Benefits of Constructed Wetland for Urban Wastewater Treatment in Rwanda

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Abstract

Constructed wetland (CW) is easily operated and maintained, and has low cost and strong potential for application in urban areas than conventional treatment systems. Although CWs are useful in wastewater management; they are not yet applied in Rwanda. This study analyzed the benefits of constructed wetland in wastewater treatment at the University of Lay Adventists of Kigali (UNILAK) in the City of Kigali of Rwanda. The authors compared physico-chemical parameters namely: the Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solid (TSS), Total Nitrogen (TN) and Total Phosphorus (TP) collected at the influents and effluents of the CW during rainy and dry seasons. The parameters were finally compared with standards of the World Health Organization (WHO). Finally, the economic benefit analysis was performed by using data on wastewater treatment cost before (2003-2015) and after CW (2015-2020). And both before and after constructed CW treatment cost were projected to 2050 in order to indicate which method is more beneficial to the UNILAK. The results showed high pollution before the wastewater enters into CW during the rainy season compared to that of dry season. However, the removal efficiencies in both seasons showed the potential of pollution reduction. Thus, CW is beneficial and useful in wastewater treatment towards water quality maintenance and high sanitation as well. Regarding the economic benefits analysis, if the CW is operating, the university would spend only 1,620,000 Rwfs until 2050. However, 18,655,000 Rwfs could be spent in case the university remains with the traditional wastewater treatment method up to 2050. Further application of CW in other organizations/institutions (public and private) is greatly suggested.

Keywords: Constructed wetland; Physico-chemical parameters; Wastewater treatment.

1. Introduction

Globally, water quality for various uses has been scarce. Due to water scarcity problems around the world, it is essential to think about non-conventional water sources for fulfilling the increase in demand rate for freshwater (Qadir et al. 2007). Wastewater is seen as a viable alternative option to overcome the shortage in water supply resulting from various reasons such as population growth (Bdour 2007). However, the great variety in wastewater origins in terms of organic and inorganic constituents make the reuse of such water subject to regular monitoring to assess potential risks impacting on the total environment (Fatta-Kassinos et al. 2011).

The constructed wetland treatment system artificially batches sewage with land that is usually in a submerged state and has aquatic plants growing (such as reeds, cattails, etc.), the sewage along a certain direction of flow is purified under the synergistic effects of water resistant plants, soil and microorganisms (Pathak et al. 2009). In urban areas, increasing populations, combined with increasing water consumption and a proliferation of waterborne sanitation, create widespread wastewater disposal problems(Parkinson and Tayler 2003). In many cases, wastewater is discharged locally onto open ground and vacant plots, creating ponds of foul-smelling stagnant water (Ojha 2014)

Population growth, considered as a demand pressure, will increase the urban, irrigation, and industrial water demand, which results in sharply rising discharges of various types of pollutants such as chemical and biochemical oxygen demands, particles (suspended solids and turbidity), ammonia-nitrogen, nitrate-nitrogen, hardly biodegradable organics (e.g., petroleum hydrocarbons, organic solvents, pesticides, and pharmaceuticals), heavy metals (e.g., chromium, copper, and zinc) and microbes (e.g., fecal coliforms and salmonella) (Bichai et al. 2012).

In the City of Kigali (CoK), the concept of wastewater management is an emerging issue for which high importance is now attached. The bulk of the wastewater produced in CoK is treated to a very minimal degree, if at all, and can be classified into a few broad categories. These are described in terms of their prevalence and risk to the environment and human health(Mbateye et al. 2010). Pit latrines are the typical form of domestic excreta removal in the CoK. Regarding wastewater treatment systems, only on-site or individual facilities for some institutions and establishments exist in the CoK. These are

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especially for hospitals, hotels, prisons, banks and few of them rarely function properly(Mbateye et al. 2010).

However, it is reported (Matamoros et al. 2012; Galanopoulos et al. 2013; Kivaisi 2001) that constructed wetland contributes significantly in reducing wastes loading into waters and hence minimizing the pollution likelihood mainly in urban areas where much wastes are generated by industries, commercial activities and grouped settlements as well. In Rwanda, wastewater treatment is still at low pace and associated consequences are gradually increasing. These include not limited the pollution of water quality which in turn affects people's health.

Therefore, the authors based on this gap and then chose to conduct a study on the analysis of benefits of constructed wetland in urban areas. The study focused on the constructed wetland placed at UNILAK to analyze its beneficial impact on the treatment of wastewater. The authors believe that this study will serve as additional information in terms of contribution in water pollution reduction and water reuse promotion in urban areas of Rwanda.

2. Materials and Methods

2.1 Description of study area

This study considered the WC (Figure 1) of UNILAK located in Remera sector, Gasabo district of Kigali City of Rwanda. This CW helps to treat wastewater collected from all institution's divisions, and is designed regarding the requirements of universal constructed Free Water Surface (FWS) Wetlands.

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Figure 1: UNILAK- Constructed Wetland map and its geographical location

2.2 Materials

The study utilized the primary data collected from field and desk review. The field data collection process consisted of collecting physic-chemical parameters from the wastewater in constructed wetland.

The authors analyzed the Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solid (TSS), Total Nitrogen (TN) and Total Phosphorus (TP) collected at the influents and effluents of the constructed wetland during rainy and dry season. The parameters were finally compared with standards of the World Health Organization (WHO).

Finally, the economic benefit analysis was performed by using data on wastewater treatment before (2003-2015) and after constructed wetland (2015-2020). And both before and after constructed wetland wastewater treatment cost were projected to 2050 in order to indicate which method (constructed wetlands compared to conventional treatment systems) is more beneficial to UNILAK.

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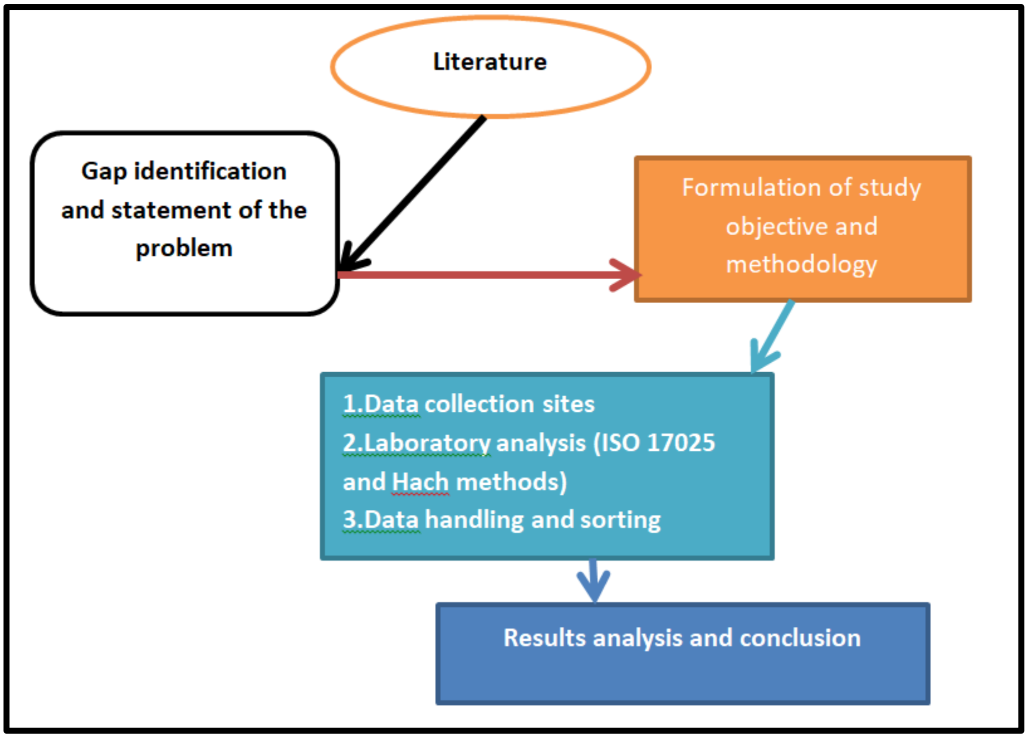


Figure 2: Methodological Flowchart of the study

2.3 Methods

2.3.1 Sampling and Laboratory analysis

During the sampling procedure, samples were taken during rainy and dry seasons and the composite sampling method was used to collect all samples. Composite samples provide a more representative sampling of heterogeneous matrices in which the concentration of the analytes of interest may vary over short periods of time and/or space. Composite samples were obtained by combining portions of multiple grab samples using specially designed extendable hand sampler.

The analysis of the collected sample was performed with reference to the requirements of Standard ISO/IEC 17025 in order to achieve our objectives as well as to get trustable results from Environmental Research Laboratory of UNILAK (UNILAK-ERL)

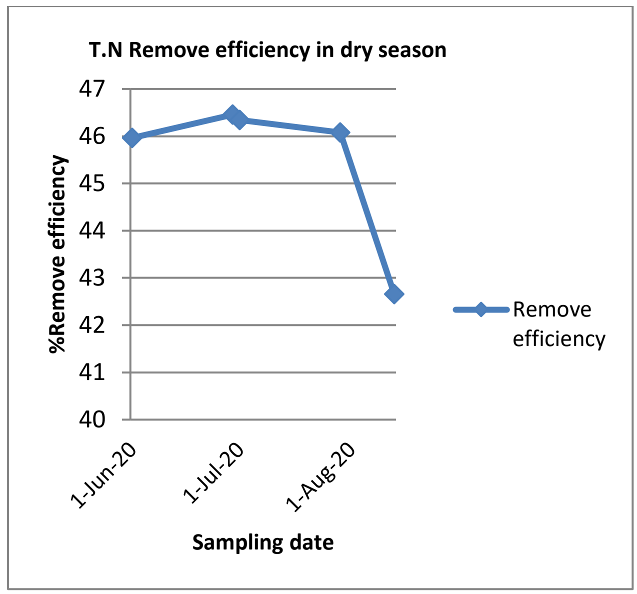
After sample collection, the authors performed a laboratory analysis. The considered physico-chemical parameters were analyzed in the Environmental Research Laboratory of the UNILAK and each parameter was specifically analyzed with reference to relevant standards. The Chemical Oxygen Demand (COD) was analyzed based on the Environmental

Protection Agency (EPA) 410.4 as test method whereas the Biological Oxygen Demand (BOD) analysis based on the Environmental Protection Agency (EPA) 405.1 as test method. The analysis of the Total Suspended Solid (TSS) referred to the Housing Authority of the City of Houston (HACH) 8006 as test method and the Total Nitrogen (TN) considered the Housing Authority of the City of Houston (HACH) 10072 as test method. Finally, the Total Phosphorus (TP) considered the Housing Authority of the City of Houston (HACH)10209 as test method. All these parameters were compared with the standards of the World Health Organization (WHO).

3. Results

3.1 Results from Total Nitrogen laboratory analysis

Considering the data provided in Figure 3, total nitrogen varied from 50.54mg/l to 27.54mg/l with the remove efficiency of 45.5% and a standard deviation of 0.80 in dry season. During the rainy season, a variation of 19.04 mg/l to 14.58 mg/l with 23.45% of remove efficiency and a standard deviation of 1.13 was noticed likely due to the dilution concept (Figure 3). The removal efficiency showed the potential of the wetland in reducing the concentration of nitrogen in wastewater passing through. The potentiality can be proved by comparison of effluent concentration and WHO standards, where the influent in dry season was above the standard (50.54>30) and effluent was under the standard (27.54<30) in rainy season (Figure 3).



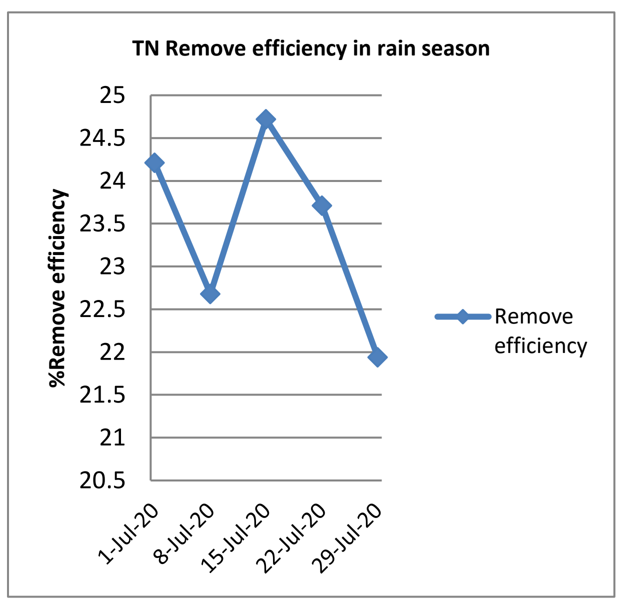


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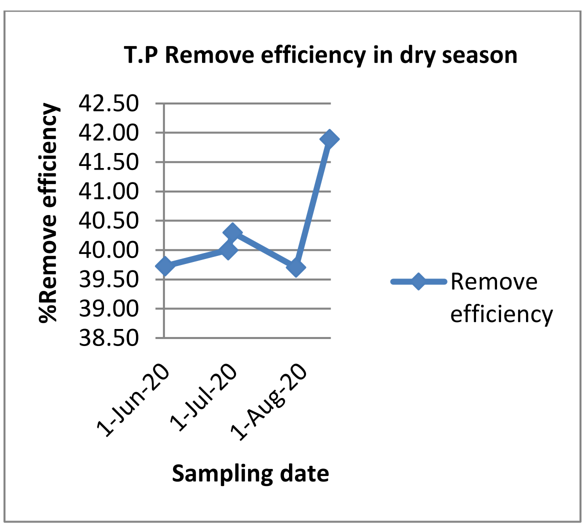
Figure 3: Total Nitrogen variation in dry and rainy season

3.2 Results from Total Phosphorous laboratory analysis

The results in Figure 4 showed that the total phosphorous was taken into consideration where the analyzed samples in dry season gave7.04 mg/l in influent to 4.20 mg/l for effluent. This led to a remove efficiency of 40.32% with a standard deviation of 0.91. In rainy season, the variation was 5.3 mg/l in influent to 3.88 mg/l for effluent. The remove efficiency was 40.32% and 26.78% during the dry and rainy season, respectively on total phosphorous which explains the benefit impact of CW on wastewater water treatment (Figure 4).



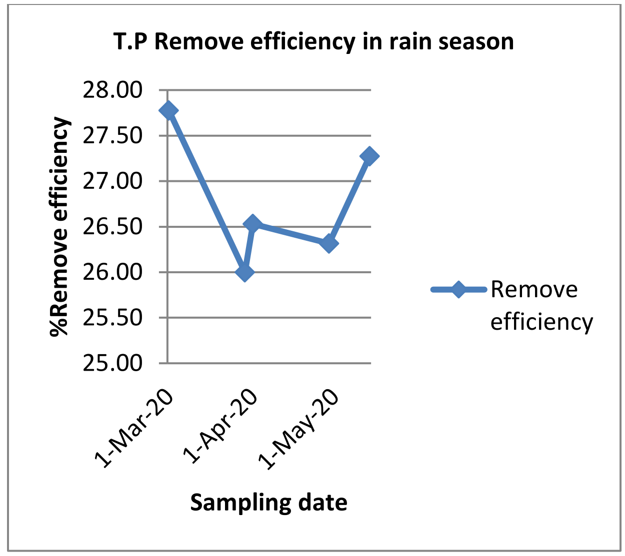


Figure 4: Total Phosphorus variation in dry and rain season

3.3 Results from Total Suspended Solid laboratory analysis

The results on the Total Suspended Solids, as illustrated in Figure 5 indicated that the TSS from 364 mg/l to 69 mg/l with the standard deviation of 0.69 in dry season and 241.6mg/l to 83 mg/l with 1.36 of standard deviation. The removal efficiency was 81.05% and 65.39% in dry and rainy seasons, respectively, and by comparing both influents with WHO standards, the great impact of CW on wastewater treatment was observed.

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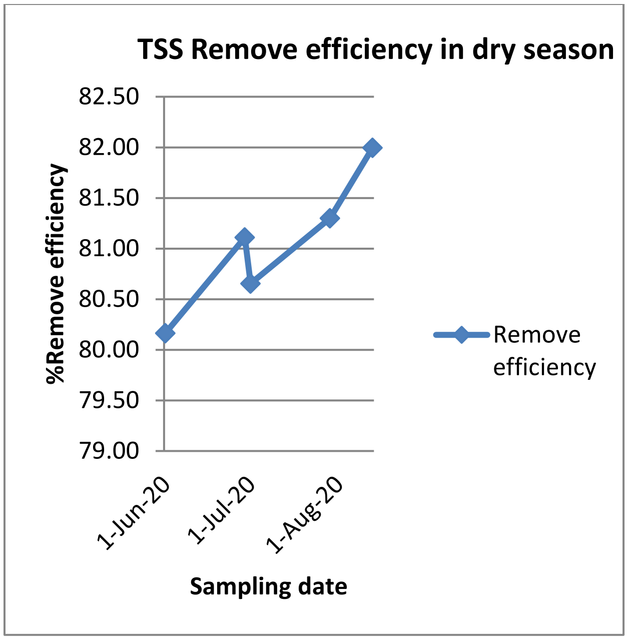


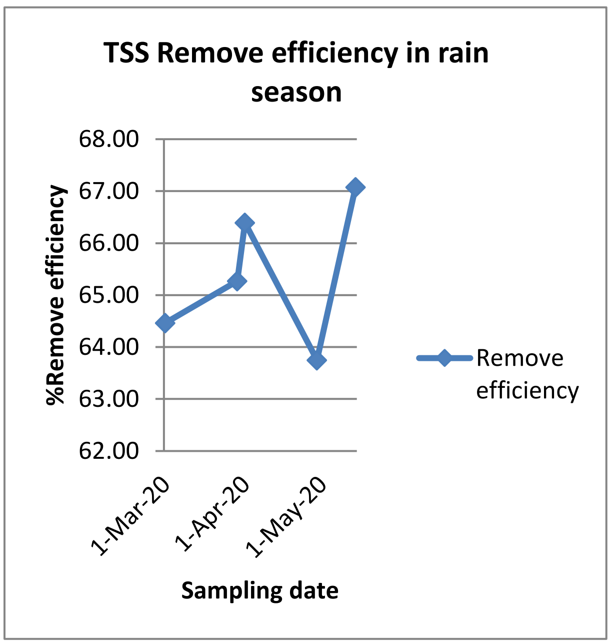
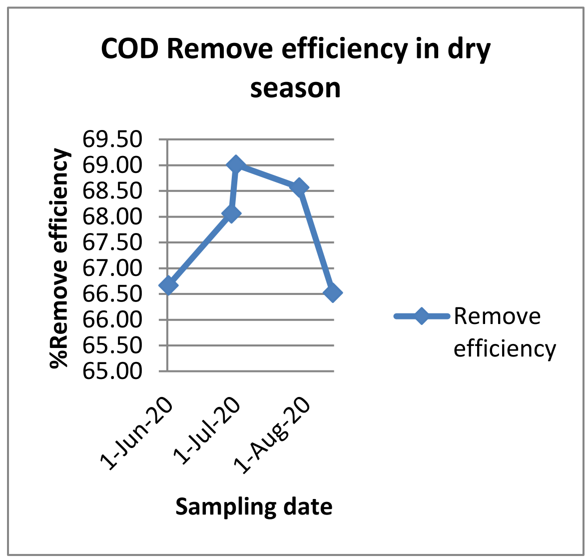


Figure 5: Total Suspended Solids variation in dry and rainy season

3.4 Results from Chemical Oxygen Demand laboratory analysis

The results Figure 6 revealed the variation of COD which was 240.20mg/l to 77.40 mg/l with a standard deviation of 1.12 and 160.80 mg/l to 47.20 mg/l and 0.87 in both dry and rainy seasons, respectively. The potential of CW on COD concentration was shown by a remove efficiency of 67.77% in dry and 70% in rainy seasons. Thus, the higher chemical oxygen demand, the higher amount of pollution in the water sample due to the reason that the COD is considered as one of the most important quality control parameters of an effluent in wastewater treatment facility.



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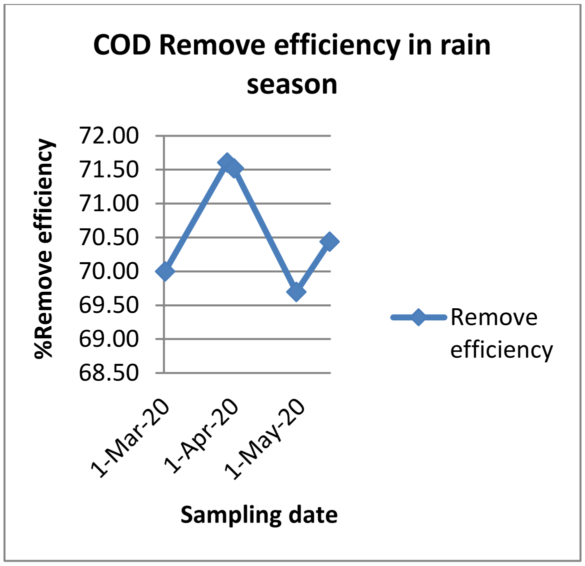
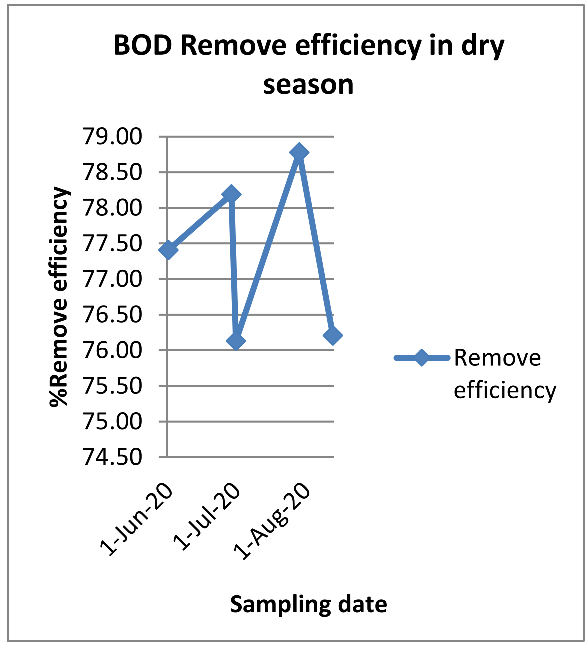


Figure 6: Chemical Oxygen Demand variation in dry and rain season

3.5 Results from Biological Oxygen Demand laboratory analysis

The results provided in Figure 7 showed that the BOD varied from 113.02 mg/l to 25.58 mg/l in dry season and 60.50 mg/l to 15.04 mg/l in rainy season with a standard deviation of 1.18 and 0.73 for both dry and rainy seasons, respectively. The significance capacity of the studied CW on wastewater treatment was also shown by its removal efficiency of 77.34% in dry and 75.17% in rainy seasons of BOD (Figure 7).

The comparison of BOD concentrations on effluent and influent with WHO standard showed that influents were greater than 40 mg/l then less than that standard on effluent (Figure 7). This likely expresses how powerful CW is in wastewater treatment. The discharge of wastes with high levels of BOD can cause water quality problems such as severe dissolved oxygen depletion in receiving water bodies.



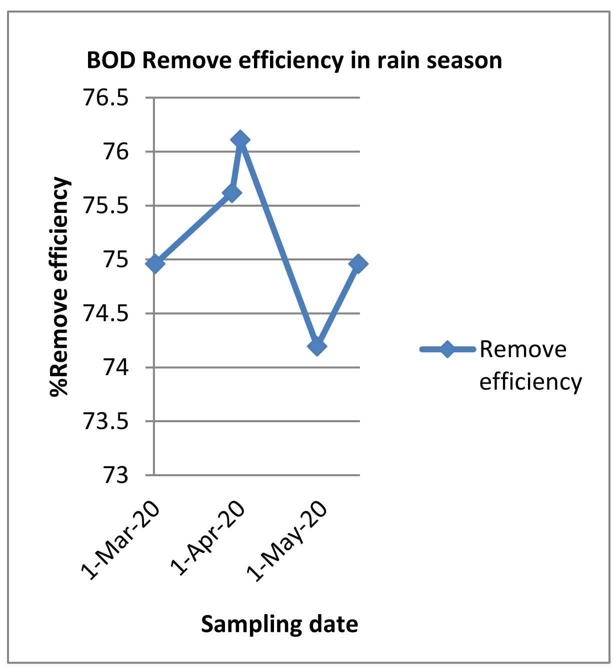


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Figure 7: Biological Oxygen Demand variation in dry and rain season.

3.6. Economic benefits of CW

This section presented the economic benefits which resulted from the constructed wetland at UNILAK. The authors chose to indicate the waste treatment cost which was registered by UNILAK before the constructed wetland and the employed data in Table 2 were collected from the management department of UNILAK.

Table 1: Cost of wastes management before CW at UNILAK

	Before CW (2003-2015)		**Up to 2050**
Naming	Annual cost	Total cost	
Waste treatment cost	480,000	5,760,000	17,760,000
Maintenance cost	53,000	636,000	1,855,000
Total	533,000	6,396,000	18,655,000

The results in Table 2 showed that before the constructed wetland (2003-2015), the waste treatment cost was 480,000 Rwanda Francs and 53,000 Rwanda Francs for maintenance of septic tanks per year. The cost was predicted from 2015 when the constructed wetland was built and then assumed in case the waste treatment would remain the same up to 2050. It was noted that the cost would reach 18,655,000 Rwandan Francs (Table 2).

Thereafter, the authors considered the cost associated with wastes management after constructed wetland. The results in Table 2 showed more related details.

Table 2: Cost of wastes management after CW at UNILAK

	After CW (2015-2020)		**Prediction up to 2050**
Naming	Annual cost	Total cost	
CW construction cost	0	6,300,000	0
Waste treatment cost	0	0	0
Maintenance cost	54,000	270,000	1,620,000
Total	54,000	6,570,000	1,620,000

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The results in Table 3 showed that after the constructed wetland, the construction cost was 6,300,000 Rwfs and the CW maintenance cost was only 54,000 per year which is predicted up to 2050. The prediction showed that the constructed wetland is more beneficial in terms of wastewater management cost. The CW showed that in 2050, only 1,620,000 Rwfs Francs will be paid, which is low cost compared to formal way of treating wastes at UNILAK which would cost 18,655,000 in 2050 (Table 2). This is based on the fact that the difference between the formal way of waste treatment (Table 2) and the Constructed wetland (Table 3) is 17,035,000Rwfs (18,655,000 - 1,620,000), which is indicate the big different between the two scenarios.

4. Discussion

Wastewater management is becoming a big burden to the community especially in the urban areas and this expresses the need of appropriate management policies which enhance the city's beauty and sustainability as well (Liu and Lipták 2020). Despite recent methodologies developed for the treatment of wastewater, it is reported that most of them are cost-effective and and/or require complex use and maintenance. The constructed wetland however, proved to be less economic (its construction and maintenance) and sustainable but also energy efficient in comparison to other existing wastewater treatment methods (ElZein et al. 2016; Irwin et al. 2018).

The above advantages of constructed wetland are mentioned mainly due to the reason that they are treatment systems which employ natural processes such as wetland vegetation along with their associated microbial assemblages which help in improving the quality of water (Irwin et al. 2018). In addition, constructed wetlands (CW) help to treat the industrial or municipal wastewater, storm water runoff or greywater. The CW can also facilitate the land reclamation after mining toward mitigation of the lost land development (Stefanakis 2020).

However, it is reported that in poor and developing countries wastewater is becoming much under low treatment. This is similar to Rwanda, mainly in the City of Kigali, lack of wastewater treatment increase water pollution and poor sanitation as well, whereas the constructed wetland at the Kigali İnstitute of Science and Technology proved to be useful in wastewater treatment(Nikuze et al. 2020; Kazora and Mourad 2018). Nevertheless, their limited number still hinder the treatment of waste water which

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causes natural resources, particularly water pollution and poor sanitation across the city (Kazora and Mourad 2018).

The results on the considered physico-chemical parameters indicated high pollution before the wastewater entering into the constructed wetland mainly during the dry season compared to the rainy season (Figures 3, 4, 5, 6 and 7). In addition, the removal efficiencies during both rainy and dry season generated low values of the considered parameters on effluent points (Table 3) which expresses that constructed wetland is beneficial and useful in wastewater treatment. This was previously reported by (Benvenuti et al. 2018) that after wastewater introduction into the constructed wetland, the organic matter and nutrients within the wastes are reduced at a satisfactory level.

Furthermore, as indicated in Tables 2 and 3, the economic benefit analysis showed that before the constructed wetland at UNILAK, waste treatment cost was 480,000 Rwanda Francs and 53,000 Rwanda Francs for maintenance of septic tanks per year up to 2015 which would reach 18,655,000 Rwandan Francs in the case the situation remains the same until 2050. However, after the constructed wetland (Table 3), the university recorded 6,570,000 Rwfs for its construction and maintenance cost from 2015 to 2020. More importantly, if the CW is under operation at UNILAK, only 1,620,000 Rwfs will be paid until 2050. And this amount 18,655,000 Rwandan Francs could be paid in case traditional wastewater treatment method is not changed up to 2050 (Table 3).

Based on the above, it can be mentioned that constructed wetland are not only contributing to wastewater treatment but also, they reduce the treatment cost. Hence, as long as the construction of CW is not expressive, organizations/instructions should adopt the CW in treating their wastewaters not only for the public benefits but also for their economic benefits. This was recently emphasized by researches (Abdelhay and Abunaser 2020; Liu et al. 2019)on economic benefits of CW that after their construction, only maintenance cost is paid and the wastes are treated and the environmental quality is protected as well.

5. Conclusion

This study was conducted with the aim of analysing the benefits associated with constructed wetland at UNILAK. The researcher analysed five physico-chemical parameters namely the Total Nitrogen, Total Phosphorous, Total Suspended Solids, Chemical Oxygen Demand and Biological

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Oxygen Demand during rainy and dry seasons. The results showed that high pollution before the wastewater enters into the constructed wetland and high level of the considered parameters was recorded using rainy season compared to that of dry season. However, the removal efficiencies during both rainy and dry seasons showed low values of the considered parameters and expressed that constructed wetland is beneficial and useful in wastewater treatment towards water quality maintenance and high sanitation as well. Regarding the economic benefits of the constructed wetland to the UNILAK, it was noticed that if the constructed wetland is under operation at UNILAK, only 1,620,000 Rwfs will be paid until 2050. And this amount 18,655,000 Rwandan Francs could be paid in case traditional wastewater treatment method is not changed up to 2050. Finally, analysis of institutions/organizations willingness and ability to adopt constructed wetland is suggested from which the government can facilitate them through cost sharing scheme to build the constructed wetland in order to protect the environment for public interest.

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Appendix:

Presentation of the results of physico-chemical parameters

The constructed wetland performances were evaluated in terms of organic matter and nutrients removal analyzed during the rainy and dry seasons. The results in Table 3 showed each parameter's value in both dry and rainy seasons, and the removal efficiency after calculating the mean of concentration from the seasonal samples taken on each studied parameter.

Table 3: Descriptive samples analysis

Parameters	Unity	Sample number (N)	Dry Season				Rainy Season				WHO Standards
			Influent	Effluent	Remove efficiency/ %	Std. Dev	Influent	Effluent	Remove efficiency/ %	Std. Dev	
TN	mg/L	5	50.54	27.54	45.5	1.60	19.04	14.58	23.45	1.13	<30
TP	mg/L	5	7.04	4.20	40.32	0.91	5.30	3.88	26.78	0.73	<5
TSS	mg/L	5	364.00	69.00	81.05	0.69	241.60	83.60	65.39	1.36	<100
COD	mg/L	5	240.20	77.40	67.77	1.12	160.80	47.20	70.65	0.87	<250
BOD	mg/L	5	113.02	25.58	77.34	1.18	60.54	15.04	75.17	0.73	<40

TN: Total Nitrogen, TP: Total Phosphorous, TSS: Total Suspended Solids, COD: Chemical Oxygen Demand and BOD: Biological Oxygen Demand

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