COD, 0.30 mg $l^{-1}$for cyanide and 100 mg $l^{-1}$for TSS. The average concentration of oxygen in outlet of anaerobe tank was 0.97 mg l^{-1}, whereas in outlet of transitional tank or inlet of constructed wetland was 5.72 mg l^{-1} $O_2$and increased to 5.97 mg l^{-1} O_2in outlet of constructed wetland.

Discussion

This research demonstrates that the pre-treatment of subsurface vertical flow constructed wetland (sedimentation tank, anaerobe tank and transitional tank)

Table 2: Removal percentage from anaerobic tank and transitional tank (Pre-treatment)

No.	*Parameter*	*Anaerobe*		*Removal percentage*	*Transitional*		*Removal percentage*	*Total removal*
		Inlet	*Outlet*		*Inlet*	*Outlet*		
1	COD (mg/l)	4000.86	762.59	80.94	762.59	409.34	46.32	89.76
2	BOD_5 (mg/l)	2472.94	537.59	78.27	537.59	313.25	41.73	87.33
3	Cyanide (mg/l)	0.144	0.096	33.38	0.096	0.087	9.49	39.58
4	TSS (mg/l)	739.53	162.92	77.97	162.92	120.36	26.12	83.72

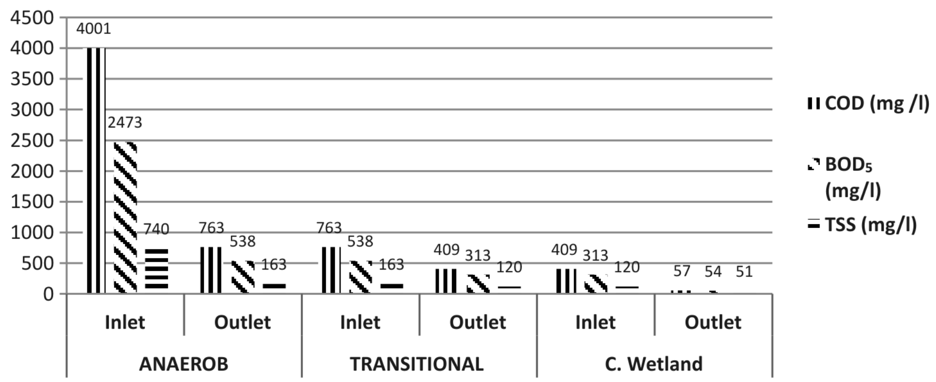


Figure 4: Concentration of COD, BOD_5 and TSS (mg l^{-1}) in anaerobe tank, transitional tank and constructed wetland (main treatment).

to treat wastewater from tapioca factory in Sumedang Indonesia has high treatment efficiency in terms of the biological oxygen demand (BOD_5), chemical oxygen demand (COD), cyanide and total settleable solids (TSS). The average of treatment efficiency of BOD_5, COD, cyanide and TSS from pre-treatment was 87.33% for BOD_5, 89.76% for COD, 39.58% for cyanide and 83.72% for TSS, whereas the average of whole removal efficiency (combination of pre-treatment and constructed wetland as a main treatment) was 97.83% for BOD_5, 98.58% for COD, 95.37% for cyanide and 54.86% for TSS.

According to Cooper and Green (1995), vertical flow system of constructed wetland can achieve full BOD_5 and COD removal because of high amount of oxygen transfer through the reed bed. The average concentration of oxygen in this constructed wetland was increased from 0.97 mg l^{-1} in inlet to 5.97 mg l^{-1} in outlet. Bacteria required high concentration of oxygen to degrade organic pollutants such as BOD and COD in this constructed wetland. Platzer and Mauch (1997) stated that removal efficiency of vertical flow system of constructed wetland is mainly based on very efficient soil aeration and, therefore, BOD_5 and COD removal is high. The vertical subsurface flow system has a high oxygen content and better substrate aeration (Bahlo and Wach, 1992). Macrophyte plant roots and rhizomes in the rhizosphere leak oxygen into microzone in an otherwise anaerobic zone and stimulate the breakdown of carbonaceous compounds (Juwarkar et al., 1995). The most important function of macrophytes plant roots and rhizomes in constructed wetlands with subsurface flow in term of organic matter removal is supply of oxygen to aerobic bacteria (Brix and Schierup, 1989). The colloidal and soluble BOD_5 and COD remaining in solution are removed as a result of the metabolic activity and physico-chemical interaction within the root zone (Wood, 1990).

Conclusion

This study showed that the pre-treatment facilities (sedimentation tank, anaerobe tank and transition/ aerobe tank) have average of removal percentage of 87.33% for BOD_5, 89.76% for COD, 39.58% for cyanide and 83.72% for TSS, whereas subsurface flow vertical constructed wetland planted with emergent plant *Phragmiteskarka* has removal percentage of 98.58% for COD, 97.83% for BOD_5, 95.37% for cyanide and 54.86% for TSS. The average of whole removal efficiency from this constructed wetland from pre-treatment and constructed wetland as a main treatment was 97.83% for BOD_5, 97.83% for COD, 95.37 for Cyanide and 54.86% for TSS. The average of COD, BOD_5, Cyanide and TSS in outlet of constructed wetlands were far lower than the Indonesian standard for tapioca processing wastewater.

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Table 3: Removal percentage of constructed wetland (main treatment) and combination of pre-treatment and constructed wetland

No.	Parameter	Pre-treatment	C. Wetland		Removal (%)	Removal combination of pre-treatment and C Wetland (%)
		Inlet	Inlet	Outlet		
1	COD (mg/l)	4000.86	409.34	56.81	86.12	98.58
2	BOD_5 (mg/l)	2472.94	313.25	53.67	82.87	97.83
3	Cyanide (mg/l)	0.144	0.087	0.065	71.55	95.37
4	TSS (mg/l)	739.53	120.36	51	25.27	54.86

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