International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 22 (2019) pp. 4105-4111

Sustainable Design of Wastewater Treatment Plant in Kibiligi Quater

Shyaka Eugene[1,*] and Niyonzima Emery[2]

[1, 2] Department of Architecture and Civil Engineering, Shaoxing University, Zhejiang, China.

Abstract

Considering the millennium development goals (MDGs) and Rwanda vision, it's remarkable that Rwandan cities are growing at high rate which lead to the increase of population, the increase of population should go with the increase in sanitation infrastructures. Otherwise it results in practice of discharging wastewater directly into the bodies of water. This study is to estimate the quantity of wastewater (the effluent flow), to design a wastewater collection system, gravity sewer system design and to design an adequate horizontal sub-surface flow wetland for wastewater treatment system in kibiligi quarter. As results shown that the average daily water consumption per capital has been 96 liters which is in the standards limits and the higher usual is due to temporally activities like construction, the sewer pipe diameter found was below to the minimum recommended diameter of a sewer pipe therefore, we selected a convenient sewer pipe diameter, the average design influent flow has been 342m^3/day which has to be treated in a detention time of 2.42days in a constructed wetlands system, considering a minimum average annual temperature of 20ºC for treatment efficiency.

Keywords: Wastewater, Sewage, effluent quality, effluent quantity, Wetland.

INTRODUCTION

Background

According to the world Health Organization about 2.4 billion people lack access to basic sanitation. Therefor 2 million people die every year from diarrhea (including Cholera) associated with inadequate water supply, sanitation, hygiene and the majority had been children in developing countries. In Africa, about 80 million people are at risk from waterborne diseases like dysenteries, Cholera and 16 million cases of typhoid infections each year are result of lack of clean drinking water and adequate sanitation [1]. Around 40% of world's population, 2.6 billion people don't have access to basic sanitation facilities and more than one billion people don't have ability or access to safe drinking water [2].

In Rwanda, tremendous efforts have been made to launch a national policy for the water and sanitation management sector that consists of strategies and programs for the development and the rehabilitation of human resources, social and economic infrastructure. The long-time vision is to provide better guidance for the development and the coordination of water sector. According to the planning and policy document of Rwanda, the government is making concerted efforts to improve water and sanitation coverage both in rural and urban areas [3].

Actually, onsite pit latrines and few septic tanks are the most method of disposal of excreta and wastewater encountered in many cities of the country. Some institutions have on-site or individual facilities for wastewater treatment where only few of them operate adequately, and as the Rwandan population is significantly increasing, these methods will be unsustainable in coming years in the future and these modes of disposal will have a high sensitive pollution to the atmosphere and ground water which is the main source of water, and that is the reason why, as a civil engineer can contribute in providing new different methods of wastewater management where constructed wetland can be one of sustainable approaches to afford.

A constructed wetland is a solution for sustainable and safe mode of wastewater disposal and treatment, and meets all sustainability conditions including pollution control, environmental protection, reuse and economic feasibility for urbanization and cities agglomeration as sanitation is the main factor in basic infrastructure to count on.

The aim of this research was particularly interested to the design of a sewer system and a horizontal subsurface flow treatment wetland (SSF) in one of Rwandan cities, MUHANGA district city, precisely in KIBILIGI quarter, result in contribution to urban planning, land use and protection of the environment by reducing the environmental pollution due to the expansion and increase of population.

METHODOLOGY

Description of the study area

Generally, constructed wetlands as one of wastewater treatments approaches can be an adequate, flexible and environmental approach if applied in Rwanda. But by scoping, our study was conducted in KIBILIGI quarter, NYAMABUYE sector, MUHANGA district. Recently, the quarter is habited by 627 populations (UBUDEHE list, 2018) with a remarkable rate of occupancy. It has a superficies of 2km^2. The site apart

[*]Corresponding Author: Shyaka Eugene
E-mail ID: *shyakaeugene22@gmail.com*

of being a residential quarter, it has also a motel, bars, hostels, a training center, a tribunal court, a petrol station, a car wash and institutions including one stop center, Rwanda revenue authority, and NGO's. The quarter does not have any system of wastewater collection, disposal and treatment system. Every house has its own mean of wastewater disposal. Whereby, most of the wastewater is discharged in pits, anywhere in parcels, and few in septic tanks. Figure1 indicates MUHANGA district and NYAMABUYE sector where KIBILIGI quarter is located and Figure2 indicates KIBILIGI quarter' s boundaries.

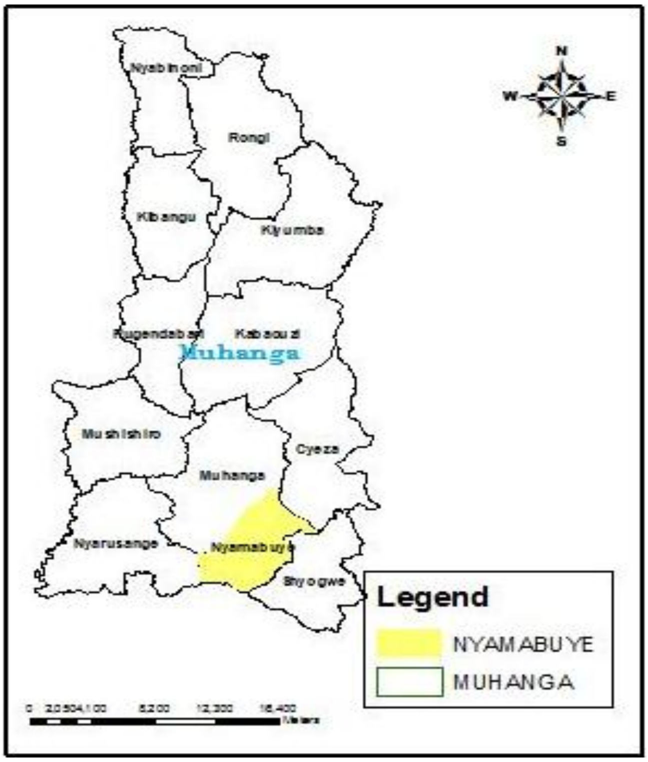

Figure 1. Nyamabuye sector

Figure 2. Kibiligi quarter

METHOD FOR ESTIMATION OF WASTEWATER FLOW

Water consumption

The water consumption data was obtained from WASAC, a sample of 16 houses, the tribunal court, hostels, carwash and training center was used. For households the water consumption data, the total number of persons, the consumed water and their corresponding duration was determined. And for tribunal court, carwash, hostel and training center, we took the monthly water consumption from their WASAC counter and then we have calculated the average daily water consumption. Knowing the quantity of consumed water, the quantity of discharged wastewater was determined. Relying on theory wastewater was assumed to be 80% of the water consumed [4]. Knowing the per capita per day wastewater discharge and the number of forecasted population, the per capita per day discharge at the end of the design period has been found.

Population of the area

The population of the area was obtained from the local administration. According to statistics results of 2018, the national demographic rate of the recent social census is 2.7% and 4% for the KIGALI city. In the design of municipal sewage collection systems, the design period of 20 years is the minimum recommended, for our study we have used a design period of 30 years. Knowing the above, the forecasted population is calculated using the formula below:

$$\boldsymbol{P = P_{act}(1 + r)^n}$$

Where; P: forecasted population, P_{act}: the actual population, r: the demographic rate and n: the design period.

Determination of design flows

Apart from the wastewater discharge, the design capacity shall include extraneous flows which inevitably enter in the total flow. These flows include groundwater flows and rainfall dependent infiltration. The groundwater flow component in cities is generally insignificant and maybe accounted using conservative per capita flows. While, the rainfall dependent infiltration flows are accounted by designing pipes to have a $\boldsymbol{d/D}$ ratio of 0.5 for Peak dry weather flow (PDWF) [5].

The design flow is assumed to be the average daily flow for a continuous 12 months period, this happen until the end of the design period. It is obtained by multiplying the average daily flow by the peak factor. The peak factor is a ratio between water consumption at a certain moment of the day and the average daily consumption. The peak factor used for safety of sewer systems is 2.5.

Design flow=Peak factor × average daily flow

Materials selection

Based on the life expectancy, resistance to scour, resistance to acids, alkalis, physical strength, availability in sizes required, cost, handling and installation, the polyvinyl chloride pipe was selected because it presents many of these factors. It can be used as an alternative to asbestos-cement and vitrified-clay pipe with light weight. It's manning's n=0.01 and because it is better to use a manning greater than n=0.01 for design purpose, therefore we have used manning n=0.015, Polyvinyl Chloride (PVCs) are the most widely used pipes for gravity sewer system for many years.

Design of sewer system

They are four elements are discussed in design criteria location, pipe size, slope and alignment. Location of sewers is usually on the side of roads at the part of right of way, the depth of sewers must be sufficient to prevent freezing and gravity sewers shall laid at least 3m horizontally edge to edge Pipe size is a principal factor respected in designing wastewater [6]. when designing laterals, it is recommended to design at half full flow in order to provide a factor of safety but not for interceptors [7]. The design was based on the average daily flow of the projected population and their corresponding wastewater generation. Having the design flows, material's roughness and the slope of sections between two manholes. The hydraulic equation $Q = (A_c R^{2/3} S^{1/2})/n$ was to determine the size of sewers.

$$Q = V \times A = (A_c R^{2/3} S^{1/2})/n \quad \text{Chezy-Manning formula} \quad (0)$$

$$V = (R^{2/3} S^{1/2})/n \quad \text{Chezy-Kutter formula} \quad (1)$$

For full sewer flowing, $R = \frac{AC}{P} = \frac{\left(\frac{\pi}{4}\right)\times D^2}{\pi D} = \frac{D}{4}$ **(2)**

And replacing (3) in (2) $Q = \frac{0.312}{n} * D^{8/3} * S^{0.5}$ **(3)**

From the formula above, we can determine the pipe diameter:

So, $D = \left(\frac{Q*n}{0.312*S^{0.5}}\right)^{8/3}$ **(4)**

Design of a horizontal sub-surface flow treatment wetland

Generally constructed wetlands are designed based on their Five-day Biochemical Oxygen demand (BOD_5) removal ability, operation in treating waters from lead, zinc, silver, gold, copper, nickel and uranium mines [8]. Having the wastewater flow (the influent) from the sewer system, the quantity of Biochemical Oxygen demand (BOD) in the influent (mg/L), the desired effluent BOD, the vegetation in the wetland, the temperature and assuming the bed slope of 1% (recommended for ease construction), we determined the size and the bed depth of our sub surface flow wetland. The followings are the formulas used;

$$[C_e = C_0] = e^{(-K_T t)} \quad (6)$$

$$A_s = [Q(lnC_0 - lnC_e)]/(K_T dn) \quad (5)$$

$$A_c = Q/(K_s \times S) \quad (6)$$

$$W = A_C/d \quad (7)$$

$$Q = K_S A_s \mathrm{S} \quad (8)$$

$$K_T = K_{20} \times (1.1)^{T-20} \quad (9)$$

Where, K_{20} is the rate constant at 20ºC

The vegetation selection

As vegetation within a wetland has to be emergent or floating, in this study we focused on vegetation which meet those conditions and can be commercial. In this case we decided to plant white arum in the wetland and floating water hyacinths in the outlet pond, a pond which take waters from the treatment wetland through the outlet. Those two kinds of plants produce commercial flowers and make a good view for recreational case.

RESULTS PRESENTATION AND DISCUSSIONS

Water consumption

The wastewater discharge has been estimated to be 80% of the water consumption. It has been estimated using the water consumption of 16 houses, tribunal court, carwash, hostel and training center data from WASAC. Where, for tribunal court (TC), carwash (CW), hostels and motels (H&M) and training center (TrC) we took the monthly consumption divide by 30 days and got the average daily consumption. On car wash we have count the number of worker as users and the car wash has 20 persons who clean 60cars per day, on those institutions we assumed a daily frequency of persons. (Table1)

Table 1: Water consumption of the area

No	m^3	Days	pers	dwc (m^3/ca.d)	No	m^3	days	pers	dwc (m^3/ca.d)
1	132	211	5	0.125	13	7	28	5	0.050
2	82	63	9	0.145	14	23	28	7	0.117
3	58	126	5	0.092	15	51	90	6	0.094
4	39	63	6	0.103	16	76	262	6	0.048
5	9	33	5	0.055	TC	120	30	40	0.100
6	62	91	4	0.170	CW	96	30	20	0.160
7	11	27	7	0.058	H%M	720	30	160	0.150
8	59	148	3	0.133	TrC	42	30	60	0.023
9	14	30	6	0.078			sum of dwc		**1.903**
10	78	185	4	0.105			average of dwc		**0.096**
11	38	85	9	0.050			max dwc		**0.16**
12	49	148	7	0.047			min dwc		**0.023**

From table1, after calculating the daily water consumption per person considering every house, it has been found that the water consumption was 89.5 liters per day by average. While the minimum found was 20 liters and a maximum of 180 liters per capita per day of water consumption.

Estimation of wastewater

Forecasted population

The number of forecasted population to be served is given by;

$$\boldsymbol{P = P_{act}(1+r)^n}$$

Where, the actual population (P_{act})= **627 persons**

The demography rate (r)= 2.7%(in Rwanda except Kigali city which has a rate of 4%)

The design period (n) = 20 years

Thus; P= 627(1+0.027)^{20}=**<u>1069 people</u>**

The forecasted population is about 1069 people.

Peak flows

Q_{max}=P × q ×2.5×80%

With P= 1069 persons, (forecasted population)
q= 0.16 m^3/c.day : per capita per day water consumption

Peak factor=2.5 And 80%: the relation between the water consumption and wastewater production

Thus;

Peak flow=Q_{max}= (1069×0.16×2.5×0.8) m^3/day= **<u>342 m^3/day</u>**

Minimum flows

The minimum flows occur when there is low use of supplied water and it is calculated as follows:

Q_{min}=P×q×2/3×80%= (1069×0.16×2/3×0.8) m^3/day= **<u>91.2 m^3/day</u>**

As our minimum flow is greater than 0.221/s for a slope s=0.01, it is sufficient for self-cleansing of the sewer system.

Minimum and maximum velocity

A mean velocity of 0.3m/s is usually sufficient to prevent the deposition of organic solids and a mean velocity of 0.75m/s is required for mineral matter water. All sewers shall be designed and constructed to give a mean velocity, when flowing full, of not less than 0.6m/s based on manning's formula. As measure to prevent sewer from deterioration, the maximum velocity must be less than 4.5m/s based on Manning's or Kutter's formulas for "**n**" equal to 0.013.

Design of sanitary sewers

Determination of pipe size

The diameter gas been calculated using the following formula from manning equation;

$$\boldsymbol{D = \left(\frac{Q\times n}{0.312\times S^{0.5}}\right)^{3/8}}$$

Where; Q is the design discharge=342 m^3/day=0.0039 m^3/s

S natural slope (sewer slope in m/m) = 0.1

n (Manning roughness coefficient) = 0.0152

So, $D = \left(\frac{0.0039\times 0.015}{0.312\times 0.1^{0.5}}\right)^{3/8} m = 0.062m$=62mm

This diameter was very small; the minimum recommended diameter for a slope of 0.1 is 200mm.

Then the full flow capacity for the selected diameter of 200mm has been given by;

$$Q_t=\frac{0.312}{0.015}\times 0.2^{8/3}\times 0.1^{0.5} = 0.028 m^3/s$$

Therefore, a partial condition has occurred, the flow depth was determined using the partial flow diagram in figure 3

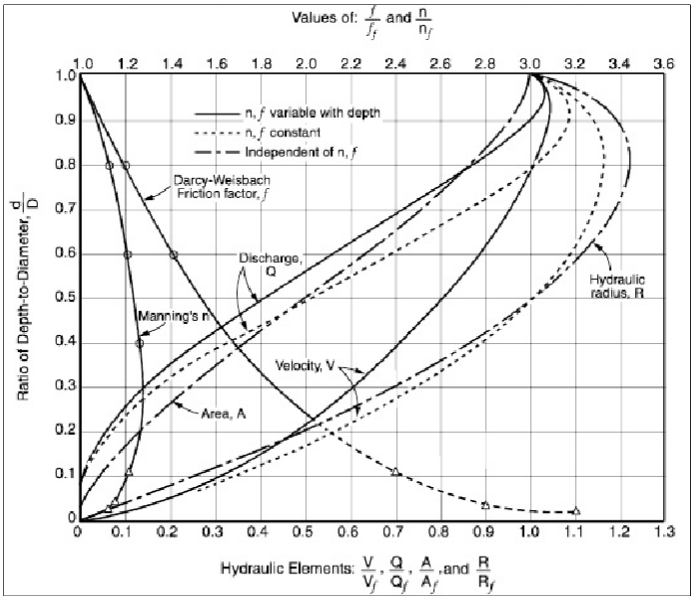

Figure 3: Hydraulic properties of circular sewers (Adapted camp, 1946)

$\frac{Qmax}{Qf} = \frac{0.0039}{0.028} = 0.14$ Then from the figure 3, $\frac{d}{D} = 0.28$

Hence D=0.32×200=64mm of flow depth.

The full flow velocity, $Vf = (R^{2/3}\times S^{0.5})/n$

So, $Vf = \frac{\left(\frac{D}{4}\right)^{2/3}\times 0.01^{0.5}}{0.015}$ =**<u>2.84m/s</u>**

From figure 4.1; for $\frac{d}{D} = 0.28$, then $\frac{V}{Vf} = 0.72$ therefore V=0.72×2.84m/s=**2.04 m/s**

The velocity lied within the limits, between 0.6 to 4.5 m/s.

In the design, a minimum diameter of 200mm and a natural slope of 0.1 were used.

Layouts of sewer systems

The layout is a detailed map that shows the horizontal sewer alignment, it was drawn to represent the proposed sewer alignment. An arrow is placed near the line indicating the flow direction [9]. The site master plan provides the directing route and parcels has been used to draw the sewer alignment.

Manholes were located on the sewer lines in accordance with the design criteria for spacing. The proposed lateral sewer alignment was sketched on the photo.

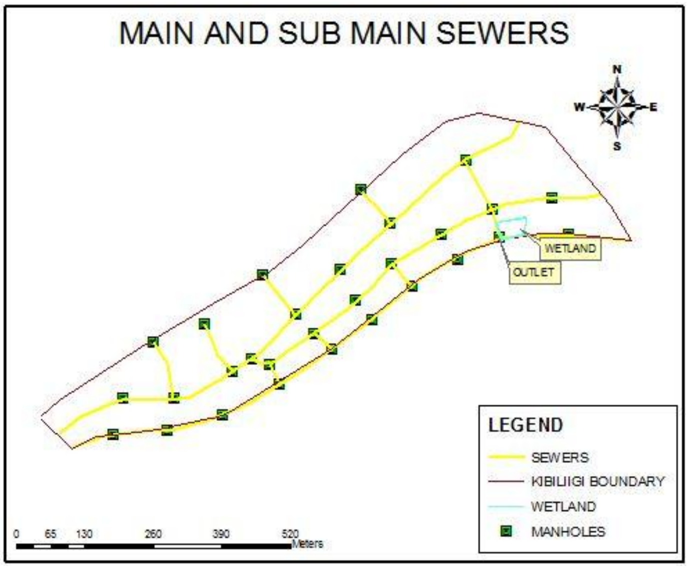

Figure 4: Layout of the sewer system.

Design of the sub-surface flow treatment wetland

Wetland size and depth determination

As, generally the design of a treatment wetland is defined by its BOD removal performance, the wastewater from the study area has shown a BOD5 of 312mg/L (C_o) (data from CST, KIGALI Campus Chemistry Laboratory). The effluent BOD has to meet the standard of water treated for several usages like cleaning, irrigation, washing etc. therefore the desired BOD5 is 30mg/L (C_e).

Geographically the study area is located in moderate climate of the country, where the temperature is in the range of 20-24°C. To design our wetland at maximum size we considered a minimum temperature of 20°C.

The wetland has a media of coarse sand and the vegetation of white arum which has roots that penetrate approximately 0.7 m into the medium (aquatic vegetation), the bed media depth (d) should therefore be 0.7m. And the slope of the wetland is 1% or 0.01 for an adequate system (Ks=<8.60) and for ease of construction.

Reed et al. have indicated the need to check the value $k_sS < 8.60$. Choose a media of coarse sand and from Table1, n = 0.39, k_s=480 and K_{20}= 1.35.

$$Ks \times S = 480 \times 0.01 = 4.8 < 8.60$$

Solve for the first-order temperature-dependent rate constant (K_T) using the following equation.

$$K_T = K_{20}(1.1)^{T-20}$$

As our design temperature is 20°C, the value of $K_T = 1.35(1.1)^{20-20}$=**1.35**

Determine the cross-section area (Ac) of the bed.

$$Ac = Q/(Ks \times S) = 342/(480 \times 0.01) = \underline{\mathbf{71.25\ m^2}}$$

Determine the bed width using the following equation.

$$W = A_c \div d = 71.25/0.7 = \underline{\mathbf{101.7\ m}}$$

Determine the surface area required.

$$A_s = [Q(\ln C_o - \ln C_e)]/(K_T d\, n)$$

$$= [(342) \times (5.74-3.40)] \div [(1.35) \times (0.5) \times (0.39)] = \underline{\mathbf{3040\ m^2}}$$

Determine the bed length; $L = A_s / W = 3040/101.7 =$ **29.9 m**

Determine the detention time (t).

$$t = V_v \div Q = L \times W \times d \times n \div Q$$

$$= 29.9 \times 101.7 \times 0.7 \times 0.39/342 = \underline{\mathbf{2.42\ days}}$$

Divide the required width into individual cells of 25 m wide for better hydraulic control at the inlet zone. Construction of 4cells, each 25m x 30 m could be adequate.

Wetland design layouts

The wetland layouts contain a plan view of the whole treatment wetland system, it consists of structural arrangement of wetland cells, outlet pond and the inlet screen which helps to remove suspended solids by using sieves of 20mm. Figures below; Figure 5 indicate the location of the wetland system and the Figure 6 shows the composition of the wetland system.

Figure 5: Location of the wetland system.

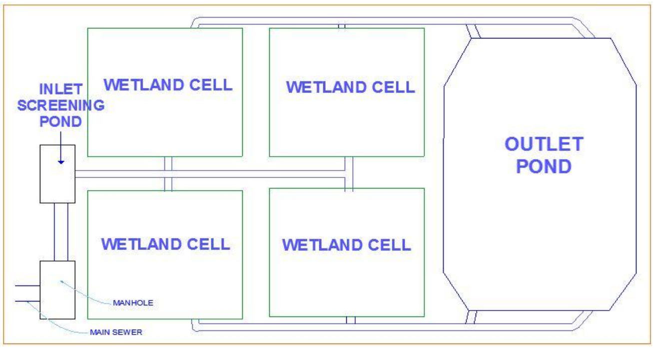

Figure 6: Layout design of the treatment wetland system

RESULTS OBSERVATION

For the sewer system, the sanitary sewer system has a horizontal distance, the obtained velocity of 2.04m/s lies in the standard range for safety of sewers as the velocity is 0.6-4.5m/s. a sewer pipe of 200mm diameter was the selected as the minimum diameter recommended instead of 62mm obtained because it was very small and the manholes was placed according to factors, the distance between two manholes is 90-100m.

For the constructed wetland, the wetlands system is composed by 4 wetlands cells of 25m x 30 m, an outlet ponds to detent treated water before being reused for several activities that do not require clean water (car washing, cleaning, construction activities, gardening, and toilet flushing). The influent flow has to be treated within 2 days and 10 hours (2.42 days) and the effluent flow will be BOD 30mg/L; safe water for several domestic activities.

CONCLUSION

The main study of this paper was to carry out a design of a constructed wetland with its sanitary sewer system in KIBILIGI quarter. Those objectives were significantly achieved through an intensive literature and application of several methods. Preliminary study of the area and considering the slope and gradient it was decided to design a conventional gravity sewer system as a method of collection and conveyance of wastewater, and considering the amount and the quality of the wastewater, the design of horizontal sub-surface treatment wetlands has been a solution for treating the wastewater of the area. The following notifications have been observed as the analysis of obtained results;

For the design of sewer system, the average daily water consumption per capita has been 96 liters which is in the standards limits, the maximum was daily water consumption per capita was 160 liters and the minimum 23 liters, the higher difference as usual is due to temporally activities like construction. The sewer pipe diameter found was 62mm which is below the minimum recommended diameter of a sewer pipe; therefore, our sewer pipe diameter selected was 200mm. After, the obtained design parameters were checked to meet the design standards as prescribed in the literature review

For the design constructed wetland, the average design influent flow has been $342m^3$/day which has to be treated in a detention time of 2.42days in a constructed wetlands system area of $3040m^2$, considering a minimum average annual temperature of 20^oC for treatment efficiency.

REFERENCE

[1] World health organization (WHO), 2000 world health report.

[2] Dusingizumuremyi, 2006. Impacts of Inadequate Sanitation and Unsafe Drinking Water on Human Health.

[3] Wali, U.G et al, assessment on wastewater management practices in Kigali city Rwanda.

[4] Viessman and Hammer, 2005 water supply and pollution control 7th edition.

[5] Rania Amen, Paul Buehler et Al, 2013. Sewer Design Guide

[6] GLUMRB, 2004.Fundementals of wastewater treatment and engineering

[7] Steel and McGee, 1979. Water supply and sewerage.

[8] Suhail N. Abed, Miklas Scholz et al. ,2018. Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review.

[9] Mackenzie L.D., 2010.Nanotechnology for water and wastewater treatment.

[10] METCALF and EDDY, 2003.water engineering, treatment and reuse 4th edition.

[11] Viessman. U, 2007. Fundamentals of biological wastewater treatment, Menlo Park: Addison- Wesley

[12] Vince and Robert, 2008. Design guidelines for sewage works, Ontario, ISBN 978-1-4249-8438-1

[13] EPA, 2011. Primer for municipal wastewater treatment systems, EPA 625-R-92-013 (revised), Washington DC.

[14] Twagirayezu. P, (2010). Optimization of a natural wastewater treatment in Kigali, Rwanda.

[15] Reddy, K.R., and W.H. Smith (Eds.), 1987. Aquatic Plants for Water Treatment and Resource Recovery. Magnolia Publishing Inc.,

[16] EPA, 1988. Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment Design manual, EPA /625/1-88/022.

[17] IWA, 2000. Constructed wetlands for pollution control, IWA specialist group.

[18] Melbourne Water, 2010. Constructed wetlands guidelines

[19] Reed et al., 1995. constructed wetland to treat wastewater.