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Organic Carbon Removal from Domestic Sewage using Constructed Mangrove Wetlands in Coastal Areas of Dar es Salaam City, Tanzania

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ABSTRACT: Mangroves store up to five times as much organic carbon as tropical upland forests. This article provides some insights on organic carbon removal from domestic sewage in constructed mangrove wetlands in coastal areas of Dar es Salaam City, Tanzania using standard methods. The wetlands were operated in intermittent flow and batch modes. The one that was operated in an intermittent flow mode showed higher removal rates as compared to the one that operated in batch mode. About 49% of organic material measured as COD was removed from sewage in the wetland cell operated in the intermittent flow mode. The lower removal rates resulted from frequent interruption of the wetland system by uncontrolled natural tides at the site and shorter retention time of three (3) days cycles of flooding with sewage and drying-up of mangrove wetland. The constructed mangroves wetlands have a good capacity in removing up to 80% of organic carbon material from sewage when a more controlled environment and a longer retention time of about 5 to 15 days are employed. If adjustments will be made, they are recommended to be applied as treatment technologies for sewage in coastal areas.

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Wetlands have massive numbers of organic carbon consuming micro-organisms living in aerobic surface waters and anaerobic soils. Therefore, the wetlands have high ability of removing organic materials from a diversity of sewages. Organic carbon in wetlands is decomposed into carbon dioxide and methane, by which both escape as gases to the atmosphere. Wetlands also have ability to accumulate and recycle the plentiful quantities of organic carbon that are contained in litter, vegetation, animals and micro-organisms (Kayombo, 1999; Sgroi *et al*., 2018; Su *et al*., 2011). Thus, wetlands have a tendency to be natural transporters of organic Carbon as an effect of breakdown of organic matter into simpler substances that can easily dissolve in water. The more easily decomposable organic carbon compounds can be quickly removed in wetlands. Wetlands can also remove non-degradable organic Carbon compounds including petroleum products, via biological mechanisms, however the removal amounts might be significantly lower. Normally, BOD (Biochemical Oxygen Demand) is a parameter used to measure the available biodegradable organic Carbon that is essentially a measure of the proportion of Oxygen spent by micro-organisms to degrade organic carbon material in the soils and water (Kaiser and Kalbitz, 2012). Organic material comprises around forty-five to fifty percent of organic carbon (C) that is exploited by a varied collection of micro-organisms as a source of energy. A big number of these micro-organisms use oxygen gas (O_2) to breakdown the organic material to simpler compounds that includes carbon dioxide (CO_2), a manner that supplies energy for microbial growth. Thus, the discharge of high quantities of organic carbon material to water resources can cause a significant reduction of Oxygen in aquatic

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environment, as the result it will lead to death of aquatic organisms (Hansell and Carlson, 2014). Therefore, organic carbon is required to be reduced in sewage to acceptable levels before being discharged into receiving water bodies. The study focuses on organic matter because the best removal of organic matter from the domestic sewage in most cases reflects the good removal of other contaminants. The mangroves constructed wetland was engaged to reduce the concentration of organic carbon in the domestic sewage from coastal areas and hence its contributing factors for good performance in reducing the organic carbon from domestic sewage were checked. Knowledge of contributing factors for good performance in reducing the organic carbon from domestic sewage helps to properly design and operate the constructed mangroves wetland. Hence, the objective of this paper is to evaluate the organic carbon removal from domestic sewage in constructed mangrove wetlands in coastal areas of Dar es Salaam City, Tanzania

MATERIALS AND METHODS

The methodologies used were documents review, interview, treatment performance and statistical analyses with regard to the mangroves constructed wetlands in organic carbon removal.

Documents Review and Interview: Relevant research reports on constructed wetland technologies in Tanzania were reviewed. Different researchers who researched on constructed wetland technologies in Tanzania were interviewed.

Laboratory Analysis and Treatment Performance: In order to analyze the treatment performance of Mangroves constructed wetlands in removal of organic carbon from domestic sewage in coastal areas of Dar es Salaam city, site assessments were made in two horizontal surface flow mangroves constructed wetland units of 40m x 7m each. The operations of these units were copying the natural phenomenon of tide flow at the site and therefore one wetland unit was operated in an intermittent continuous flow mode of three days cycles of flooding and drying up and the other wetland unit was operated in batch mode of flooding / loading and drying up exchanges cycles of every 12 hours. Both constructed wetlands used already existing mangroves specie *Avicennia Marina* and they were not able to work in a more controlled environment as they were frequently interfered with natural tides. The wetland units received a combination of seawater and sewage at a ratio of 4:6 and at a flow rate of 5 m^3/day. The inlet and outlet sewage samples into and out of the wetland systems on the first and last day of the specified retention times were analyzed and the percentage removal associated with reduction in concentrations of COD for batch and intermittent continuous flow systems were determined. The COD was determined by Closed Reflux, Titrimetric Method (Accuracy is ± 2% of the value) in accordance with the Standard methods (APHA *et al.*, 2002)

Statistical Analysis: Since the presented results involved two kinds of wetland units that operated in two different modes, this means there are two kinds of statistical treatments involved and therefore student t-test was performed. The student t-test was performed to detect if there were significant differences on removal rates of COD between intermittent continuous flow and batch systems. A single test at 95% Confidence Interval (0.05 probability level) was performed. Six replicates of removal rates were used for this analysis. The data that was used for the discussion of the results on comparison of the treatment efficiencies were the mean values of the six replicates.

RESULTS AND DISCUSSION

Treatment performance: In the intermittent continuous flow wetland unit, the observed removal rate of COD was 49% and it is presented in Figure 1. The lower removal rate was the result of frequently interference of the wetland system by uncontrolled natural tides at the site and shorter retention time of three (3) days cycles of flooding with sewage and drying-up of mangrove wetland. As presented in Figure 2, the observed removal rate of COD was 9% in the batch wetland unit. A relatively lower removal of COD of 9% was observed compared to the intermittent flow wetland unit. This difference is attributed to the difference in retention time whereby the batch cell had a retention time of 12 hours while the intermittent cell had a retention time of 3 days. The spikes as observed in the diagram could be caused by change in the inflow pattern of sewage from the source. Organic carbon in mangrove wetland system may be removed by settling of particulate matter and utilization of degradable carbon compounds during metabolic process by micro-organisms. In mangroves constructed wetlands, a high percentage of the organic material which cannot be removed as CO_2 gas is colonized by algae, fungi and invertebrates such as gastropods, crabs which assist in the decomposition process. Aerobic heterotrophic bacteria oxidize the remaining organic matter, which was not colonized by the above mentioned micro- and macro-organisms. The Oxygen essential for oxidation of organic material is found primarily via photosynthesis process of algal population which grows abundantly and naturally in free surface wetlands and from the roots of mangroves (Weston *et al.*, 2011).

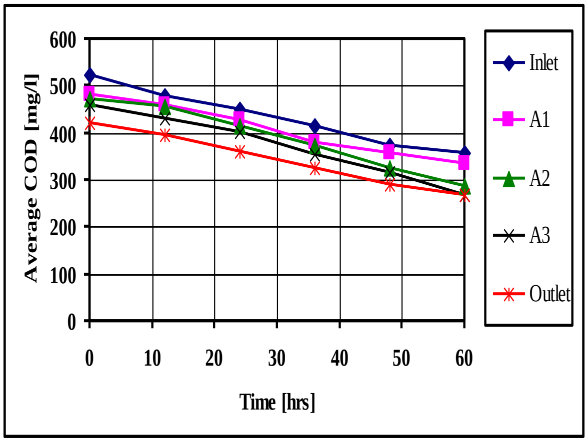

Fig 2: Variation of average COD concentrations with inundation times

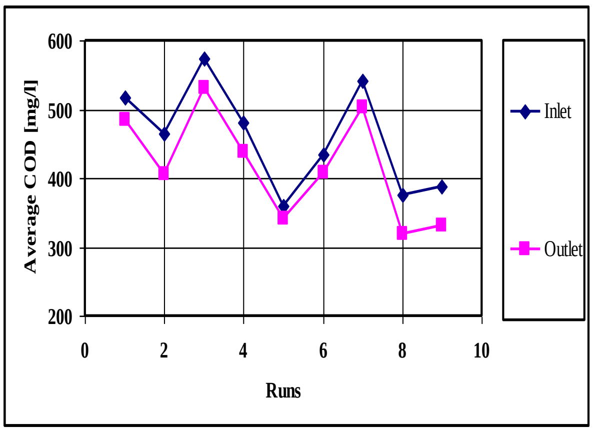

Fig 2: Variation of average COD concentration with inundation times in no. of runs

Statistical Analysis of the results: The student t-test has been performed to detect if there were significant differences on removal rates of COD and between batch system and intermittent continuous flow system. A single test at 95% and 99.9% Confidence Intervals (0.05 and 0.01 probability levels) has been performed. The tabularized value of T at 95% Confidence Interval is 2.23; also, the tabularized value of T at 99.9% Confidence Interval is 4.59. Computed T value (T = 13.99) exceeds this tabularized T value. Since the computed t-value exceeds tabularized T-values at 95% Confidence Interval even at 99.9% Confidence Interval, then there is high significant difference on removal rates of COD between batch system and Intermittent Continuous Flow System. Therefore, the Intermittent Continuous Flow System has significant high rates of COD removal as compared to batch system.

Needs for the best performance of Mangrove constructed wetlands in Organic Carbon Reduction: There six (6) crucial areas to be considered for the best performance of the technology in treatment of sewage that are type of the technology, macrophytes, mode of operation, sewage strength, retention time and soil type.

Type of technology: As compared to conventional systems, constructed wetlands are taken as most perfect technology to safeguard the mangrove ecosystems as researched by the Waste Stabilization Ponds and Constructed Wetlands Research Group at the College of Engineering and Technology of University of Dar es Salaam in Tanzania (Mbwette *et al.*, 2005). Constructed wetlands (CWs) are planned, designed and constructed treatment systems, which utilize wetland plants to help treatment of sewage in a meticulous environment as compared to that occurring in natural wetlands.

Table 1: Comparison between Constructed Wetland treatment systems and Conventional treatment systems

Constructed Wetlands treatment systems	Conventional treatment systems
The effluent of good quality is easily obtained	They not easily adjustable to new technologies
Promote water conservation	Do not support conservation of water
They employ natural mechanisms in the process of sewage treatment	Demand the utilization of chemicals in the process of sewage treatment
Re-use of water and recovery of nutrients is optimized	Re-use of water and recovery of nutrients is not optimized
Low cost in-terms of capital, operation and maintenance.	High cost in-terms of capital, operation and maintenance.
Operation and maintenance do not require considerable skills	Operation and maintenance require considerable skills in operation and maintenance
Reduction of most pollutants including faecal coliforms is relatively high	Reduction of most pollutants including faecal coliforms is relatively low

These wetlands are “eco-friendly” technologies which utilize natural environment to remove pollutants. They are low cost technologies in-terms of capital, operation and maintenance and they are very effective in treatment of secondary and tertiary municipal and industrial sewage. As compares to most ecosystems, wetland ecosystems have a high rate of biological activities and they are able to reduce various contaminants that are found in sewages into harmless simpler compounds. The removal of pollutants is accomplished by virtue of the potential of the vast land area and natural environmental energies of plants, wind, sun, animals and soil. Because the natural mechanisms perform in a wetland treatment system, thus in most cases the wetlands require no or slight fossil fuel energy and no chemicals and therefore makes this technology to be sustainable in terms of operation costs (Mbwette *et al.,* 2005)

Macrophytes: Macrophytes (wetland plants/vegetation) play a significant part in the treatment of water by assisting the physical, biological and chemical processes that occur (Chazarenc *et al*., 2003). Wetland vegetation are capable of developing in land that is frequently flooded by water for five or more days during the growing season, and are regularly characterized as either floating, emergent or submerged (Kadlec and Wallace, 2008). There exist a range of wetland vegetation because of the range of physical and chemical functions present in wetlands. Most commonly used wetland plants include reeds such as Phragmites spp., cattails such as Typha spp., rushes such as Juncus spp.), sedges such as Carex spp. bulrushes such as *Scirpus spp*. and mangroves such as *Avicennia Marina spp*. (Mitsch and Gosselink, 2009). Mangroves and cattails are the main species employed in surface flow constructed wetland systems since their root penetration within the soil is low. However, mangroves can only grow and survive in saline environment. Unlike cattails and mangroves, root penetration of bulrushes and reeds is deeper within the soil, and thus reeds and bulrushes are commonly in subsurface flow constructed wetland systems (Wolanski *et al*., 2009). The idea of using mangrove vegetation for secondary sewage treatment has been suggested since the 1970s because mangroves have unique characteristics that may make them particularly suited for sewage treatment. According to Perillo *et al*., (2018), the unique characteristics of mangroves include; (1) they are tolerant of extreme environmental conditions such as high temperature, tide, muddy, salinity and shifting aerobic/anaerobic soils conditions. There might be no further cluster of plants with such profoundly created natural, morphological, physiological and biological variations that can withstand extreme environments (Ye *et al*., 2001); (2) they have a high potential biomass sink for nutrients; (3) they are tolerant of periodically inundated water conditions; (4) they have aerial roots and oxygen translocation systems that make them highly adapted to growth in anoxic muds. A few investigations estimating the two kinds of treatment units, with and without vegetation, show that removal efficiencies are higher when plants are available (Chazarenc *et al*., 2003). Studies show that in properly designed, operated and maintained constructed wetland, wetland plants can reasonably take-up and eliminate up to 80% of organic carbon material found inside the treatment plant contingent upon the kind of vegetation and climatic conditions. Nevertheless, reduction of organic carbon material via direct take-up by plants is just huge in a short term (Kadlec and Wallace, 2008). Wetland plants have various different properties that help in the treatment of sewage in constructed wetlands. Wetland plants can move oxygen into the root zone through lenticles, which are little openings on the above segments of these plants, and aerenchymous tissue, which transport gases to and from the roots (Denny, 2012). Oxygen is then diffused into the water making an oxidized condition in the anoxic silt. This animates both degradations of organic carbon material and development of decomposing microorganisms. Additionally, aquatic plants can produce extrinsic roots, which have ability to extract oxygen and organic material from water in areas where gases and organic material may be more accessible than in anoxic soil zones. Plants additionally give the shade, garbage for carbon (C) and energy, and much expanded surface territory, required for the dynamic microbial networks (Su *et al*., 2011). In the research done by Siajali in 2008 to compare two mangrove species *Rhizophora* and *Avicennia marina*, the findings show that the A*vicenia marina* performed better in reduction of all pollutants from domestic sewage.

Mode of operation: Mangroves experience changeable environment with spring and neap tides and drying up conditions. In order to replicate the natural circumstances of changing flooding with seawater and drying up conditions of natural mangroves, the best operation mode for a constructed mangrove wetlands is an intermitted continuous flow mode of flooding and drying up cycles (Mahenge, 2010).

Sewage strength: Sewage strength is important to look at while dealing with mangrove wetlands because sulphide may be produced under anaerobic conditions and can result in growth retardation or death of mangrove plants. Also mangroves grow well in saline conditions and therefore there is a need to mix sewage with seawater. The sewage mixing ratio was developed from trial experiments that were conducted from 2006 up to 2007 by Siajali (2008). For the best performance of a constructed mangrove wetland in reduction of pollutants, the recommended ratio between seawater and sewage is 4:6.

Retention Time: The tide duration in natural mangrove wetlands is about six hours. As researched by Mahenge (2010), the retaining time should be lengthy enough (5 to 15 days) to enable the wetland to operate in a more constant conditions for treatment of sewage to agreeable levels for safe re-use or disposal.

Soil Type: Soil is one of most important components of constructed mangrove wetlands as it offers the support as well as the substances for mangroves growth. It also supports the microbial growth. Most media utilized incorporate squashed stones/gravels and various soils, either alone or in blend. Research findings by Mahenge (2010) and Siajali (2008) have showed that normal soils perform well in organic matter reduction.

Conclusions: The constructed mangroves wetlands have a good capacity in removing high loads of organic carbon material from sewage when more controlled environment and longer retention time of are employed and therefore, if small adjustments will be made in terms of retention time and controlled environment, they are recommended to be applied as technologies for sewage treatment in coastal areas.

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