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Assessment of Wastewater Management Practices in Kigali City, Rwanda

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Abstract: This study aimed to assess the current wastewater management practices in the City of Kigali (CoK). It focused on the quantification of household wastewater production, estimation of its quality, and the development of practical strategies for sustainably managing the wastewater, now and into the future. It is based on data on population, water supply and on data from questionnaire surveys carried out which are used to assess and derive figures on water consumption, unit wastewater production by the three different residential categories according to dwelling type and household income; these are high, medium and low standings. Three samplings runs were conducted in order to assess the quality of wastewater. The average water consumption was found to be 184 l/ca.d for high standing, 57 l/ca.d for medium standing, and 20 l/cap.d for low standing dwellings. The respective return flows (or wastewater discharge coefficients) were found to be 0.52, 0.68 and 0.75. For the monitored main parameters of pH, conductivity, Dissolved Oxygen, Total Dissolved Solids, Chemical Oxygen Demand, Total Nitrogen, and Total Phosphorous, the effluent quality far exceeded the limits for effluents discharged into sensitive waters. It is recommended that all concerned institutions and key stakeholders should work together in formulating an appropriate wastewater management strategy, with special emphasis on decentralized sanitation, reuse of wastewater components wherever possible, and cleaner production in industries.

Keywords: City of Kigali, water consumption, wastewater generation, wastewater management strategies, urban wastewater management, wastewater reuse.

INTRODUCTION

Tremendous efforts have been made to launch a Rwandan national policy for the management of the water and sanitation sector that consists of strategies and programs for the development/rehabilitation of human resources, social and economic infrastructures. The long term vision is to provide better guidance for the development and the coordination of the water sector. According to the planning and policy document of Rwanda [1], the government is making concerted efforts to improve water and sanitation coverage in both rural and urban areas. The current distribution of drinking water is still inadequate and the rate of access in the country is estimated at 54% but does not exceed 44% in the rural areas. Regarding sanitation, even though over 80% of the country's population has access to latrines, only 8% of these meet hygienic standards. In order to achieve the Millennium Development Goals (MDGs) and the 2020 Vision, in 2005 the Government of Rwanda launched a 15-year water and sanitation program in rural areas. This program aims to improve the percentage of people with access to clean water, then estimated at 44%, and increases the sanitation rate from 8% to 66% in 2010, to 80% in 2015 and ultimately to100% in 2020.

In the City of Kigali (CoK), with the surface area of 73,100 hectares [2], 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. 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 especially for hospitals, hotels, prisons, banks and for some estate of Caisse Sociale; and few of them rarely function properly. There is currently no data available on domestic or industrial wastewater quality and quantity in CoK, and for Rwanda in general. It is therefore not possible to design and develop effective strategies without information on the quantity and trends of wastewater generation. The main objective of this study is therefore to estimate the quantity of wastewater generated in CoK and derive unit figures for water consumption and wastewater production for future use in Rwanda. These figures will be useful for modelling and decision making of strategies for wastewater management in CoK, and this will contribute to the achievement of the goals of the National Sanitation Policy and MDG's in Rwanda.

MATERIALS AND METHODS

Quantity of Water Consumed and Wastewater Production

A survey was carried out to find suitable data to derive the quantity and the quality of water consumption by different domestic uses. The questions asked were on household

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Table 1. Structure of Water Consumption in 2005-2006 – modified (Electrogaz, 2007)

	Consumption in 2005		Consumption in 2006		Annual Change
Type of customers	Quantity (m^3)	%	Quantity (m^3)	%	%
House connections	4,705,325	77	5,044,284	77	7.2
Public standpipes	233,672	4	272,417	4	16.6
Administration	801,730	13	808,209	12	0.8
Industries	378,766	6	452,249	7	19.4
Total annual	6,119,493	100	6,577,159	100	7.5
Daily water consumption	16,766		18,020		7.5

water consumption and uses, on the used soap and detergents, and on wastewater disposal systems. According to the purpose of the study, the population size and the availability of resources, a sample size of 100 was adopted, with ±10% as the precision level, 95% as the level of confidence and 0.5 as the degree of variability. The used methods of sampling are the stratified and systematic methods [3]. The used strata consist of habitat and income standings (categories) for different dwellings in the CoK. The category distribution in CoK according to habitat and economic status are high 16 %; medium 22 %; and economic or low income 62 % [4]. The investigated urban districts are Gasabo, Kicukiro and Nyarugenge, in their cells respectively Kimihurura, Rugando, Rukiri, Niboye, Rwezamenyo and Kimisagara. Household wastewater generation was derived from water uses with the bulk of the non-consumptive water uses leading to wastewater generation, *e.g.*, toilet and bath water, laundry, kitchen washing, etc. From this data it was then possible to determine the wastewater return flows for each landuse category. Total water consumption of the study area was determined from Electrogaz (energy and water utility company) data, which include also the water consumption of big consumers. For the districts studied, wastewater was calculated on the basis of population and the average of wastewater production per capita per day.

Assessment of the Quality of Wastewater in CoK

The selection of the six sites used for wastewater quality sampling was done based on the type of activities and institutions. The selected sampling sites are Muhima *thalweg* (stormwater drain), Kigali Institute of Science and Technology (KIST), Mille Collines Hotel, Union Trade Center, Kigali Central Prison and the effluent from the Industrial Park. Due to resources constrains, only three sampling runs were conducted. The sample collection, preservation and analysis were done according to [5] and parameters monitored are pH, conductivity, Dissolved Oxygen (DO), Total Dissolved Solid (TDS), Chemical Oxygen Demand (COD), Total Nitrogen (TN), and Total Phosphorous (TP). Data analysis involved the determination of mean and standard deviation using Microsoft Excel and SPSS software packages. Since there are no effluent discharge regulations in Rwanda, the Zimbabwean regulations for effluent discharge into sensitive waters [6] and the Composition of Typical Residential Untreated Wastewater Guideline [7] were taken as the basis for discussion. Basing on results obtained and the current wastewater management options being applied worldwide, the basic scenarios for wastewater management in the CoK have been suggested.

Study Area

Coverage

The City of Kigali is the capital city of Rwanda and is also the largest and fastest growing city in the country. It covers a total area of about 73, 100 hectares (ha) and the population of CoK was estimated to be 970,000 in 2007, with 5.4% as an annual population growth rate [4]. Its population is expected to reach 2,000,000 by the year 2020. The CoK consists of two parts, one urbanized and the other non-urbanized. It is the urbanized party which was considered in this study. In 2002, the urbanized area only covered about 6,560 hectares with a population of about 765,300. The urbanized part represented 8% of the total surface area of the city and about 78% of its population [2].

Water Consumption in CoK

The water consumption pattern of each category for the years 2005 and 2006 are presented in Table **1**. These data are from the Commercial Services Department of Electrogaz. The individual connections represent special residential connections or small consumers. The table shows only those consumers supplied by Electrogaz whilst the rest of the people in Kigali are supplied from private sources. The figures also don’t show the amount of losses in the system and these losses have not been quantified.

The drinking water consumption at the national scale during the period 2000-2006 increased at an average annual growth of 6.5% [4]. The highest growth rates have been recorded during the years 2000 and 2002 with yearly rates respectively of 12% and 15%. The increase in water consumption in CoK during the same period of 2000-2006 has been particularly important, with the annual water billed increasing by 12.8% [4]. The water consumption in CoK increased by 7.5% from 2005 to 2006, with a clear dominance of domestic consumption as shown in Fig. (**1**). The large consumers are mainly industries and institutional establishments.

Fig. (1). Distribution of consumption based on the categories of consumers.

Wastewater Collection, Treatment and Disposal in CoK

The management of collection, treatment, disposal of wastewater plus sludge handling infrastructures is the responsibility of the Municipality of Kigali through its Public Infrastructures Department. The Department consists of 4 units: (i) Sewerage Network and Sanitation (sewerage network include storm water collection), (ii) Transport unit, (iii) Water and Electricity unit, and (iv) Open Spaces unit [8]. Only around ten significant wastewater treatment facilities exist in the City of Kigali area and these are shown on Fig. (**2**).

Wastewater Disposal

Only a small portion of the wastewater in CoK is treated by the existing treatment facilities, mainly for some large water consumers and 3 small treatment systems for high income dwellings (Nyarutarama, Gacuriro and Kacyiru Caisse Social estates). Generally, the other part of wastewater generated is discharged into either septic systems or to open drains which are designed for storm water conveyance. This direct discharge of wastewater is prevalent especially in areas close to wetlands (Kajevuba, Kagugu, Rwampara, Gatenga and Mulindi) and streams.

RESULTS

Per Capita Water Consumption by Housing Category

From the survey carried out in this research for 100 households, figures for water consumption per capita per day in the CoK were derived. Table **2** gives a summary of the derived water consumption data, together with the data from [4]. The Electrogaz data is based on desk studies for all towns, which may not reflect the real situation prevailing in Kigali. However, further studies using a larger sample size would give a statistically more accurate figure.

The considered domestic uses are: cooking, dish washing, bathing, cleaning, washing, toilet flushing, car wash and garden watering (Fig. **3**). The water from dish cleaning, bathing, washing/laundry, and toilet flushing was assumed to end up as wastewater. From this questionnaire data, a mean discharge coefficient for each housing category has been derived respectively as 0.5, 0.7 and 0.75 for high, medium and low income categories.

Fig. (**4**) illustrates statistically the data on water consumption based on different household water uses. The black line in the box shows the median and whiskers show the

Fig. (2). Map showing the location of existing wastewater treatment plants and respective technologies applied in the CoK (Electrogaz, 2007).

Table 2. Summary of Water Consumption Data For Different Residential Categories in Kigali City Compared with the Figures Given by Electrogaz (2007)

Housing Category	Average No. of Persons Per Household	Average Monthly Water Consumption m^3/Household	Average Water Consumption l/ca.d	Estimates from Electrogaz (2007) l/cap.d
High income	5	32.5	184	140
Medium income	8	16.4	57	80
Low income	9	5.5	20	20

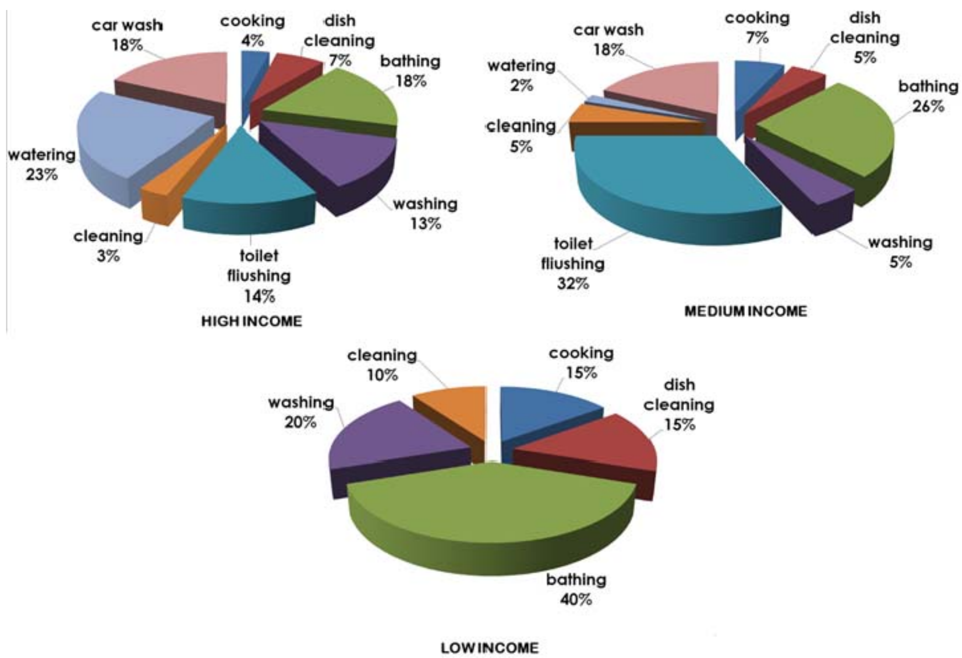

Fig. (3). Proportions of water consumption in Kigali for different domestic uses in l/ca.d.

quartiles and extreme values. The box plot provides a vertical view of the data. The box contains the middle 50 percent of the data. The position of the median and the box itself identify the center of the distribution. The length of the box is called the "hinge spread". This provides a visual representation of the spread of the distribution. A less reliable measure of spread is the "whisker spread". The symmetry of distribution could be judged by the position of the median within the box and box within the whiskers. Also, the presence of outside values toward one side of the box suggests asymmetry. There is no data for toilet flushing for low income households because they do not have flushing toilets.

The sample size is 100 households, with respectively 16, 22 and 62 households for high, medium and low income categories. As observed in Fig. (**4**), the possible reasons which caused extremes and outliers may be either the skewed population distribution especially in dwellings for low standing or to the small sample size of each housing category.

Domestic Water Uses and Wastewater Generation

High income category: Fig. (**3**) shows percentage proportions of water use in high income dwellings of Kigali. These percentages represent the average of the amount of each water use per capita per day and per housing category. The domestic activity which consumes much the highest amount of water is watering (23%) and the one which consumes little amount of water is floor cleaning (3%). Car washing and bathing also consume considerable amounts at 18% each. The estimated amount of wastewater for this category, coming from toilet flushing, clothes washing, bathing, and dish washing is 96 l/cap.d. Garden watering and car wash water is not considered in wastewater calculation. Water from floor cleaning is also disposed of in the garden.

Medium income: As observed for high income category, for medium income also, it is the toilet flushing that consumes much the highest amount of water (32 %), followed by bathing (26 %), whilst floor cleaning, clothes washing and dish washing all consume 5% of the 57 l/cap.d of household water consumption. Car washing also contributes considerably at 18%. The estimated amount of wastewater generation for this category is 39 l/cap.d.

Low income: The difference with other categories is the absence of connection to a water supply network for most houses. That is why there are no flushing toilets. Also, as the plot surface area in low income areas is very small (>500

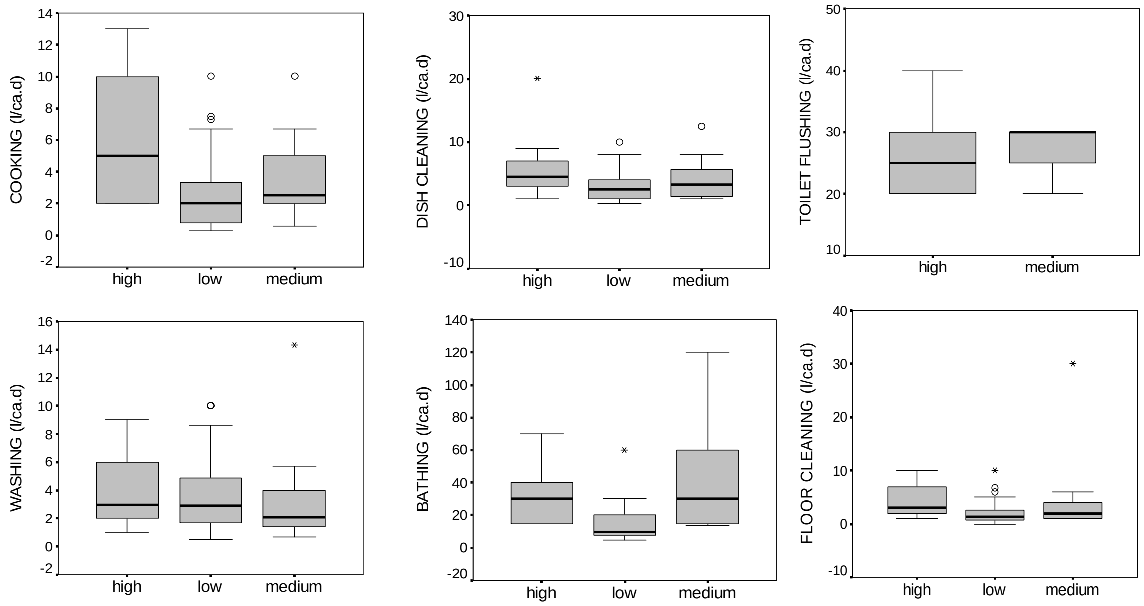

Fig. (4). Questionnaire results showing average proportions of daily wastewater generation for different housing categories in l/ca.d.

Table 3. Results of Conductivity, Total Dissolved Solids, Chemical Oxygen Demand (COD) and Dissolved Oxygen (DO) for Samples Collected in October and November 2007

Sampling Site	Conductivity (µs/cm)			TDS (mg/l)			COD (mg/l)			Dissolved Oxygen (mg/l)	
	A	B	C	A	B	C	A	B	C	B	C
Muhima	892	961	792	472	519	402	630	800	1015	0.0	4.4
KIST	811	623	528	434	339	267	177	222	271	4.0	3.2
Milles Collines	428	581	508	230	315	257	142	293	380	4.2	8.0
UTC Rujugiro	1081	851	-	588	466	-	97	121	-	5.6	-
Industrial Park	623	645	621	332	347	315	37	74	72	3.0	4.4
Central Prison	3	3	4	1737	1655	1926	2210	2130	3230	0.0	0.0
Untreated residential Effluent Standard *					700			500			

Key A = 10 October 2007 B = 1 November 2007 C = 8 November 2007
* Composition of Typical Residential Untreated Wastewater (Burks and Minnis, 1994)

m^2), there is no garden watering. The main water uses in this category are bathing (40 %), washing (20 %) dish cleaning (15 %) and cooking (15 %). Floor cleaning is the least contributor at 10%. The estimated amount of wastewater for this category is 15 l/cap.d.

Wastewater Quality

Tables **3** and **4** summarize the analytical results for different wastewater samples collected around the CoK and analyzed under this study for the period October to November 2007. All analytical results appear to be high compared to the composition of typical residential untreated wastewater [7, 9]. Wastewater in Kigali is generally highly concentrated because of low water usage in most areas. Most of the systems flow intermittently because of erratic water supplies, whilst others have holding facilities on sight. This explains why TDS, COD, and TN were particularly very high.

Estimation of Wastewater Flow and Pollution Loads

Table **5** gives an estimation of the volume of wastewater and nutrients produced in Kigali. It attempts to cover all the areas including those not supplied by Electrogaz. The figure on wastewater would be a potential figure and would be useful for planning purposes. From Table **1**, approximately 14,050 m^3/d is supplied to residential areas by Electrogaz and this represents 27% of the estimated demand of 52,670 m^3/d shown in Table **5**. Whilst the current figures of water supply by Electrogaz are not available, the deficit should be lower in view of current efforts by Electrogaz to develop

Table 4. Results of pH, Total Nitrogen and Total Phosphorus for Samples Collected in October and November 2007

Sampling Site	pH			TN			TP		
	A	B	C	A	B	C	A	B	C
Muhima	7.3	6.9	6.9	42.4	33.4	42.6	44.0	39.76	39.4
KIST	7.6	7.4	7.5	247.8	249.4	249.6	44.0	40.64	21.4
Milles Collines	7.3	7.3	7.3	118.8	125.0	126.4	34.2	54	61.2
UTC Rujugiro	7.7	7.7	-	158.2	136.0	-	32.4	38.88	-
Industrial Park	6.9	7.6	7.2	178.4	150.2	160.6	5.0	5.04	2.6
Central Prison	6.7	6.8	7.1	16.4	15.8	16.8	>132.0	>132.0	>132.0
Untreated residential Effluent Standard *				40			12		

Key A = 10 October 2007 B = 1 November 2007 C = 8 November 2007
** Composition of Typical Residential Untreated Wastewater (Burks and Minnis, 1994)*

Table 5. Calculated Current Water Consumption and Wastewater Production in City of Kigali Based on Residential Categories

Landuse (Housing Category)	Total Population Per Category **	Water Use l/cap.d	Total Water Consumption m^3/d	Wastewater Production, l/cap.d	Total Wastewater Production, m^3/d	Unit TN Production, g/cap.d *	Total TN Production, kg/d	TP Production, g/cap.d *	Total TP Production, kg/d
High-income >1,500 m^2	154,968	184	28,514	96	14,877	4.3	664	1.4	221
Medium income 500 - 1,500 m^2	213,080	57	12,146	39	8,310	4.3	913	1.4	304
Low- income ≤ 500m^2	600,499	20	12,010	15	9,007	4.3	2,574	1.4	858
Total	968,547		52,670		32,040		4,151		1,384

*N.B. * The used figures for TN and TP are from the study carried out by Twagirayezu (2007)*
*** The population is based on percentages of 16% (for high income), 22% (medium), and 62% (low) given earlier.*

Nzove bank filtration system, among other developments. The results also show the wastewater would potentially contain 1,515 tonnes/year as TN and 505 tonnes/year as phosphorus. This calls for innovative methods of recovering these valuable nutrients considering that the soil fertility in Rwanda is gradually decreasing [9].

DISCUSSIONS

The existing wastewater management system in CoK is very precarious. There is no planned wastewater management either at national level or at CoK. For example, the effluent from the Central Prison, consisting of black and grey water, is discharged every day during the night for around six hours (from 5:30 pm to 11:30 pm) and it passes just near households before reaching into the Nyabugogo River. That river is used by people who stay on its surroundings for some domestic uses such as washing and cleaning. There is no institutional framework for managing wastewater, no standards and regulations, and therefore no enforcement. Whilst an attempt has been made by a number of firms and establishments to construct some wastewater treatment facilities, the effluent and sludge quality needs to be monitored and controlled to ensure environmental protection.

Estimation of Wastewater Quantity

Domestic uses that consume more water and consequently generate much more wastewater are as follows:

- In high and medium income categories, bathing and toilet flushing
- In medium income category, the amount of water used in bathing is very high, this is due to the higher number of persons per household (8 compared to 5

Table 6. Measures Assigned to the Proposed Strategies for Wastewater Management in CoK

Measures		
Decentralized Sanitation	**Eco-Technologies**	**3-Step Approach**
Primary treatment methods • Septic tanks • Imhoff tanks *Secondary treatment methods* • Intermittent sand filters • Re-circulating sand filters • Macrophyte lagoons • Constructed wetlands • Off-shelf package plants • Alage ponds + irrigation	*Natural processes:* • Wetlands, • Algal ponds • Macrophytes • Stabilisation ponds *Systems for nutrient and energy recovery and reuse:* • Anaerobic treatment, • Aquaculture(in stream assimilative capacity improvements) • Harvested macrophyte ponds	*Step 1: Prevention/reduction of waste production:* • Reduce water use • Water saving technologies (in industry and household) • Reuse grey water • Ban undesirable compounds • (e.g. P-detergents, toxics) • Apply low water use or dry sanitation • Apply rainwater harvesting *Step 2: Treatment and recovery of waste components* • Convert waste to something useful for reuse (e.g. biogas, fertilizer, protein). • Select treatment process that makes best use of possible side products • Optimise effluent reuse *Step 3: Safe disposal of any waste components not recycled or reused by stimulating self purification*

number of persons per household for high income).

- For low income category, washing, cooking and dish cleaning are the highest consumers of water. This may be attributed to the high number of children and babies in household (from the questionnaire information, the average of children under 12 years is 3 per household). Also, the water used for cleaning is much more than in other categories because cleaning, for most cases, is done every day and two times per day.

The calculated domestic wastewater quantity of 32,040 m^3/day far exceed the water supplied, 18,020 m^3/day, given by Electrogaz for year 2006. This is because the amount of wastewater generated in CoK was calculated based on the obtained figures in this research and for the whole population of the City, i.e. including the non-urbanized part, which is not supplied with water from Electrogaz. The total water consumed calculated for the whole city is 52,670 m^3. Therefore, the return ratio of consumed water to wastewater generated for the CoK is around 60%. For the coming years, the water consumption is expected to increase if Electrogaz increases also its production and adequately supplies the whole population. In fact, the 2005 to 2006 Electrogaz water production represents only 27% of the calculated demand in the CoK. Electrogaz gave this figure as 70% when they considered only the urbanised part of Kigali [4]. If water consumption increases, wastewater generation will also increase, necessitating more attention to wastewater management to avoid further environmental pollution.

Wastewater Quality

Most of the analyzed parameters exceeded standards for typical residential untreated wastewater [6]. The COD concentration for Muhima and Central Prison sites are out of the given range, and the latter had the highest concentration. For TN, except for the two sites at Muhima and Central prison, others exceeded the standards for effluent discharge. It was the same case for TP with the exception of the Industrial Park site. The high concentration of TP might be attributed to the used soaps and detergents as direct discharge of domestic wastewater was particularly observed for the site which has the highest concentration, the Central Prison. This concentration was very high so much that only 0.5 ml of sample had to be used in order to stay within the range of the spectrophometer used. Also, all concentrations of TN and TP far exceeded the limits for effluents discharged into sensitive waters, i.e., 10 mg/l for TN and 0.5 mg/l for TP, as given by the Government of Zimbabwe (2000). The pH readings were within the expected range.

Proposed Strategies for Wastewater Management in CoK

In order to ensure environmental sustainability on the CoK, it is necessary to select the “most appropriate technologies”, a very difficult task in itself, taking into account the many different operations and options in a city. Whatever technologies are eventually adopted, two key issues of affordability and appropriateness should play a central role. Based on the affordability, which is related to the economic conditions of the community, and on the appropriateness, which is linked to the environmental and social conditions, strategies for wastewater management are proposed in the Table **6**. It is proposed that management strategies should be site specific, accounting for social, cultural, environmental and economic conditions in the target area. The strategies recommended, therefore, are decentralized sanitation, eco-technologies and the 3-Step approach [11]. The reason is that they combine many practical options and represent a vast choice in wastewater management technologies. To each strategy measures are assigned as shown in Table **6**.

In addition to the measures proposed above, the following issues are important in the case of CoK:

- A clear policy and regulations for developing and managing wastewater treatment systems would ensure that domestic, industrial, commercial and institutional sectors manage wastewater in a systematic and sustainable manner.
- Wastewater should only flow in covered conduits, not in open drains as is currently happening. This would reduce the exposure of humans and the environment to risks and hazards.
- Water supply coverage needs to be increased rapidly to ensure a hygienic environment.
- The development of professionals and practitioners in wastewater management by government and educational institutions would stimulate the adoption of appropriate wastewater management practices.

CONCLUSION AND RECOMMENDATIONS

1. Wastewater effluents are discharged in the environment without treatment, a situation which is not sustainable and requires urgent attention. The excessive use of septic tanks and soakaways could lead to groundwater contamination and needs to be investigated. Adequate monitoring measures and systems are required for existing treatment facilities to ensure that they comply with safe environmental standards
2. The amount of domestic wastewater generated in the City of Kigali was estimated to be 32,040 m^3 per day and the estimated pollution load is 4,151 kg/day of TN and 1,384 kg/day of TP. For high and medium income category, bathing and toilet flushing are the domestic water uses which consume much more water. Water conservation measures that target these two particular uses would be more effective.
3. The analyzed parameters of Total Nitrogen, Total Phosphorus, pH, Total Dissolved Solids, Conductivity and Chemical Oxygen Demand showed that the quality of wastewater discharged into the environment in the City of Kigali is bad as most parameters do not meet the typical effluent standards used in other countries. The use of continuous monitoring could help in generating more reliable data and provide real-time data for operational control. Further research on wastewater quality (microbiological and other toxic compounds), assessing the health risk and the pollution of water resources which is taking place in City of Kigali is therefore recommended.
4. Decentralized sanitation, eco-technologies and the 3-Step Strategic Approach are proposed as strategies to solve the wastewater-related problems in the City of Kigali. These would reduce environmental pollution and ensure the recovery of wastewater by-products of nutrients, water and energy.

ACKNOWLEDGEMENTS

The authors are very grateful to Nuffic for sponsoring this study through the WREM Project, a collaborative capacity building project between the National University of Rwanda and the UNESCO-IHE Institute for Water Education. We would also like to acknowledge the cooperation and assistance given by Electrogaz and the City of Kigali during this research.

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Received: February 25, 2010 Revised: August 08, 2010 Accepted: August 26, 2010