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ORIGINAL ARTICLE

# Municipal wastewater management using *Vetiveria zizanioides* planted in vertical flow constructed wetland

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**Abstract**

This study investigated wastewater management using *Vetiveria zizanioides* planted in vertical flow constructed wetland (VFCW). Wastewater from the grit removal chamber and the primary sedimentation tank of Daspoort Wastewater Treatment Works was fed into six-pilot VFCW consisting of 1000-L plastic tanks having 500-mm-deep, 10–15-mm-diameter granite substrate planted with *V. zizanioides*. Irrigation of macrophytes using effluent from the grit removal chamber and primary sedimentation tanks was done after 3 months of planting and the VFCW monitored. Wastewater samples were collected and analysed using standard procedures. The pollution parameters of the initial sample were total alkalinity 297 ± 27.3 mg/L; COD 627 ± 149.0 mg/L; EC 82.53 ± 5.4 ms/m; free and saline ammonia 36.02 ± 4.1 mg/L, nitrate/nitrite 0.09 ± 0.1 mg/L; pH 7.66 ± 0.4; phosphate 3.07 ± 0.3 mg/L, sulphate 44.57 ± 3.1 mg/L; TDS 551 ± 37.8; TSS 319 ± 34.2 mg/L; and TKN 41 ± 6 mg/L. Percentage removal of 89.57, 98.34% TSS; 98.95, 98.62 free and saline ammonia; 89.87, 91.44% TKN; and 80.65, 58.02% COD for screen and settled wastewater, respectively, was obtained from the VFCW. VFCW using locally available *V. zizanioides* is a viable alternative for municipal wastewater treatment.

**Keywords** Vertical flow constructed wetland · *Vetiveria zizanioides* · Municipal wastewater

## Introduction

Access to safe drinking water is a basic necessity; its provision should be a main public health priority. This concern has been widely addressed in developed countries; however, availability of sanitation and clean water is not the rule in most developing countries. The shortage of safe drinking water is one of the major worries in developing countries. The available safe drinking water is placed under pressure continually by the rapid increase in population, thereby reducing the daily per capita availability. To improve the health of people mostly in the developing world, there is always the need to provide communities with safe and clean water, thus meeting the United Nation Sustainable Developmental Goal of access to water (Malik et al. 2015). Point and non-point pollution from anthropogenic and other sources has been a major concern in developing countries. Omole et al. (2016) opined enhancement of flow along Skinnerspruit by cleaning observed growth in the channel and suggested further investigation of activities causing pollution upstream on the Apies River.

A valuable source of water in a semi-arid country such as South Africa is the reuse of wastewater. Daspoort Wastewater Treatment Works (DWWTW), one of the 10 wastewater treatment plants in the Tshwane municipality, utilizes a certain degree of indirect reuse of treated effluent. The treated wastewater effluent is discharged into Apies River, and it flows into dams or reservoirs, from where it is withdrawn to water treatment plants. The quality of the treated effluent deteriorates in the dams due to some algal growth. This is as a result of eutrophication of the river caused by enhanced input of nitrogen and phosphorus (Nyenje et al. 2010).

Many high-technology wastewater treatment systems have been developed and tested to ensure the removal of nutrients before discharge into stream/rivers. DWWTW employs biofiltration and biological nutrient removal activated sludge

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systems. The DWWTW uses averagely R 5.4 million (about \$378,884) worth of energy per annum, with a higher percentage used on the anaerobic digestion processes and activated sludge system. It also requires high initial investment, consistent power supply and skilled labour for operation and maintenance. Constructed wetlands using locally available plants have been shown to be a potentially viable option for wastewater treatment in developing countries (Badejo et al. 2015; Konnerup et al. 2009; Zhang et al. 2014).

Constructed wetlands (CWs) are engineered systems, designed and constructed to utilize simple components, which interact in a complex manner to provide an ideal medium for wastewater treatment (Kadlec and Wallace 2008; Vymazal 2010). CWs are systems that function predominantly on naturally occurring integrated and mutually dependent biochemical processes, which work by solar and microbial processes and do so within a controlled environment (Faulwetter et al. 2009; Foladori et al. 2015). CWs are treatment facilities duplicating the processes occurring in natural wetlands consisting of macrophytes, substrate and microbial assemblage. CW has been shown to have many advantages over the traditional systems—they are less expensive in construction, operation and maintenance; they consume less energy; they save high cost on sewage collection system; they can be operated on different scales; they guarantee convenient recycling; and they add aesthetic value to the environment (Chen et al. 2008; Zhang et al. 2014).

Various categories of CW can be designed to operate different flow patterns, varying substrate sizes and macrophytes of different species (Badejo et al. 2013). The flow could be intermittent with fill and drain mode (Poach et al. 2007), continuous down flow, continuous sprinkling or erratic (Kadlec and Wallace 2008). CW may be classified according to the macrophytes as free-floating, emergent and submerged macrophytes. They are classified broadly as free water surface (FWS) wetlands or surface flow (SF) constructed wetlands, and vegetated submerged bed (VSB) systems or subsurface flow (SSF) constructed wetlands (Arias *and Brown* 2009; Kadlec and Wallace 2008). The literature also shows that the combination of CW with other treatment technologies achieved a 'win–win' performance and new pathway for extensive use of CW (Liu et al. 2015).

Reeds (*Phragmites* sp.), bulrush (*Scirpus* sp.) and cattail (*Typha* sp.) are the most common aquatic plants in use for vegetated submerged bed constructed wetlands as the choice of macrophytes used is vital in its design (Brisson and Chazarenc 2009; Caselles-Osorio and García 2007). Other moisture-tolerant plants are currently studied to examine their performance in wastewater treatment (Belmont et al. 2004; Brix 1997). Wetland plants generally have high productivity and growth rate (Brix 1997).

Wastewater treatment using Vetiver is a phytoremedial technology developed in Queensland (Truong et al. 2001). Studies showed that vetiver has a super absorbent characteristic required in wastewater treatment (Truong et al. 2001). Vetiver grass absorbs nutrients, particularly nitrogen in wastewater; it has also been shown to have high tolerance to elevated levels of agrochemicals and heavy metals (Badejo et al. 2015; Cull et al. 2000; Truong et al. 1998). Ash and Truong (2004) obtained 96.3 and 96.8% reduction in BOD and TSS in vetiver grass for sewage treatment and concluded that a high-technology solution is not necessarily the best available option in wastewater treatment. Vetiver has been used in more than 120 countries for environmental protection (Truong 2000). Badejo et al. (2017) used sequential activated sludge reactor and vegetated submerged bed constructed wetland planted with *Vetiveria zizanioides* for municipal wastewater treatment in Gauteng, South Africa.

Considering the importance attached to provision of safe water for health and the necessity of reuse of treated water to augment the available water in semi-arid regions, there is a need to provide a simple, cost-effective and aesthetically pleasing alternative to the traditional wastewater treatment method. This study therefore aims at providing a viable option to wastewater treatment, using vegetated constructed wetland planted with locally available *V. zizanioides*.

## Materials and methods

### Description of the study site

Daspoort Wastewater Treatment Works is located on the southern bank of Apies River, north-western side of Pretoria Central Business District, South Africa. It is designed to treat 60 million litres of wastewater per day. The DWWTW employs the bio-filtration and activated sludge methods at its eastern and western works, respectively. The experiment was carried out at the western works, which comprises of screens, grit removal tanks, primary sedimentation tanks, activated sludge and secondary sedimentation tanks. The influent into the western works undergoes preliminary treatment in the coarse screen, fine screen and grit removal chamber after which it is channelled to the primary sedimentation tank.

Effluent was pumped after the preliminary treatment and primary treatment using 65-mm-diameter pipes into a greenhouse consisting of six-pilot vertical flow constructed wetland (VFCW); irrigation was done using a 10-mm-diameter pipe. The pilot VFCW bed consisted of 1000-litre plastic tanks (Fig. 1) with a surface area of 1.2 $m^2$ each. The substrate was 500 mm deep, containing 10–15-mm-diameter granite with 100 mm thick overlay of manure from the DWWTW sludge, to ensure adequate growth of the macrophytes before wastewater irrigation. Inlet pipe 10 mm

**Fig. 1** Experimental setup showing pipe connections with *V. zizanioides* in VFCW

diameter was provided to ensure even irrigation and outlet points to ensure sample collection and wastewater discharge.

Vetiver is a tall and erect grass which forms a dense hedge when planted close together in row. It grows very quickly with new shoots developing underground. It has short rhizomes without stolons and enormous root system that grows fast (Chen et al. 2004). Vetiver plants were obtained from Hydromulch (PTY), South Africa. The *V. zizanioides* tillers, averaging 75 cm in height, were transplanted into VFCW.

The six-pilot VFCW beds were planted with transplanted rhizomes of *V. zizanioides*. They were planted at 200 mm centre to centre and irrigation with wastewater began 3 months after planting. Tap water from DWWTW was used for irrigating the VFCW during the commissioning months. Dried sludge from the sludge drying bed within the treatment plant was used to support initial plant growth.

Wastewater was abstracted from the grit removal chamber and effluent from the Dortmund primary sedimentation tank; this was pumped separately in batches using RYOBI pumping machine into the pilot VFCW. Three-pilot VFCW beds received effluents from the Dortmund primary sedimentation tank and another three from the grit removal chamber (Fig. 2). The wastewater was analysed for characterization and performance evaluation of the system. Grab samples were collected from the grit chamber, primary sedimentation tank and the VFCW at three days interval over a period of 30 days using standard procedures. The beds were saturated with wastewater for the entire period of the experiment; the design and operation of the 6 VFCW (receiving wastewater from both the sedimentation and grit removal tanks) were identical throughout the experimental period.

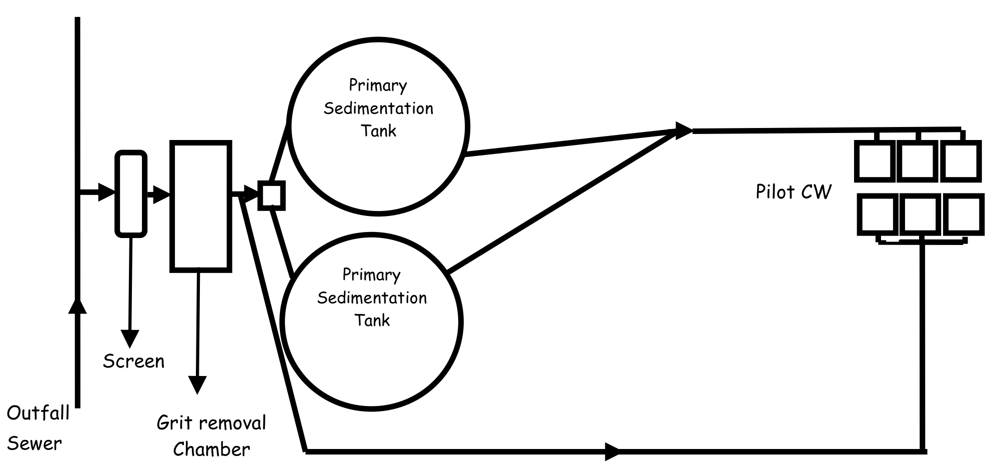


**Fig. 2** Schematic diagram of flow from the Outfall sewer to VFCW

The measurement of pollution parameters like total alkalinity, chemical oxygen demand (COD), pH, electrical conductivity, free and saline ammonia, nitrate, orthophosphate, sulphate, total dissolved solids (TDS), total suspended solids (TSS) and total Kjeldahl nitrogen was taken using standard methods (APHA 2005). Samples were analysed at the Water Resources and Environmental Engineering Laboratory, Civil Engineering Department, Tshwane University of Technology and DWWTW laboratory. Three replicate samples were taken for each of the sampling point, and the mean values were used in the analyses. The test was repeated in some cases to control for errors.

## Results and discussion

### Characterization of wastewater

Sample analysed during the period for the raw wastewater after mechanical screening and grit removal had average values and standard deviation of total alkalinity 297 ± 27.3 mg/L; COD 627 ± 149.0 mg/L; EC 82.53 ± 5.4 ms/m; free and saline ammonia 36.02 ± 4.1 mg/L; nitrate/nitrite 0.09 ± 0.1 mg/L; pH 7.66 ± 0.4; phosphate 3.07 ± 0.3 mg/L; sulphate 44.57 ± 3.1 mg/L; TDS 551 ± 37.8 mg/L; TSS 319 ± 34.2 mg/L; and TKN 41 ± 6 mg/L. The VFCW performance was assessed by the listed parameters, and results are presented in Tables 1 and 2.

The pH varied between 7.14 and 7.3 for effluents from the VFCW receiving influent from the grit chamber and the primary settling tank. This range is favourable for bacteria

**Table 1** Characteristics of wastewater from the grit chamber before and after treatment in VFCW

| Parameters | Before treatment | After treatment[a] (days) | | | | |
|---|---|---|---|---|---|---|
| | | 6 | 12 | 18 | 24 | 30 |
| Total alkalinity (mg/L) | 316 | 336 | 334 | 302 | 282 | 266 |
| COD (mg/L) | 481 | 170 | 124 | 100 | 112 | 93 |
| EC (ms/m) | 80.5 | 83.6 | 74.6 | 71.2 | 65 | 66.1 |
| Free and saline ammonia (mg/L) | 43.06 | 9.33 | 5.24 | 2.68 | 0.51 | 0.45 |
| Nitrate + nitrite (mg/L) | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0 |
| pH | 7.93 | 7.31 | 7.34 | 7.44 | 7.42 | 7.14 |
| Phosphate (ortho) (mg/L) | 3.54 | 32.47 | 25.96 | 16.57 | 15.2 | 14.64 |
| Sulphate (mg/L) | 38.1 | 20.41 | 18.63 | 17.80 | 15.9 | 15.29 |
| TDS (mg/L) | 524 | 560 | 499 | 477 | 435 | 443 |
| TKN (mg/L) | 43 | 13.4 | 10.15 | 6.67 | 4.42 | 4.31 |
| TSS (mg/L) | 84.4 | 17.4 | 17.4 | 11.2 | 12.4 | 8.8 |

[a]Average from three-pilot VFCW

**Table 2** Characteristics of wastewater from the primary sedimentation tank before and after treatment in VFCW

| Parameters | Before treatment | After treatment[a] (days) | | | | |
|---|---|---|---|---|---|---|
| | | 6 | 12 | 18 | 24 | 30 |
| Total alkalinity (mg/L) | 290 | 289 | 264 | 262 | 224 | 243 |
| COD (mg/L) | 162 | 122 | 113 | 92 | 88 | 68 |
| EC (ms/m) | 75.5 | 76.6 | 77.2 | 69.4 | 69.6 | 69.5 |
| Free and saline ammonia (mg/L) | 36.26 | 4.39 | 7.91 | 2.43 | 3.14 | 0.5 |
| Nitrate + nitrite (mg/L) | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 |
| pH | 7.72 | 6.84 | 7 | 7.24 | 7.22 | 7.3 |
| Phosphate (ortho) (mg/L) | 2.93 | 26.52 | 21.34 | 10.99 | 13.17 | 11.94 |
| Sulphate (mg/L) | 40.13 | 67.34 | 78.24 | 47.71 | 73.08 | 69.77 |
| TDS (mg/L) | 506 | 513 | 517 | 465 | 466 | 466 |
| TKN (mg/L) | 36 | 9.55 | 13.9 | 6.85 | 8.4 | 3.51 |
| TSS (mg/L) | 675 | 20 | 22.8 | 22 | 7.6 | 11.2 |

[a]Average from three-pilot VFCW

growth and activities required for wastewater treatment. The total alkalinity reduced from 316 to 266 and from 290 to 243 mg/L in the VFCW receiving wastewater from the grit chamber (after screening) and primary sedimentation tank, respectively. The TSS was observed to reduce from 84.4 to 8.8 mg/L (89.57% reduction) in the VFCW receiving wastewater from the grit chamber and by 98.34% in the VFCW receiving wastewater from the primary sedimentation tank.

The electrical conductivity of wastewater from the screens and primary settling tanks was observed to reduce by 17.89 and 7.95%, respectively, after 30-day retention period in the pilot VFCW.

### Nutrients removal

Nitrogen is present in many forms in municipal wastewater. Nitrogen discharged by humans is in the form of organic nitrogen and urea. This organic nitrogen is broken down to ammonia by microorganisms in the wastewater, which is then broken down into nitrate in the presence of oxygen. The experimental result showed a sharp drop after 30 days of treatment in the pilot VFCW. A percentage reduction of 98.95% in free and saline ammonia was observed in the pilot VFCW fed with wastewater from the grit removal chamber, while 98.62% was observed in that irrigated with wastewater from effluent from the primary sedimentation tank. The result agrees with Bigambo and Mayo (2005) where it was observed that the roots of some macrophytes provided required oxygen for nitrification process to be completed since denitrification cannot be completed outside nitrification.

Nitrate has severe health effects on people when ingested directly, especially from contaminated water sources such as dams and streams. Excess nitrogen in the Apies River can also stimulate eutrophication, thereby making it difficult to achieve recycling. Nitrate/nitrite level was also reduced, almost at the same rate in the two effluents as shown in Tables 1 and 2. TKN in pilot VFCW reduced rapidly. TKN was observed to reduce by 89.87% in the effluent from grit removal chamber and 91.44% in effluent from the primary sedimentation tank. Pelissari et al. (2014) opined that nitrogen removal in CW is achieved through uptake by macrophytes, bacterial biomass and adsorption to the filter medium. This shows *V. zizanioides* is efficient in nitrogen removal in wastewater (Cull et al. 2000; Truong et al. 1998).

Orthophosphate increased in the VFCW for both the effluent from the grit removal chamber and the primary sedimentation tank as shown in Tables 1 and 2.

### COD removal

The percentage removal of COD in the VFCW was faster in the wastewater from the grit removal chamber than that from the primary sedimentation tank. Result showed that 80.65% of COD was removed by the VFCW receiving wastewater from the grit chamber as against only 58.02% of COD that was removed from wastewater from the primary sedimentation tank. This result agrees with Chen et al. (2008) and Caselles-Osorio and García (2007) where it was concluded that the presence of aboveground biomass improves the removal of COD. The percentage reduction of the various parameters from the grit chamber is shown in Fig. 3.

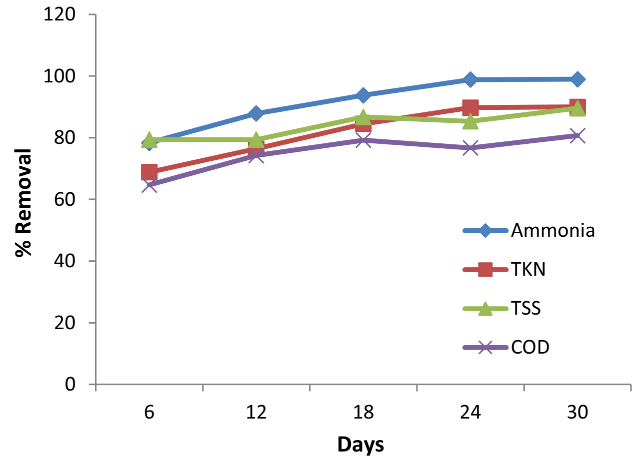


**Fig. 3** Percentage reduction from the grit chamber after treatment in VFCW

## Conclusion

The study revealed that vertical flow constructed wetland using locally available *V. zizanioides* is a viable wastewater management option. The highest percentage removal efficiency of COD (80.65%), TKN (91.44%), TSS (98.34%), free and saline ammonia (98.95%) was obtained. This showed VFCW is appropriate in wastewater treatment with or without primary treatment. The components required for construction are available in commercial quantity and could be adequately sustained. The operation and maintenance of this technology are also relatively cheap, and the technology is environmentally friendly.

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