Performance assessment of DEWATS constructed wetlands

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by

Chris Buckley and Preyan Arumugam
Pollution Research Group
University of KwaZulu-Natal

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PROJECT OUTLINE

Background Information

South Africa has prescribed a National Development Plan (NDP) whereby Government aims to alleviate poverty and inequality amongst its nation by 2030 (National Planning Commission, 2012). Part of the goal to eliminate poverty is basic service delivery of which housing, water and sanitation are key components. Despite significant progress in all sectors, backlogs remain, which have serious knock-on environmental and health effects.

One such issue is wastewater pollution stemming from poor or inadequate sanitation. According to Stats SA, 4.9 % of the total number of households in South Africa have no sanitation facility. KwaZulu-Natal is the second highest province with 124 000 of such households (Stats, SA, 2014). Whilst municipalities in the province, and nationally, have set forth their five-year Integrated Development Plan (IDP) to eradicate delays in service delivery, the eThekwini (Durban) Municipality still faced a backlog of 158 837 consumer units as of 31 December 2015 (eThekwini Municipality, 2016).

The need for employment has seen the increase in rural migrants proliferating the formation of informal settlements in urban areas over time. The eThekwini Municipality estimates these communities to comprise a third of its total population of 3.2 million people (Schneider, 2016). To circumvent open defecation thereby upgrading the living conditions in these settlements, the South African Government provided interim services of communal water, washing and sanitation facilities in the form of Community Ablution Blocks (CABs).

Essentially, a "public washroom" (Schneider, 2016), CABs are made from prefabricated shipping containers with toilets, showers and basins for washing. The eThekwini Water and Sanitation (EWS) unit has installed over 2 500 CABs (Schneider, 2016) that are all connected to the sewer system. However, it is estimated that there is approximately an equal number of residents living in informal settlements which are not close to the sewer system and municipalities have identified the high cost associated with extending the existing system. Decentralised wastewater treatment systems (DEWATS) offer an inexpensive, feasible solution to this problem which does not require highly sophisticated technologies and technical expertise for operation and maintenance as compared to conventional centralised systems (Massoud et al., 2009, Singh et al., 2009). As a leading municipality in the country, in terms of water and sanitation provision to its communities, eThekwini partnered with the Bremen Overseas Research and Development Association (BORDA), a German non-profit professional association aimed at providing sustainable solutions for water and wastewater treatment to developing nations.

The first DEWATS plant in eThekwini was designed according to BORDA guidelines (Sasse, 1998) in association with the eThekwini Water and Sanitation unit (EWS). The demonstration plant was constructed at the Newlands Mashu Research Site (29° 46' 25.648" S, 30° 58' 28.329" E) that is owned by EWS. It serves as a research ground for engineers and scientists from the University of KwaZulu-Natal and Durban University of Technology. Operational since 2010, the plant treats domestic wastewater generated by 83 middle-income households. Primary treatment is facilitated in a settler consisting of two chambers which also acts as a biogas collection point and later distributes effluent evenly into three parallel anaerobic baffled reactor (ABR) trains. Trains 1 and 2 are identical consisting of seven chambers while Train 3 has four chambers, the first three being double the size of the chambers from Trains 1 and 2 while the fourth compartment is equal to the size of the last chamber in Trains 1 and 2. A two-chambered anaerobic filter (AF) follows the ABR. The effluent from Train 1 (i.e. a third of the total effluent leaving the ABR) enters into a siphon chamber which mechanically discharges into a vertical constructed wetland (or commonly referred to as a planted gravel filter) of 94 m2 in area and 0.75 m deep, half the recommended depth by BORDA. The design hydraulic loading rate is 0.15 m3/m2/d, although the flow rate is variable. The final effluent is diverted back into the sewer system (Ref). For the effluent to be discharged into a nearby water course, EWS requires a Water Use Licence for the site from the Department of Water and Sanitation.

Constructed wetlands have been established as efficient, cost-effective, environmentally sustainable technologies for the treatment of various wastewaters (Vymazal, 2011) however, the performance and sustainability of these system for domestic wastewater treatment in South Africa have not been documented or adequately researched. Unique to other engineered systems treating wastewater, constructed wetlands mimic natural wetlands by promoting natural processes facilitated by vegetation, sediment and microbial assemblages but in a controlled manner (Lee et al., 2009; Vymazal, 2010). Nutrients and organic matter are mainly removed or transformed from the wastewater entering the system by microbial degradation or plant uptake, reducing substantial costs associated with alternative treatment technologies. Constructed wetlands are broadly classified by the hydraulic flow of the system: surface flow and subsurface flow (Kadlec and Wallace, 2009; Vymazal, 2010), of which both can be further categorised according to the vegetative growth and direction of hydraulic flow, respectively (Vymazal, 2011). Furthermore, these systems can be constructed in remote locations outside the centralised sewered system (Verhoeven and Meuleman, 1999) increasing the application of these systems in rural areas.

The use of surface flow or free water surface flow constructed wetlands can be eliminated due to the health and safety hazards associated with children playing near the site. Furthermore, the free or open surface water may promote the breeding of pests such as mosquitoes. Due to the undulating landscape of the KwaZulu-Natal province, vertical flow constructed wetlands appear to be the more feasible option due to their smaller footprint (Zhang et al., 2009) and therefore more applicable as compared to horizontal flow wetlands. Moreover, since these systems provide nitrified effluent, it can be integrated with agricultural practices by the communities involved. This encourages the reuse of DEWATS effluent decreasing the demand on fresh water for irrigation. Furthermore, due to ongoing reports of theft of electricity cables in the city, reported to cost the Municipality approximately R230 million annually (eThekwini Municipality, 2014), all technologies implemented in these communities need to be energy-independent.

It would seem as though the best sanitation option for informal communities with installed CABs are decentralised septic tanks followed by post treatment in vertical flow constructed wetlands. The first phase has already been completed whereby the first DEWATS module also designed by BORDA was installed by EWS in an informal settlement, just 40 km north of Durban and part of the eThekwini Municipality. The Frasers settlement has installed CABs with decentralised septic tanks as it is located 2 km away from the centralised sewer system. The final effluent is diverted to evapotranspiration areas (BORDA, 2011).

Problem statement

The performance of the entire Newlands Mashu DEWATS plant, specifically chemical oxygen demand (COD) removal, and flow characterisation through the anaerobic baffled reactors have been studied and is on-going. However, no attempt has been made to evaluate the performance of the vertical flow constructed wetland at its current operation. In addition, no one has determined or defined its limitations, if any, by the restriction of the depth to the current landscape, the manifold design, and functionality of the mechanical siphon, media gradation or the selected vegetation. According to BORDA, the plant species selected were chosen due to its availability at the site and not based on any recommendations in literature. Moreover, for EWS to achieve a Water Use Licence for the site, the quality of the final effluent must meet government imposed discharge standards for domestic effluent (Table 1).

Table 1. National Discharge Limits applicable to the irrigation of any land or property up to 2000 m^3 (sourced and adapted from National Water Act 36 of 1998 - Regulations and Notices - Government Notice R665, 2013 http://www.saflii.org/za/legis/consol_reg/nwa36o1998rangnr665604/)

Variables	Limits
Chemical Oxygen Demand (COD)	75 mg/l
Ammonia (ionised and un-ionised) as Nitrogen	3mg/l
Nitrate/Nitrite as Nitrogen	15 mg/l
Ortho-Phosphate as phosphorous	10 mg/l
Suspended Solids	25 mg/l
pH	5,5-9,5
Electrical Conductivity	70 milliSiemens above intake to a maximum of 150 milliSiemens per metre (mS/m)

In the Small Domestic Wastewater Treatment Plant Guideline issued by the Department of Public Works it is mentioned that treated effluent can only be discharged into a river or water course if all parameters fall within the limits imposed by the Department of Water Affairs. A preliminary assessment of the final effluent over a three month period (November 2015-January 2016) revealed high levels of ammonium (15 mg/l) and nitrate (21 mg/l). The latter is expected since these systems are unsaturated and intermittently fed to allow for maximum oxygen diffusion into the media thus providing the adequate conditions required by nitrifying bacteria. However, it is well known that nitrified effluent pose a threat to the receiving environment by contributing to eutrophication and loss of aquatic life by depletion of oxygen. Thus, the overall performance of the full scale constructed wetland needs to be examined over a long period to determine any faults and failures in the system as well identify any limitations by the modification in the depth.

Furthermore, for the eThekwini to guide the rapid roll out of CABs to communities located outside the boundaries of the centralised sewer network, a guideline needs to be put in the place to assist in the design, operation and maintenance of DEWATS plants. The benefits and limitations of the DEWATS module is currently being studied however, no experimentation has been done of the performance if vertical flow wetlands with different design configurations. The effects of hydraulic loading rate of domestic wastewater and the change in media gradation in the treatment efficiency of vertical flow constructed wetlands in South Africa is still unknown. It is hypothesised that a higher hydraulic detention time will occur in a stratified filter layer of coarse sand above a layer of fine sand. Moreover, Wu et al (2015) recently reviewed the design and operation of constructed wetlands for wastewater treatment and found that pollutant degradation is evident at different depths. The effective depth (i.e. where the transformation of pollutants has reached its peak and its concentration will not change along the rest of the depth of the wetland) has not been established for the strength of influent at Newlands Mashu.

Since no guideline exists on the design, operation and maintenance of vertical flow constructed wetlands in South Africa, the DEWATS plants described above will serve as a basis for the design model of vertical flow constructed wetlands serving these communities. This study will contribute to the knowledge on the performance of these systems as a post treatment from DEWATS from a South African perspective. It will aid in understanding the reliability of these passive systems, the design criteria for optimal performance as well as how to maintain it for on-going functionality.

RESEARCH AIMS

1. Evaluate the performance of a full scale vertical flow constructed wetland receiving anaerobically treated (anaerobic baffled reactor - ABR) domestic effluent for nutrient and organic removal in a decentralised wastewater treatment system
2. Examine the effect of hydraulic loading rate, flow fluctuation, media gradation and depth on the performance of pilot scale vertical flow constructed wetlands fed with ABR effluent
3. Provide a short guideline for the design, operation and maintenance of vertical flow constructed wetlands treating ABR and septic tank (CAB) effluent in KwaZulu-Natal.

The review will focus only on the design parameters suspected to affect the treatment efficiency of the full scale vertical flow constructed wetland in the Newlands Mashu DEWATS plant fed anaerobic baffled reactor (ABR) effluent. These parameters will be described in more detail to provide the information necessary to design, construct and operate pilot scale vertical flow constructed wetlands that will determine the most optimum design for higher performance and sustainability. This data will allow for a compilation of a short guideline for the design and operation of these systems in DEWATS serving CABs in eThekwini and the greater KwaZulu-Natal area. Lastly, a brief design of the experimental pilot scale wetlands will be given.

LITERATURE REVIEW

The outline of this literature review will provide a short classification of vertical flow constructed wetlands, explain the biological processes for the removal of nitrogen since total nitrogen removal is poor in these systems, define the selected design parameters affecting the performance of these systems and lastly, describe the design of the pilot scale vertical constructed wetlands receiving ABR effluent. The result of this study will assist in devising a preliminary guideline for the design, operation and maintenance of these systems for DEWATS serving CABs.

1. Classification of vertical flow constructed wetlands

A subsurface flow constructed wetland, vertical flow systems (typically consisting of more than one stage) are unsaturated and intermittently fed to allow for maximum oxygen diffusion into the media thus providing the adequate conditions required by nitrifying bacteria. Wastewater permeates through the filtration media in a vertical path either in an up or down direction and is discharged through a drainage pipe. Oxygen is thus able to diffuse into the empty pore spaces in the media. As a result, these beds require a smaller area compared to another type of subsurface flow constructed wetlands, horizontal flow systems (Cooper, 2009; Zhang et al., 2009). Danish systems have inserted ventilation pipes to facilitate the movement of air from the surface to the base of the constructed wetland CW (Brix and Arias, 2005). However, since there are entirely aerobic conditions these systems do not provide any denitrification and halt total nitrogen removal (Brix and Arias, 2005; Nivala et al., 2013, Zhang et al., 2009). Despite poor nitrogen removal (Jia et al., 2010; Scholz, 2010), vertical CWs are very efficient in the removal of suspended solids and organics (Brix et al., 2002; Molle et al., 2005). Sellami et al. (2009) speculates that the high suspended solid removal in vertical flow constructed wetlands is due to the accumulation of solids near the surface of the bed that reduces the hydraulic conductivity of the media. Conversely, while the attached suspended solids in the filtration media may be high, it limits oxygenation of the system that can decrease the removal of organics and nitrogen (Sellami et al., 2009). The beds are usually filled with sand. Four layered sand-based systems have been designed in Germany (Nivala et al., 2013). Gravel however, is the substrate of choice as it increases the hydraulic conductivity of the media (Kadlec and Wallace, 2009; Saeed and Sun, 2012). More recently, some studies have investigated the effect of local resources such as granulated blast furnace slag (Korkusuz et al., 2005) and sludge-ceramsite (Wu et al., 2016). Ávila et al., (2014) however, confirmed that sand based systems performed better than gravel based systems for emerging organic contaminant removal as well as conventional pollutants.

2. History and current status

Vertical flow constructed wetlands did not receive much interest in the past possibly due to the higher operating needs of the system for intermittent feeding (Vymazal, 2010) and hence, performance data of these systems were scarce. However, in the 1990s, Europe recognized the potential for higher effluent quality in these systems due to its oxygenation capacity (Cooper, 2009) compared to the favoured passive horizontal flow systems. Since then, vertical flow constructed wetlands have been widely implemented in Europe usually designed for less than 4000 person equivalents PE, especially for domestic wastewater treatment from small communities (i.e. decentralised systems) (Sani et al., 2013). Presently, these systems are chosen as a small secondary treatment option for domestic sewage (Cooper, 2009) and a growing trend has emerged on the use of vertical flow constructed wetlands since 2005 established from the demand of higher ammonia removal from the influent wastewaters (Brix and Arias, 2005, Vymazal, 2005, 2008), greater hydraulic loading rates and reduced area requirement compared to horizontal flow systems. Since, vertical flow constructed wetlands typically consist of more than one stage for higher treatment capability, it would be interesting to find design features that can be enhanced/modified to improve the complete nutrient removal in these systems.

One drawback of vertical flow constructed wetlands is clogging (Cooper, 1999; Zhao et al., 2011). Sani et al. (2013) describes clogging as a seasonal phenomenon spawn upon by macrophyte growth intensified by nutrient uptake and subsequent litter due to senescence at the end of the growing season in addition to the retention of suspended particles in the filtration media which inevitably compromises the performance of the system. Petitjean et al. (2016) however, correctly identifies that the clogging nature of these systems is what allows for the treatment capability of the system. Therefore, research must attempt to distinguish between natural clogging to a dysfunctional system inhibited by clogging (Petitjean et al., 2016). They diagnosed that low effluent nitrate concentrations and absence of dissolved oxygen along the depth of the bed will give early insight to the possibility of clogging. Ye et al. (2016) confirmed that oxygen profiles in vertical flow beds rise then decrease along the depth of the bed with the main contributor of oxygen being transfer from the atmosphere. Dissolved oxygen is mainly consumed in the upper parts of the bed by organic degradation and then later used for nitrification near the roots which also contributes to the redox potential of the system (Petitjean et al., 2016; Ye et al., 2016).

In order to maximise the performance of any constructed wetland, the underlying chemical and biological processes driving the treatment efficiency of the system needs to be completely understood. Langergraber and colleagues have been influential over the past decade (since 2005) formulating and creating numerical models of the processes in subsurface flows constructed wetlands (Langergraber, 2008; Langergraber et al., 2009) highlighting the need for transient variably saturated flow models for vertical flow systems due to the dynamic nature of the system.

3. Biological nitrogen removal in vertical flow constructed wetlands

Biological treatment, involving the microbial degradation of organics and pollutants, has been more often favoured over physical and chemical processes due to its low cost and efficiency. For nitrogen removal in subsurface flow constructed wetlands, this process usually consists of a primary aerobic phase followed by a secondary anaerobic phase, the nitrification-denitrification pathway (Percival et al., 1997) usually in a hybrid configuration (i.e. a two stage system consisting of both types of constructed wetlands) (Kadlec and Wallace, 2009).

Nitrification is a two-step aerobic process facilitated by chemoautotrophs which involves an initial oxidation of ammonia to nitrite (by Ammonia Oxidizing Bacteria – AOB) followed by subsequent oxidation of nitrite to nitrate (by Nitrite Oxidizing Bacteria – NOB) (Kadlec and

Wallace, 2009). Energy is derived from both reactions and carbon dioxide (CO_2) is used as a carbon source. Nitrified effluent however, cannot be discharged into a water source since the high nitrate concentration may not meet Government imposed discharge limits and hence, needs to be further treated (Vymazal, 2007).

Denitrification, mediated by heterotrophic microbes, has been described as the most efficient respiratory process in eliminating nitrogen under anaerobic or anoxic conditions. Here, oxidized nitrogen species (such as nitrates) are reduced to gaseous N2O and N2 in the presence of an external carbon source (Vymazal, 2007). Initially, NO_3^- (nitrate) is reduced to NO_2^- (nitrite) by the enzyme nitrate reductase (*Nar*). Thereafter, nitrite reductase (*Nir*) catalyses the reaction whereby nitrite is converted to nitrous oxide (N_2O). The third enzyme, nitric oxide reductase (*Nor*) converts N_2O to NO (nitric oxide) followed by the conversion of NO to dinitrogen gas (N_2) with nitrous oxide reductase (*Nos*) as the catalyst (Kumar and Lin, 2010).

Due to the oxygenation capacity of vertical flow constructed wetlands, nitrification is promoted and confirmed by the high nitrate concentration in the effluent (Vymazal, 2008, 2011). However, research into increased depth and different media gradation is needed to establish if aerobic denitrifier communities can be established to perhaps not fully removal the total nitrogen content but decrease to a concentration that meets or falls under the discharge limit of 15 mg/l (Table 1).

4. Design parameters affecting the performance of vertical flow constructed wetlands

Design forms an integral component in the functionality and sustainability of any system. Performance data from various studies have given sufficient insight into the factors affecting the treatment efficiency of vertical flow constructed wetlands. However, to first improve an establish system, one needs to first identify the limitations of the system at its current design compared to recommended design.

The following limitations were identified in the full scale vertical flow constructed wetland at Newlands Mashu:

1. The recommended **depth** was 1.5 m however, during construction the depth was limited to 0.75 m due to site landscape.
2. The **hydraulic loading rate** is variable per day since the mechanical siphon feeding the wetland is unstable and does not discharge at the same frequency each day causing increased resting periods for the bed.
3. The **media** composes of fine and coarse gravel only. The large pore spaces between particles, compared to sand, may increase infiltration of the influent as it passes through the depth of the bed. A higher infiltration rate decreases the contact time of the wastewater with the microbial populations which is responsible for most of the nutrient transformation in the system (Lee et al., 2009). Thus, performance may be inhibited by a lower **hydraulic retention time**.
4. The **vegetation** is dense and composed of indigenous and invasive species.

Wu et al. 2015 stated that plant (vegetation) type and media serves as the two most integral biological components of the system that leads to overall treatment efficiency. These parameters, including those highlighted earlier will be discussed in more detail.

4.1 Type of vegetation

The use of vegetation has generally been accepted to enhance pollutant removal in constructed wetlands (Wu et al., 2015) since the most reactive zone of the wetland is in the rhizosphere (Stottmeister et al., 2003). Plants release oxygen near their roots creating an oxidation-reduction potential for the aerobic dependent reactions such as nitrification, and the uptake of nutrients, such as nitrate and phosphorus (Tanner, 1996). Zhang et al. (2009) comments that despite this, the quantitative role of plants in a constructed wetland is debatable and the uptake of nutrients is often minute compared to the incoming influent concentration. Verhoeven and Meuleman (1999) explain that the storage of nutrients is not permanent and often at the end of a plant's life cycle, much of these nutrients are leached back into the system by decaying litter during senescence. Some authors have that regular harvesting events may counteract this issue by removing the stored nutrients, especially nitrate, while some have maintained this practice is negligible for nutrient removal (Vymazal, 2005).

Phargmites australis is the most commonly used species for wastewater treatment in constructed wetlands due to their extensive, longer lived root system and perhaps high root zone aeration, amenability to unmaintained systems and competitiveness with other species (Saeed and Sun, 2012; Tanner, 1996). Ideally, the choice of vegetation depends on the availability of local species and its adaption and tolerance to the nutrient and organic load entering the system. The second criteria is for the survival and treatment potential of the species selected (Wu et al., 2015). Plants are sensitive to stress and the quality of the wastewater being treated should not cause major physiological changes to the species that harbours the overall treatment of the constructed wetland

Zurita et al. (2009) showed higher treatment efficiency in vertical flow systems with more than one species perhaps due to the greater distribution of the rooting system. Similar findings were documented by Zhang et al. (2010) and Zhu et al. (2010) who found plant species richness to be positively correlated with plant biomass production and retention if nitrogen in the filtration media thus improving the overall performance of the system.

Two of the four species in the Newlands Mashu vertical flow bed is invasive and will not prove beneficial in EWS gaining a Water Use Licence for the site and may affect the EIA. Thus, these species will be need to be removed immediately and the remaining indigenous species replanted across the surface of the bed. The latter species, *Cyperus sexangularis* and *Typha capensis* have not been studied or compared for nutrient uptake previously and will add to the list of acceptable species used in constructed wetlands.

4.2 Substrate or media type

The function of the substrate within a wetland is to serve as a medium for plant and microbial growth and facilitate the permeation of wastewater through the depth of the bed (Kadlec and Wallace, 2009). Moreover, the sorption capacity of a substrate forms an important aspect in the removal of specific pollutants such as phosphorous. Wu et al. (2015) highlights states that the life span of subsurface flow constructed wetlands may be significantly reduced due to clogging. As mentioned previously, clogging is a treatment limitation in vertical flow systems that generally contain sand. Thus, the choice of media forms an important parameter for sustainable systems.

Nivala et al. (2013) recommends that the media should be modified to the location of the intended constructed wetland system since washed, well-graded sand is not available in all regions of the world. Sand and gravel are often inexpensive media types that are readily available. However, the treatment efficiencies using coarse sand against fine gravel have not been evaluated (Nivala et al., 2013).

Contrarily, Stefanakis and Tsihrintzis (2009) compared the use of different porous media and found no significant differences between the treatments. They believed that since the contact time with the substrate and wastewater are facilitated by the gravitational flow of effluent through the depth of bed, the contact time with different substrates does not differ significantly hence there is no major difference in pollutant removal efficiency.

However, since the hydraulic conductivity is higher in gravel than sand, it would be interesting to compare different gradations using both media types to determine if a higher hydraulic retention time could be attained to improve performance but not cause clogging.

4.3. Hydraulic Retention Time

Lee et al. (2009) attributes higher nitrogen treatment efficiency to a higher hydraulic retention time. This is because the contact time between the incoming wastewater and microbial communities in the substrate are increased contributing to the performance of the CW. Furthermore, nitrogen removal requires a higher HRT compared to organic reducing reactions (Lee et al., 2009). Typical retention times range from 2-6 days (Wu et al., 2015) however, longer period may reduce BOD removal (Saeed and Sun, 2012).

The Newlands Mashu DEWATS plant is gravity fed while the fed to the vertical flow constructed wetland is controlled by the mechanical siphon adding to the energy independence of the system requiring less expertise in the design, operation and maintenance. Therefore, the hydraulic retention time needs to be controlled by the infiltration rate of the water through the media whereby a lower porosity will retain the wastewater to improve contact time with microbial communities responsible for pollutant transformation and degradation.

4.4 Depth

Depth is also an important parameter that will increase the hydraulic retention time in a vertical flow bed. Wu et al. (2015) describes the depth of vertical flow constructed wetlands to be in the range of 1-2 m. However, no one has defined the effective depth (i.e. the depth at which no further transformation of pollutants occurs)

4.5 Hydraulic Loading Rate

Much research has been done of the effect of hydraulic loading rate on the performance of vertical flow constructed wetlands (Stefanakis and Tsihrintzis, 2012). However, due to faulty siphon and irregular loading of the system, it is important to determine the exact effect of flow fluctuation.

5. Experimental pilot scale vertical flow constructed wetlands at Newlands Mashu

5.1 Design, construction and start-up

The pilot wetlands will be constructed using manhole rings and fed with the same ABR effluent as the full scale system. Eight above-ground pilot scale vertical flow constructed wetlands will be constructed from concrete manhole rings at the Newlands Mashu Research site. The diameter of each ring will be 0.75 m and a height of 0.25 m. Since the full scale system was constructed at half of its recommend depth (0.75 m) for the quality of wastewater being treated, the height of all pilot trails will be at 2 m to investigate the effective depth for optimum performance. Thus, eight rings will be stacked and will sit on a concrete base of an area of 1.56 m^2 (l x b; 1.25 m x 1.25 m). Surface area = 0.44 m^2 with a volume capacity of 0.88 m^3 = 880 l.

5.2 Operation

5.2.1. Vegetation

The pilot trials will be planted with *Cyperus sexangularis* and *Typha capensis* (2 plants per species = 4 plants/m^2). One shoot from each trial will be analysed for nutrient uptake bi-annually. Each plant will be planted parallel to the 1st and 3rd pair of perforations of the inlet pipe (three pairs of perforations in total).

5.2.2 Media

Two different media gradations will be investigated. Media grading will be composed of porous media of sand and gravel size that are readily available and hence, cost effective. One treatment will be the same as the full scale system however, the thickness of filter and drainage layers will be amended to suit the depth to establish if performance could be enhanced with a greater depth.

M1 = That of the full scale system in the same proportions (a 0.55 m filter layer of fine gravel 2-4 mm and a 0.15 m drainage layer of coarse gravel 19-25 mm). This proportion will be multiplied to suit the height of the pilot constructed wetland (1.5 m filter layer and 0.3 m drainage layer).

M2 = A stratified grading of a 1.1 m filter layer of coarse sand 0.5-1 mm on top on another filter layer of 0.4 m fine sand 0.1-0.25 mm and a 0.3 m drainage layer of coarse gravel 19-25 mm.

5.2.3 Depth

Since the height of each trial will be 2 m with a 0.2 m free board, the depth of the media will be 1.8 m.

For each trial, four wetting front detectors (WFD) will be embedded in the media at depths of 0.75 and 1.25 m to track the changes in chemical properties and concentrations of the effluent as it passes down the CW. The type of WFDs employed will have a long extension tube or modified to accommodate for the depths at which it will be placed in the media. At a depth of 0.75 m, the WFDs will be situated directly under the rooting of the plant species. At 1.25 m, the WFDs will be positioned adjacent to the first set at 0.75 m. Samples at these depths will be compared with the final effluent at 2 m.

5.2.4 Hydraulic Loading Rate

Four different loading rates will be investigated. This will be derived from the design HLR of the full scale vertical flow constructed wetland at Newlands Mashu.

$$q = Q/A \tag{1}$$

Where q = HLR
Q = Flow rate (m^3/d)
A = surface area of the constructed wetland

Therefore, q = 14 m^3 / 94 m^2 = 0.15 m/d

Table 2: Hydraulic loading rates for different treatments from the design HLR of the full scale system of 0.15 m/d at a surface area of 0.44 m^2

HLR (function of q)	*Rate (m/d)*	*(cm/d)*	*In flow rate Q (m^3/d)*	*(l/d)*	*Reason/Motivation*
q	0.15	15	0.066	66	Design loading rate
2 q	0.30	30	0.132	132	To determine the maximum HLR at which the system will fail due to over loading.
½ q	0.075	7.5	0.033	33	Recommended to BORDA by an independent consultant.
¼ q	0.0375	3.75	0.0165	16.5	To determine the minimum HLR at which the system will remain inactive by an inadequate feeding rate.

5.2.5 Feeding

Feeding of the ABR effluent will be Probe Level Controller (PLC). The time of the flush will depend on the number of flushes per day on a 24 hour cycle. The feeding pipe, 0. 70 m in length, will lie in the middle of the surface of the bed with three pairs of perforations; a pair at 0.2, 0.4 and 0.6 m from the inlet. The influent will be pulse loaded and flow rate will be measured accordingly.

Therefore ¼ q = 16.5 l = 1 flush per day
½ q = 33 l = 2 flushes per day
q = 66 l = 4 flushes per day
2 q = 132 l = 8 flushes per day

6. Future research and expected outcomes

It is anticipated that the empirical knowledge gained from the pilot trials will aid in providing national guidelines for the design and construction of VF CWs as a sustainable treatment option for domestic wastewater generated from decentralised wastewater treatment systems. Design must consider whether the effluent will be reused for agriculture or discharged into a local water source. However, the aim is to design systems that are non-energy requiring, sustainable and effective for high pollutant removal. Thus, the guidelines provided will be limited to simple systems with modified operating conditions for improved treatment efficiency.

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