APPLICATION OF APPROPRIATE TECHNOLOGIES TO SOLVE WATER SUPPLY AND SANITATION ISSUES IN BANDUNG MUNICIPALITY, INDONESIA

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Key words: water resources assessment, rainfall harvesting, biodrainage model

Abstract

The rapid expansion of urban sprawl and oftentimes, unplanned and even illegal development has strained water supply and sanitation situation in most developing countries, including Indonesia. Available water resources are severely impacted by over abstraction, uncontrolled surface runoff, droughts caused by global climate change and water pollution. Water supply and sanitation problem in Indonesia is widespread even in small district. While Indonesia is rich in resources and has plentiful water supply at the outset, on a number of islands of the archipelago water resources have come under increasing pressure in recent years and are facing deterioration in quality and quantity due to the socio-economic forces causing this deterioration. Moreover, the degradation of groundwater level still happens in many cities in Indonesia including Bandung Municipality, West Java. Bandung Municipality is facing these problems simultaneously, and has recognized the need to develop a program to manage water supply and sanitation in the region to address water quality and scarcity issues in the next 25 years. Some appropriate technologies are introduced to solve the issues. By rainfall harvesting technologies such as rain barrels and artificial recharge well and also biodrainage model are the offered appropriate technologies besides another alternative technology.

INTRODUCTION

The rapid expansion of urban sprawl and oftentimes, unplanned and even illegal development has strained water supply and sanitation situation in most developing countries, including Indonesia. Available water resources are severely impacted by over abstraction, uncontrolled surface runoff, droughts caused by global climate change and water pollution. Water supply and sanitation problem in Indonesia is widespread even in small district. While Indonesia is rich in resources and has plentiful water supply at the outset, on a number of islands of the archipelago water resources have come under increasing pressure in recent years and are facing deterioration in quality and quantity due to the socio-economic forces causing this deterioration. Moreover, the degradation of groundwater level still happens in many cities in Indonesia including Bandung Municipality, West Java. Bandung Municipality is facing these problems simultaneously, and has recognized the need to develop a program to manage water supply and sanitation in the region to address water quality and scarcity issues in the next 25 years.

OVERVIEW OF STUDY AREA

Geographical Settings

The Bandung Municipality is a study area that located at western part of Java Island, which is approximately 180 km south-east from the Capitol of Republic of Indonesia-Jakarta and has an area for about 233.000 hectare. The Bandung Municipality consists of two administrative jurisdictions : one is Bandung City and the other is Bandung Regency. The area comprises an elevated basin ranging from 470 m to 2,321 m (a.s.l). Geologically, the basin was made by eruption of volcanoes in the north, east and south.

Figure 1. Location of Bandung Municipality
(Source : CPF_Bandung.pdf)

Water resources assessment

Water Availability

Based on previous research by Jayamurni on year 2006, the water availability in Bandung Municipality is:

Wet Season = 2.9 x 10^9 m^3/year

Drought Season = 1.44 x 10^9 m^3/year

Average = 2.17 x 10^9 m^3/year

Thus, the potential water availability can be described in Table 1 below.

Table 1: Potential water availability in Bandung Municipality

Water Resources	**Yield (10^9 m^3/year)**
Rainwater	3.47
Surface water	0.2375 – 1.7035
Groundwater :	
Intermediate aquifer	

Deep aquifer	1.062	0.134

(Source : Jayamurni, 2006)

During the last 15 years, urbanization and industrial development in Bandung Municipality have been taking place rapidly. It has a profound influence not only on the quantity of water but also the quality of water in a certain watershed within.

Water Demand

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The rapid urbanization in Bandung Municipality has been observed in recent years. Population has been increased rapidly from 6,2 million people in 2000 to 6.9 million people in 2005. It was estimated that in 2025, the population in Bandung Municipality becomes 11.4 million people (Table 2). It brings the problems about water demand in the future. Besides, Bandung Municipality also have floods problem, degradation of quality and quantity surface water problem, and a serious groundwater level lowering problem.

Table 2: Estimated water demand in Bandung

Year	2000	2005	2010	2015	2020	2025
Population (person)	6.178.955	6.923.900	7.867.006	9.107.259	10.190.304	11.382.200
Domestic, Municipal, Industry (m^3/sec)	9.343	13.095	19.041	24.604	31.027	37.083
Irrigation (m^3/sec)	40.868	39.969	39.070	38.171	37.271	36.372
Total (m^3/sec)	50.211	53.054	58.111	62.775	68.298	73.455

(Source : Jayamurni, 2006)

ISSUES AND CHALLENGES

Rainfall

Rainfall is one of the purest sources of water. When the rainfall was fallen in Bandung area, only about 5% rainfall that absorbed by soil, the rest was become runoff in rivers and impervious area. The average rainfall intensity in Bandung area is 2500 mm per year; the average of evaporation is 3.18 mm; the average of air pressure is

917.7 mb; the average of relative humidity is 77.3%. Based on data from Statistic Indonesia Government Agency (BPS), only 2.78% people used rainfall for domestic water use. Moreover, in Java Island, there was only 0.4% rainfall that has been used.

Given the fact that the majority of total water usage is used for non-consumtive use such as showering, bathing, washing food, washing dishes, cooking and so on. So that the rainwater harvested can be used for most non-consumption uses such as general washing and flushing of toilets.

Groundwater

Groundwater in Bandung Municipality has been become one of important sources of water availability especially for industrial use. However, an excessive groundwater extraction due to rapid increase of water demand causes serious groundwater level lowering problem. In Bandung Municipality, industry sector, especially textile industries, used groundwater reached until $66,9x10^6$ m^3/year. Major groundwater abstraction has been done in Cibeureum-Leuwigajah area, Dayeuhkolot-Moh.Toha area, Rancaekek and Majalaya area, etc. Based on data from year 2004, the rate of groundwater level lowering is shown on Table 3.

Table 3: Rate of groundwater level lowering

Rate of groundwater level lowering (m/year)	Area	Land use
3.11 - 5.12	Cibaligo, Cibeureum, Leuwigajah, Utama, Cimindi	Textile Industries area
1.27 - 4.32	Pasirkaliki, Garuda, Cijerah, Husein, Buahbatu, Cibuntu, Maleber, Arjuna	Residence, Commercial area
1.61 - 3.10	Dayeuhkolot, Kebonwaru, Gedebage, Kiaracondong	Residence, Industries area
1.63 - 2.12	Cicaheum, Cipadung,	

Ujungberung
0.32 - 3.9 Majalaya Textile Industries
area
0.89 - 4.57 Pameungpeuk,
Banjaran, Ciparay,
Residence,
Industries area
0.38 - 1.6 Soreang, Katapang Residence,
Industries area
0.52 - 3.85 Cikancung, Cikeruh,
Cimanggung Residence area
(Source : Sachromi, 2006)

Surface water

Bandung Municipality has about 9 major rivers and the other surface water resources such as reservoirs and well springs. The existing major reservoirs are Cirata
Reservoir, Juanda Reservoir, and Saguling Reservoir. They have several important functions as electric generator, flood control, irrigation, recreation area, water supply
(industry and household) and aquaculture. The total area of all retention basins in
Bandung Municipality is 7.805 ha. The existing retention basins that has been built are
Cibatarua retention basin (capacity 7.5 x 10^6 m^3), Cipanunjang retention basin (capacity 22.4 x 10^6 m^3), and Cileunca retention basin (capacity 11.3 x 10^6 m^3).

Table 4: Surface water in Bandung Municipality

Major Rivers Well springs Major Reservoirs

Cisangkuy
Cikapundung
Cikeruh hulu
Citarik hulu
Citarum atas
Ciwidey hulu
Cimahi
Cibeureum
Sirah Cijagra
Cigalumpit
Tarantang
Citamiang
Cikareo
Saguling
Cirata
Juanda
(Source : Sachromi, 2006)

Existing Sanitation Condition

About 42 percent in Bandung Municipality have not a good sanitation. On the other hand, about 58 percent of sanitation system directly connected with sewer system in Bojongsoang area. Based on Word Bank data on year 2005, there was only 60.000 residences in 5 villages at Bandung Municipality that used septic tank. Furthermore, sludge withdrawn from septic tank was dumped into river. Therefore, treatment facilities in the area did not seem to working efficiently. Meanwhile, people who does

not have private toilet was using shared toilet. Most of shared toilet stood along channel or ditch, and wastewater was directly discharged. Human excrements were discharged into natural water body through nearly no treatment process in present condition. In fact, feces floating in channel were always visible. In case inundation occurred, that water comes to living area. It is not good hygienic condition.

ANALYSIS OF THE OFFERED APPROPRIATE TECHNOLOGIES

Based on the calculation, the water demand on year 2005 in Bandung Municipality can be covered approximately 62.5% from potential water availability.

Meanwhile, the estimated water demand on year 2025 is 2.316×10^9 m^3/year and it means the water demand on the future is higher than the average water availability that only about 2.17×10^9 m^3/year so that there is a deficit for about 0.146×10^9 m^3/year.

To cover the deficit, there are several appropriate technologies offered to solve water supply issues, by using rainfall harvesting facilities such as rain barrels and artificial recharge wells.

Rain Barrels

The total rainfall yield is calculated as follows :

Total Rainfall Yield = Roof Area x Annual Rainfall x 0.9

Taking 100 m^2 for roof area so the total rainfall yield = 100 m^2 x 2.5 m x 0.9 = 225 m^3/ year

Table 5: Rainfall yield

Roof Area (m^2)	Rainfall Yield (m^3/year)
100	225
200	450
400	900
600	1350
800	1800
1000	2250

Taking the assumption that to cover the deficit of water demand on year 2025 if only depend on rain barrels facility so the roof area should be 6.5×10^7 m^2. The total area of Bandung Municipality is about 2.33×10^9 m^2, so that only about 2.8% of roof area that should be built rain barrels facility to harvest rainwater.

Artificial Recharge Well

By taking an assumption that the minimum volume area of artificial recharge well is 6 m^3 (Source:Books of Specification Standard about Artificial Recharge in Yards /SNI: 03-2453-2002), the targeted artificial recharge well can be calculated. If on year 2025, the estimated population in Bandung Municipality is 11.382.200 persons, furthermore, if one residence has 5 family members, so there are 2.276.440 residences in Bandung Municipality. Each residence should have at least one artificial recharge well facility with the minimum volume 6 m^3 in their yard. So it means about 90.64% can cover the water demand on year 2025. Figure 3 shows a typical design of artificial recharge well.

Figure 3. Typical design of artificial recharge well
(Source : practLowImpctDevel.pdf)

Biodrainage

For the alternative solution to handle the sanitation issues, there is a simple facility that it called biodrainage model. This model is similar to Decentralized Wastewater Treatment Systems (DEWATS) technology that effective, efficient and affordable wastewater treatment solution for small and medium sized enterprises. It is an effort to process wastewater with plant media. It is also an eco-friendly way of treating polluted wastewater for reuse. Biodrainage used plant species that are suitable in Bandung area, they are among others : red or yellow Anthurium, yellow or violet allamanda, fragrant grass, water bamboo, red or yellow or white Canna, Dahlia sp., red or green Dracenia, yellow or red Heleconia, dotted or black Caladium, red or white Kenyeri, yellow or red lotus, red onje, red or white pacing, grass plants, papyrus, banana plant, ponaderia, red or white sempol, spider lily, etc. From the past research, it is a considerably effective and efficient means for handling heavy metal and poisonous substance pollution so that it could be used to reclaim a waste disposal area by growing plants on top layer of the disposal area or applying wetland method for a leachate pond.

Besides that, biodrainage model in a small scale also relatively economical as long as land is available.

Figure 4. Typical design of Biodrainage model

Based on previous research, the results for the biodrainage model showed that the efficiency removal rate of some parameters was good.

Table 6: Efficiency removal rate

Parameter	Efficiency Removal Rate
BOD	77.35% [1]
COD	71.36% [1]
Orthophosphate	90.93% [1]
Turbidity	95.41% [1]
Bacteria	90% [2]
Total Suspended Solids	90% [2]

Source : [1]Tallar (2005)
[2]PGDER (1993)

CONCLUSIONS

- Rainfall harvesting technologies and biodrainage model are very appropriate to be applied in Bandung Municipality to cover the water demand in the future that have a deficit about 0.146 x 10^9 m^3/year and to solve water supply and sanitation issues in Bandung Municipality.
- The design of this technologies depends on the typical conditions and the site objectives, for examples the soil permeable condition, space requirement, the height of water table, the slope, the socio-economic conditions of the residents and so on.

RECOMMENDATIONS

- This technologies can be applied at schools, residence area, industries area, commercial area, and the other public areas in Bandung Municipality.
- There is a need for law enforcement and suitable regulations from government, and also public awareness to apply this technologies.

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Collection of useful data for sizing a grey water treatment plant at Butare Central Prison

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Key words: wastewater, grey water, flow rate, BOD, fecal coliforms, Waste stabilization ponds, constructed wetland.

Abstract

Rwanda faces serious environmental challenges as do many developing countries. Environmental group from the Institute of Scientific and Technological Research (IRST) has selected Butare Central Prison (BCP) to be the first beneficial of its research activities because this centre has for long been in an alarming wastewater pollution situation. Our *goal is to conduct a profound and practical study of wastewater treatment aimed at reversing the current status quo of environment disaster and thereby, protecting and enhancing the public health. At the current stage of the project the group has achieved some results such as the unification of all wastewater streams into one flow and the flow rate measurement, and, the chemical-biological analyses. Results are important as they will serve in the calculation and the designing of the natural system based wastewater treatment plant: BOD_5 measured by iodometric method has an average of 2150 mg/l. From ISO test, fecal coliforms are greater than 10^5. The flow rate measured using triangle spillway and Kindsvater formula had a mean value of 116.64 m^3/day. The design temperature is estimated to be 18.4° C. The results from analyses show that grey water from BCP is highly polluted and must be treated before its disposal. The study and the feasibility of the plant treatment installation continue and the construction activities of the facility itself will be launched as soon as all parameters are determined and funds gathered.*

Introduction

Rwanda is a developing country with a remarkable growing population. It is among African countries with the highest density of population and the rural exodus phenomenon increases the population in major cities. The urban population increase is associated with the rise in water consumption and therefore, the increase of wastewater production. The results from a study done in 2003 showed a mushroom increase in wastewater generation especially after the year 1999 [8]. Important quantities of wastewater produced in Rwanda municipalities are not purified before its disposal and yet, inadequate handling of wastewater has serious consequences for human health, the environmental and economic development. It contaminates water supply, increasing the risk of infectious diseases and deteriorating groundwater and other local ecosystems, for instance after flooding [5]. Also, wastewater with phosphorous and nitrates causes eutrophication of receiving water bodies [7]. We can also mention unpleasant smell resulting in organic waste decay. In order to help to solve this growing concern, the Institute of Scientific and Technological Research (IRST) launched this wastewater treatment project that started in Butare city and the experience obtained from here will be reproduced at several sites of the country. The present paper is done in order to report the results of the first phase of an ongoing project at Butare central prison. The grey water

from bathroom, kitchen and sometimes from the medical facilities is our main preoccupation.

After the reunification of all wastewater streams, chemical and biological analyses were carried out and flow rate was measured and data obtained will be used in sizing a treatment plant.

Experimental set up

Description of the site

Butare central prison is located in Huye District, Southern Province. This prison of more than 6 thousand inhabitants gets its water from a nearby well. After usage, black water is conducted with faces into a biomethanisation unit to produce biogas that helps in cooking, while grey water is delivered into nearby banana plantation without any treatment. Grey water from BCP is considered to carry organic manure for plantations. Although the soil is an excellent adsorbent for most soluble pollutants, domestic wastewater must be treated before it can be used for crop irrigation to prevent the risk to both public and the environment [4].

Reunification of wastewater flows

The canalization of the grey water from BCP was done using PVC pipes, and collectors. Two existing collectors were repaired and 7 new collectors were built. Those

collectors were interconnected with the pipes of 110 and 160 mm of diameter in compliance
with the estimated quantity of wastewater to be conducted. Upstream from the first collector,
screens and bypasses were installed in order to protect pipes downstream, but also to reduce
pollution by grit removal (figure 3):

Figure1: Exit from homes Figure 2: Solid waste from degritting

Figure 3: Main exit after degritting Figure 4: Exit from kitchen

It was observed that the composition of solid waste from screening was composed as follows:

-For the grey water from the dormitory site (figure 1 and 2), solid waste are essentially
composed of avocado seeds and peeling, worn clothes, packaging waste etc.

- For the grey water from the kitchen (figure 4), they are essentially composed of charcoal
pieces, beans and maize seeds, etc.

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The screening reduces solid waste in wastewater, therefore, the generation of gases
that occurs by solid waste decay in water downstream. At the last collector, a channel was
built and a triangle spillway set up for flow rate measurement (figure 6).

Flow rate measurement

The flow rate was measured according to triangle spillway (V-notch) technique as shown on the image below. The spillway was made from a piece of metal sheet that we
painted and graduated.

Figure 5: Triangle spillway Figure 6: Flow rate measurement and sampling

Where: h= level of water above the notch in m

B= channel width in m

P= distance between the notch end the bottom in m

α = angle of the spillway

After measuring the water level above the notch (h), the calculation of the flow rate is done
using Kindsvater equation as follows.

$$Q = \frac{8}{15}\,\mu\, tg\frac{\alpha}{2}\sqrt{2g}\,(h + k_h)^{5/2} \quad [1]$$

Where: Q = the flow rate in m^3/s

m = flow rate coefficient

α = angle of spillway

k_h = coefficient taking account of superficial tension and viscosity
g = acceleration of gravity in m/s^2
k_h and m are given in abacus.

In our case of study, different values are B = 29 cm, P = 9 cm, α = 90° and g = 9.81 m/s^2. The channel has 14 m of length. Abacus gives the following values m = 0.592 and k_h = 0.8 mm viz 0.0008 m [1]. Thus, numerical application in international system is calculated as follows, taking the example of the maximum value where ho = 0.11 m.

2
5 2 9.81 (0.11 0.0008)
2
90
15
= 0.592 8 +
°
Q x xtg x x x

Q = 0.005715 m^3/s viz 5.7 l/s

The detail from flow rate calculations is reported in the figure 7.

Chemical and biological analyses

Sampling

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The sampling was done at the last collector, manually with latex gloves, polyethylene bottle and cooling boxes to maintain the temperature around 4° C before reaching the laboratory. After we noticed that the changes were important during a day more than between days, multiple samples (6 per day) were taken for few days.

Methods of analysis

Table 1: Measured parameters and methods used

Parameter	Method of analysis
COD	HACH DR-2000 photometer and HACH COD reactor [9].
BOD	Iodometric method [9]
TSS	HACH DR-2000 photometer
Nitrates	Method MgO-DEVARDA [6]
Nitrites	Method MgO-DEVARDA [6]
Total nitrogen	Kjeldahl method [6]
Total phosphorus	Colorimeter method with UV-visible 320 SAFAS Monaco after digestion with perchloric acid [6]
Turbidity	HACH DR-2000 photometer
Alkalinity	Titration by sulfuric acid 0.05 N [9]
Fecal coliforms	Membrane filter techniques, Reference: NF T 90-414-402-1985 ISO 9308-1 1990

Results and discussion

Results from flow rate measurement

The application in Microsoft Soft Excel for flow rate measurement according to Kindsvater equation gave the following chart:

Figure 7: Flow rate variation with time

The flow rate was low on the days 6th November and 3rd December because of the lack of fuel wood that limited culinary activities. Peaks in morning are associated with bath and washings that are also observed around midday; while the evening peaks are related to culinary activities. Thus, the mean flow was calculated using the data from two days 7th and 22nd November. This calculation gave the mean flow of 1.8 l/s, a value that matches the

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estimation value using 15 l daily consumed by every prisoner according to prison authorities; given the number of people equal to 7790 at the date of measurement. Assuming that daily activities last 18 hours, the calculations based on measured mean flow rate led to 116.640 m^3/day, while the estimation data led to 15 l per day x 7790 = 116850 l per day videlicet 116.85 m^3/day.

Results from chemical and biological analyses

The quotations --- refer to failed analyses due to technical problems in laboratory like power blackout, while ND refers to non selected samples (not done).

Table 2: Results for sample taken on 07/11/2007

Sample reference 07/11/2007	**Alkalinity ($gCaCO_3$/l)**	**NH_4^+ (g/l)**	**NO_2^- (g/l)**	**NO_3^- (g/l)**	**P_{Tot} (g /l)**	**N_{tot} (g/l)**
8:00 AM	4.485	$1.34x10^{-2}$	$1.2x10^{-3}$	$7x10^{-4}$	$6.1x10^{-3}$	$2.2x10^{-3}$
9:00 AM	0.550	$1.02x10^{-2}$	$1.8x10^{-3}$	$4.9x10^{-3}$	$1.2x10^{-2}$	$1.6x10^{-2}$
12:00 PM	0.438	---	---	---	$4.5x10^{-3}$	$5x10^{-3}$
2:12 PM	0.590	---	---	---	$1.1x10^{-2}$	$1.8x10^{-2}$

4:12 PM --- --- --- --- $1.2x10^{-2}$ $5.3x10^{-2}$

The above parameters are not directly involved in design of treatment facility which is our aim, but they were analyzed in order to give information about others indicators of water pollution. Their analysis was done in the laboratory of High Institute of Farming and Agriculture (ISAE) located at Busogo. The following tables report results for parameters analyzed in National University of Rwanda (NUR) laboratory of water quality located at Kigali.

Table 3: Results for sample taken on 07/11/2007

06/11/07	**7 : 00 AM**	**10 : 06 AM**	**12 : 00 PM**	**1 : 33 PM**	**3 : 09 PM**	**6 : 00 PM**
COD (mg/l)	5820	2920	2220	5940	4230	3690
BOD_5 (mg/l)	---	---	---	---	---	---
Turbidity (NTU)	2100	1325	675	ND	ND	ND
MES (mg/l)	2475	1675	900	ND	ND	ND
Fecal coliforms (Cfu/100 ml)	>1x 10^5	>1 x 10^5	>1 x 10^5	ND	ND	ND

Table 4: Results for sample taken on 07/11/2007

07/11/07	**7 : 00 AM**	**09 : 00 AM**	**12 : 00 PM**	**1 : 30 PM**	**3 : 30 PM**	**6 : 00 PM**
COD (mg/l)	4030	3490	3960	4020	6190	3280
Turbidity (NTU)	1600	1230	1380	ND	ND	ND
TSS (mg/l)	2200	1600	1825	ND	ND	ND
Fecal coliforms (Cfu/100ml)	ND	ND	>1 x 10^4	<1 x 10^0	ND	<1 x 10^0

Fecal coliforms are reported to be greater than 10^5 Cfu/100 ml in the morning while they are reported to decrease in the afternoon. The presence of pathogens in the morning is associated with the body washing that is actually not taking place in the evening. Theoretical values for grey water range between 10^4 and 10^7 [2].

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Table 5: Results for sample taken on 07/11/2007

22/11/07	**07 :10 AM**	**09 : 23 AM**	**10 :52 AM**	**12 :50 PM**	**3 : 20 PM**	**4 :50 PM**
BOD_5 (mg/l)	1000	1460	2090	1746	---	---
COD (mg)	---	---	---	3150	11610	3240
Ratio COD / BOD_5	---	---	---	1.8	---	---

Table 6: Results for sample taken on 07/11/2007

Hour	**7:15 AM**	**9:08 AM**	**10:25 AM**	**11:40 AM**	**12:45 PM**	**2:00 PM**	**3:45 PM**	**5:35 PM**	**Average**
DCO (mg/l)	1630	6230	6490	5460	4950	4230	4550	2830	**4546**
DBO_5 (mg/l)	1086	2298	2800	2298	2565	2052	2052	2052	**2150**
BOD_5/ COD	1.5	2.71	2.31	2.37	1.93	2.06	2.22	1.38	**2.11**

BOD of domestic wastewater usually ranges between 50 and 400 mg/l [9]. Grey water from BCP has a mean BOD that overtakes 400 mg/l, characteristic of industrial wastewater.

This concentration of pollution is associated with the quantity consumed by each prisoner that was reported to be 15 l/prison per day according to BCP authorities. However, the ratio COD/BOD is one of urban wastewater that is generally around 2 [7]. From the results above, we can calculate the pollution generation per capita as follows: (116.64 m^3/day x 2150 g/m^3

of BOD) / 7790 people that equals to 32.2 g of BOD per capita. Note that this number is only for pollution associated with grey water not to all pollution produced by each prisoner. These results will be used to calculate and design an adequate treatment plant based on natural systems "Waste stabilization ponds and/or constructed wetlands" in compliance with site specifications. Furthermore, these technologies have proven to be effective alternatives for treating wastewater in tropical countries [3].

Conclusion

The study has shown that grey water from Butare Central Prison is highly polluted with mean BOD_5 of 2150 mg/l and more than 10^5 CFU/100 ml of fecal coliforms. The flow rate had a mean value of 116.64 m^3/day. These values indicate that the grey water from BCP needs to be treated before its disposal. In this perspective, a study of feasibility of natural system based treatment plant is ongoing and the final decision will depend on site specifications that are also planned within the current year.

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DUG WELL CONTAMINATION- THE KERALA SCENARIO

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Key words: Septic tank, Soil absorption system, Coliforms, Dug well

Abstract

In Kerala state (India), a substantial portion of the population depends on dug wells or other ground water sources for their drinking water requirements. It is estimated that there are over 6 million dug wells in the state catering to the domestic water demands of more than half of its population. The main sources of dug well contamination are identified as the on site waste treatment systems (OSWTS) like septic tanks. The guidelines laid down by building rules to avoid this contamination were found to be insufficient. The safe distance between well and an onsite sanitation system will vary from location to location. Based on Physiographic classification, sociological data and previous studies a few soil zones were identified as crucial to the study. Out of the various zones identified as important, one zone was considered for the present study. From the current investigation, it is found that the contamination level in dug well depends upon the horizontal distance between the dug well

and OSWTS as well as depth of water table. The sufficient horizontal distance for different water table depth values to avoid contamination were thus calculated.

Introduction

Kerala (between longitudes 74°54’ E & 77°25’ E and latitudes 8°17’ N & 12°47’ N) - the southern most among the twenty seven states of India- is one of the thickly populated regions in the world, even though the current population increase is only 9.4 % per decade. Unlike other Indian states, Kerala has achieved commendable progress in the social, cultural and public-health sectors. Many of the indicators of social progress for the state are comparable with that of the developed nations.

The state of Kerala is blessed with amazing greenery and water wealth. The state receives an average annual rainfall of over 3000mm. It has many small and large rivers (44), thousands of ponds (1, 35,620), numerous streams (3,200), many lakes (658) and a number of rivulets (187). Apart from these, the State has more than 6 million wells. The State which is supposed to be water rich faces so many water related problems.

The water related problems faced by the state are due to the following reasons

- Lack of serious and concerted efforts in water conservation.
- Increasing water contamination and improper use of water.

In spite of the fact that Government is taking many initiatives for providing fresh water supply in different regions of the State, more than half of the population depends on dug wells or other ground water sources for their drinking water requirements; and very often the well water is consumed without any treatment.

The main sources of dug well contamination are found to be on site sanitation systems like leach pits and septic tanks. Due to the very high density of residential units and dug wells

in the state, most of the wells are subjected to microbial contamination from septic tank effluent. If the distance between the soil absorption system (SAS) and the well is not allowed to fall below a certain limiting value (which is characteristic of a given soil type) for a particular water table depth, the contamination can be greatly reduced, there by saving the large amount of resources spent on the treatment, in terms of energy, man power, money, etc.

Present Scenario

There were many studies in the recent past which investigated into the level of contamination of dug wells in Kerala. A study conducted by Centre for Water Resources Development and Management (CWRDM), a government research institution, reveals that 80 to 85 % of dug wells in Kerala are polluted by faecal contaminants [1]. The study conducted by 'Malayala Manorama', the popular Malayalam daily, in a project named 'Palathulli' reported that majority of the dug wells in Kerala state are contaminated and not safe for drinking. Their findings are shown in fig.1. [2]

A study on the bacterial quality of water in selected wells in Kerala jointly conducted by Kerala Water Authority and Kerala Pollution Control Board (KWA, 1991) showed that water in none of the open wells investigated was safe for drinking.

The Central Pollution Control Board (CPCB) of India specifies the limit of Total Coliforms Organism (MPN/100ml) in drinking water source without conventional treatment but after disinfection, as 50 or less. According to the earlier legislation prevailed in the state, the minimum distance between dug wells and SAS was 15m, which underlines the importance of a sufficient soil-path length in contaminant removal. But as per the revised Kerala Municipality Building Rules 1999(chapter XVI), which states "…No leech pit, sock pit, refuse pit, earth closet or septic tank shall be allowed or made within a distance of 7.5 metres radius from any existing well used for supply of water for human consumption or domestic purpose or within 1.20 metres distance from the plot boundaries…", this distance was reduced to 7.5 m.

Figure 1: Spatial distribution of Faecal Coliform Bacteria in Kerala well water

Many earlier studies conducted in the state regarding microbial contamination of wells suggested safe distance between well and septic systems and this distance is much above what is given in the Kerala Municipality Building Rules 1999. Thus a critical study of the issue becomes relevant.

Experimental Investigations

The parameters which influences the removal of microorganisms from septage in soil include grain size, Ionic strength, Bacteria sizes, Temperature, Soil Profile, Moisture content, Salt content, pH, Time, Nutrient supply, Hydraulic conductivity and Length of travel. [3], [4], [5] Thus, safe distance between well and an on site sanitation system will vary from location to location. All parameters except the length of travel are assumed same for an area selected.

The length of travel depends on two factors, water table depth and horizontal distance between well and soak pit. The flow direction is also a factor but the sample stations are selected visually so that always the flow is towards the well.

'Resource Based Perspective Plan 1997', prepared by Kerala State Land Use Board divided the soil of Kerala state in to 32 types connected to regions. [6] This classification was taken as the basis for the study. As the efficiency of an SAS depends on the ability of the soil to remove contaminants which in turn depend on the soil type, depth and extend, a study conducted on one soil zone can be applied to all regions with similar soil profile. Thus, for each soil zone a safe distance can be recommended. Before selecting a study area it is important to identify the soil zones that are crucial to the study. For this, Physiographic classification, sociological data and previous studies were used as guidelines.

Kakkodi, a place 16 km from the lab where this study was carried out, has 95% of its soil profile falling in a soil zone identified as crucial to the issue of dug well contamination.

The selected area, Kakkodi, in Calicut district contains about 1750 houses. There are regions in Kakkodi where the houses are very close to each other and also regions where one can find isolated dwellings. Thus it was an ideal place for getting water samples for an unbiased analysis. The place presented a typical cross section of a Kerala village with people belonging to all social and economic status. The main source of water for the residents of Kakkodi is dug well.

From the previous studies, it is assumed that the sanitation systems which are at a distance of more than 35 metres will not affect the wells. Thus, to avoid influence of more than one septic system, only such wells were considered for study where there was not more than one septic system within a distance of 40m from it. Only the septic tank-soak pit system and wells were considered for the study. Units like a cesspool were not considered as the present regulations do not permit such systems of treatment. The wells considered for study may or may not have been used as sources of drinking water, but were visibly clean. The chances of contamination with animal waste like chicken litter, cow dug were to be avoided since that also can influence the indicator micro organism level in water. This was achieved by carefully selecting the wells.

Guidelines for drinking-water quality given by World Health Organization (WHO) recommend multiple-tube fermentation technique for detection and enumeration of coliform organisms, thermo tolerant coliform organisms and presumptive *Escherichia coli*. Drinking water standards give microbial contamination level in MPN of coliform bacteria per 100ml.Considering these points multiple tube fermentation technique was adopted as the experiment method.

A regression analysis was done by considering water table depth and horizontal distance between well and SAS as independent parameters and microbial concentration in the well water as the dependent.

Results and Discussion

The test results are shown in Fig 2. MPN of coliforms obtained in the laboratory analysis in y-axis is plotted against corresponding path length in x-axis.

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0
500
1000
1500
2000
2500
3000
3500
4 6 8 10 12 14 16 18 20
Path length in M
MPN/100ml
first trial
Expon. (first trial)

Fig.2. Relation between path length and MPN values

The path length was determined from the horizontal distance and water table depth using a Matlab code. The concentration (as MPN) when Plotted against the calculated path length gave a trend line that had a very low Percentage Root Mean Square Error (PRMSE) value of 0.3. The equation of this curve is used to calculate the safe parabolic path length and corresponding horizontal distance for any given water table depth.

▪ ▪
▪
▪ ▪
▪
–
=
34309
ln
.3781
x 1 *C*

From the above equation the safe path length, such that the C value of 50MPN suggested by the CPCB is not exceeded, is calculated as 17.27m, provided, it is the only one SAS contributing coliforms to well water. If there is more than one soak pit situated within the influence zone, the sum of the microbial concentration values contributed by each soak pit individually must be less than the limiting concentration value. So before placing a soak pit near to a well, position of existing soak pits should be considered. Now, if the worst case of having a well under the influence of 4 soak pits is considered, it can be easily shown that the safe distance increases to 21m. Thus, this distance can be suggested as the minimum safe path length for the selected soil zone. Corresponding to this 21 metres of travel distance and different water table depths, the horizontal distance are listed in table 1. The water table depth varies according to the season and the worst case should be considered to get the horizontal distance.

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Table 1. Safe horizontal distance for different water table depths

Travel Distance from well to soak pit In metres	Water table depth In metres	Horizontal distance In metres
21	0	21.0
21	2	20.60
21	4	20.00
21	6	19.25
21	8	18.25
21	10	17.00

Conclusion

The study has brought to light that the dug wells of Kerala are subject to considerable bacterial contamination during all seasons. Though the exact sources could not be identified in all cases, the latrines situated close to the wells were found to have great influence on contamination. The guidelines laid down by building rules to avid this contamination were found insufficient .Certain policy guidelines and modifications in building rules might help in improving the present situation. A horizontal distance of 21 meter between well and soak pit

will be sufficient to avoid microbial contamination due to this source in Kakkodi a village in
Calicut district. The same value can be used for other regions where the soil properties are
similar.

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Zinc and Chromium removal mechanisms from industrial wastewater by Water hyacinth, *Eichhornia crassipes (Mart.) Solms*

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Key words: Chromium, removal mechanisms, wastewater, water hyacinth, Zinc

Abstract

Zinc and chromium are environmental pollutants toxic even at very low concentrations.
Domestic and industrial discharges are probably the two most important sources for

chromium and zinc in the water environment. Rwanda is still facing problems of heavy metal discharges into natural ecosystems by factories and households without any prior treatment.
The objective is to investigate the major mechanisms responsible for Cr (VI) and Zn (II) removal form industrial wastewater by water hyacinths. pH effects, plant relative growth, trace metal remaining in water samples, translocation ability, bioconcentration factor, adsorption, bioaccumulation and uptake mechanisms were studied. The pH slightly increases from the start time (0 hr, pH= 6.7) to 48 hr (pH= 7.64 to 7.86); but after 48 hr of experiment, the pH decreases due to the saturation of bound sites, so some H^+ *are released in water samples. The relative growth significantly decreased* ($P \leq 0.05$) *from 1, 3 and 6 mg/L in 1 week but it decreased linearly slightly after 1 week, with increasing* ($P \leq 0.05$) *metal concentrations. 56.7% of Zn (II) was accumulated in petioles, 27.0 % in leaves and 16.3% in roots whereas for Cr (VI) 73.7% was taken up in roots, 14.1% in petioles and 12.2% in leaves. It was seen that 17.6%, 6.1% and 1.1% were adsorbed for 1, 3 and 6 mg/L of Zn (II) concentrations, respectively, by water hyacinth plants. For Cr (VI), 9.0, 36.4 and 54.6% were adsorbed for 1, 3 and 6 mg/L, respectively. The order of translocation ability for Cr (VI) was leaves<petioles<roots in water hyacinth whereas for Zn (II) was leaves<roots<petioles.*

INTRODUCTION

Zinc and chromium are environmental pollutants toxic even at very low concentrations. Pollution of the biosphere with toxic metals has accelerated dramatically since the beginning of the industrial revolution [1]. The primary sources of this pollution are the burning of fossil fuels, the mining and smelting of metals, municipal wastes, fertilizers, pesticides and sewage. Heavy metals are of great concern primarily due to their known toxicity to aquatic life and human health at trace levels [2]. It was reported that domestic and industrial discharges are probably the two most important anthropogenic sources for metals in the water environment [3]. However, the lack of a reliable method to predict metals distribution in treatment units is a key weakness in determining metals fate and transport in wastewater treatment processes, and therefore, the development of effective pre-treatment guidelines [4].

The removal of heavy metals from aqueous solutions has therefore received considerable attention in recent years. However, the practical application of physicochemical technology such as chemical precipitation, membrane filtration and ion exchange is

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sometimes restricted due to technical or economical constraints. For example, the ion exchange process is very effective but requires expensive adsorbant materials [5] [6].

The use of low-cost waste materials as adsorbents of dissolved metal ions provides economically viable solutions to this global problem and can be considered an eco-friendly solution [7] [8]. At present, emphasis is given to the utilization of biological adsorbants for the removal and recovery of heavy metal contaminants [9].

In Rwanda, the problem is still critical because there is no appropriate system of heavy metals removal, particularly for zinc and chromium. The development of such a system to remove these toxic contaminats is possible in Rwanda given the availability of water hyacinth. Water hyacinth in the country causes serious problems in many aquatic ecosystems; however, it is possible to use it in wastewater treatment by inoculating wastewater treatment ponds with water hyacinth. This system is inexpensive and can contribute to cleanup in Rwanda with more appropriate technologies.

EXPERIMENTAL SET UP

Sample collection area description

The experiment was performed using free-floating water hyacinth plants. The Water Hyacinth plants *(E. crassipes)* were collected from a natural wetland area called Nyabugogo located in Kigali city and was transferred to the laboratory of National University of Rwanda in big plastic buckets as shown in Figure1and placed under natural sunlight for several days to let them adapt to the new environment in the laboratory. Then plants with similar size, weight and shape were selected, rinsed with distilled water to remove any epiphytes and insect larvae grown on plants and then put in small buckets for experiments as shown in Figure 2.

Fig.1: Water hyacinth plants in big container Fig.2: Plan view of experimental set up.

All experiments were run in batch mode, using a nutrient solution containing 500 ml of tap water from the valley located at Butare near the Natural Science Centre, 500 ml of wastewater from the Nyabugogo wetland and 20 mg of $Ca(NO_3)_2 . 4H_2O$ and NH_4Cl, and 40 mg of K_2HPO_4. Total fresh weight of plants in each bucket was measured before the start of each growing time: 1, 2 and 4 weeks.

Description of the experimental laboratory pilot scale

The experimental laboratory pilot for zinc and chromium removal mechanisms consisted of 12 small buckets as show in Figure 2. Three buckets without water hyacinth plants served as controls (blanks) containing 1, 3 and 6 mg/L of zinc and chromium. Nine (9) small buckets with water hyacinth plants were established with 3 buckets each containing1, 3 and 6 mg/L of zinc ($ZnCl_2$) and chromium (K_2CrO_4). Buckets were maintained for 1, 2 and 4 weeks as the experimental period time. All experiments were performed in the laboratory at a constant temperature (25°C).

A stock solution (1,000 mg/L) of each metal was prepared in distilled water which was later diluted as required. Individual plants were initially rinsed with distilled water to

remove epiphytes, microbes, and any nutrient that might be transferred and then placed in 2L small plastic buckets containing 1L of solution (0.5Lfrom Nyabugogo wetland + 0.5L from Butare valley). They were maintained in water supplemented by the heavy metals by adding the required volume of zinc and chromium stock solutions to obtain final concentrations of 1, 3 and 6 mg/L of Cr (K_2CrO_4) and Zn ($ZnCl_2$), respectively.
Distilled water was added in order to compensate for water loss through plant transpiration, sampling and evaporation. Water samples and pH measurements were taken every 60 minutes for the first 6 hours and then one sample per day during 1, 2 and 4 weeks of exposure to the metal solution. All samples were filtered using 0.45 μm cellulose acetate filters (wattman papers) and acidified with 5 drops of nitric acid prior to storage of samples.
Samples were then analyzed using Perkin Elmer Atomic Absorption Spectrometer.
After each test duration (1, 2 and 4 weeks), final fresh weight for each water hyacinth plant was taken and plants were harvested for other analyses. They were separated into petioles, roots and leaves and were analyzed for relative growth, metals accumulation, translocation ability, bioconcentration factor (BCF) and adsorption on the outer surface of roots. In addition, the metals remaining in the solution were measured to assess the removal potential of water hyacinth plants.

Data analyses

a) Relative Growth (RG)

Relative growth of control and treated plants was calculated to assess the effects of zinc and chromium concentrations on water hyacinth plant growth: ***RG = FFW/IFW.*** Where *RG* denotes the relative growth of the water hyacinth plants during experiment period, it is dimensionless; *FFW* denotes final fresh weight in grams of water hyacinth plants taken at the end of each experiment period and *IFW* denotes the initial fresh weight in grams of water hyacinth plants taken before starting experiment.

b) Bioconcentration Factor(BCF)

The BCF provides an index of the ability of the plant to accumulate the metal with respect to the metal concentration in the substrate. The BCF was calculated as follows: $\mathbf{BCF} = \mathbf{(P/E)_I}$. Where $\boldsymbol{i}$ denotes the heavy metals, $\boldsymbol{BCF}$ is the dimensionless bioconcentration factor, $\boldsymbol{P}$ represents the trace element concentration in plant tissues (mgL^{-1}), $\boldsymbol{E}$ represents the initial concentration in the water (mg/L) or in the sediment (mg/kg dry wt). A larger ratio implies better phytoaccumulation capability.

c) Metal Accumulation

Metals accumulation in plant and water samples was measured. Digestion of samples in this study was performed according to the Standard Methods by APHA.7 [10]. Plant biomass samples were decomposed to dry matter by heating at 105° C for 24 hours in a hot air oven and the ash was digested with nitric acid (HNO_3) and hydrogen peroxide (H_2O_2), filtered through a Wattman® paper filter into a volumetric flask before Atomic Absorption Spectrometer analyses. The three following mechanisms were performed in analyses to differentiate the metal adsorbed, bioaccumulated, and translocated by water hyacinth during the experiment period.

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Adsorption

The adsorption consists of metal attached to the outer surface of the roots. To quantify the metal adsorbed by water hyacinth; after the plant exposure to different concentrations of chromium and zinc in different periods of times (1week, 2weeks and 4 weeks). After experiment duration, the adsorption was determined by putting roots of water hyacinth plant in nine 100 ml of EDTA-Na_2 3, 24 mmolar respectively for 5, 10, 15, 20, 25, 30, 35, 40 and 45 min for removal of zinc and chromium trace elements on the outer surface of the roots.

Those EDTA-NA_2 solutions were filtered, acidified by 5 drops of Nitric acid (HNO_3) and analyzed by Atomic Absorption Spectrometer (AAS) for zinc and chromium adsorbed by the plants. The most important parameter to consider is the pH [11]. Generally when the pH decreases, the toxicity of metal ions increases because the proportion of the adsorbed ion on the root system decreases [12].

Uptake

The uptake process is a mechanism by which metal ions are transported across the cell membrane and can be used in a building of new biomass or stored in vacuoles. To assess this mechanism during our research; after experiment period, water hyacinth plants were taken out form the small buckets, roots, petioles and leaves were separated, dried in dry oven at 105° C during 24h. Plant samples were transformed in ash, digested and analyzed by AAS to identify the zinc and chromium concentrations in plant biomass (roots, leaves and petioles).

The results from AAS analyses show the plant parts which contribute more in metal accumulation. The presence of carboxyl groups at the roots system induces a significant cation exchange capacity and this may be the mechanism of moving heavy metal in the roots system where active absorption takes place.

Translocation ability (TA)

The translocation ability was calculated by dividing the concentration of a trace element accumulated in the root tissues by that accumulated in shoot tissues [13]. *TA* is given by: $TA = (Ar/As)_i$. Where ***i*** denote the heavy metal, ***TA*** is the translocation ability and is dimensionless. ***Ar*** represents the amount of trace element accumulated in the roots (mgL^{-1} dw), and ***As*** represents the amount of trace element accumulated in the shoots (mgL^{-1} dw).

Statistical analysis

In order to detect quantitative differences in the data, statistical analyses were performed.

Standard deviation

It was obtained from the variance by extracting the square root and was expressed in the unit in which the measurements were taken:

S =

( ) 1

^{2}

−

Σ *n*

fd

Regression analysis

Regression is defined as the determination of statistical relationship between two or more
variables. In simple regression one variable (defined as independent) is the cause of the

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behaviour of another one (defined as dependent variable). The correlation coefficient (r) is
expressed by equation:

r =

Σ Σ

Σ

^{2} . ^{2}

.

dx dy

dx dy

RESULTS AND DISCUSSIONS

Effects of pH variations

The initial solution pH was adjusted to 6.7 in the small plastic buckets using HCl or
NaOH. This is the pH tested in Nyabugogo wetland. The results from experiments are shown
in Figure 3 and show that the effects of pH vary considerably in different buckets with water
hyacinth plants over exposure time. Metal will precipitate as hydroxides when the pH of the
wastewater is raised to pH 8 to 11 [14].

4
5
6
7
8
9
0h
1 hr
3 hr
6 hr
10 hr
15 hr
21 hr
33 hr
57 hr
105 hr
177 hr
273 hr

393 hr
537 hr
705 hr
Exposure time (h)
pH
pH, 1mg/L pH, 3mg/L pH, 6mg/L

Fig.3: pH variations in plant water samples overtime

As a result, the extent of adsorption was rather low at low pH values. However, in the equilibrium solid phase, Zn (II) and Cr (VI) ion concentrations increased with increasing pH because of increasingly negative charges on the surfaces of the roots at high pH values. This attracted positively charged Zn (II) and Cr (VI) ions more strongly. The ANOVA with replications showed that for 1 mg/L, 3 mg/L and 6 mg/L there was no effect of exposure time but high difference between pH effects and metal remaining in water samples ($P \leq 0.05$). It was seen that the pH effect variations were due to the saturation of binding sites on root systems which affect the pH in water samples with water hyacinth plants by releasing H^+ in water samples.

Plants relative growth (RG)

The relative growth of water hyacinth plants at different concentrations of zinc and chromium is shown in Table 1. It can be seen that the relative growth of plants decreases with increasing of zinc and chromium concentrations.

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Table1: Relative changes in growth of plants vs. zinc and chromium concentrations

Exposure time (week) with Zn & Cr concentrations	Initial water hyacinth fresh weight (g)	Final water hyacinth fresh weight (g)	Relative growth
1 wk, 1 mg/L	32.33	85.23	2.64
1 wk, 3 mg/L	34.50	96.91	2.81
1 wk, 6 mg/L	26.38	50.07	1.89
2 wks, 1 mg/L	29.75	55.92	1.88
2 wks, 3 mg/L	42.90	80.18	1.87
2 wks, 6 mg/L	16.24	39.96	2.27
4 wks, 1 mg/L	41.15	85.57	2.08

4 wks, 3 mg/L 39.65 98.05 2.47
4 wks, 6 mg/L 34.54 96.16 2.78

For water hyacinth plants treated with Zn and Cr, the relative growth significantly decreased ($P \leq 0.05$) from 1, 3 and 6 mg/L in 1 week but for 2 and 4 weeks, the relative growth decreased only slightly with increasing ($P \leq 0.05$) metal concentrations. The relative growth exhibited a decreasing trend caused by relative increases in toxicity of chromium and zinc.

The analysis of variance showed that for 1 week exposure time, there is a high effect (difference is significant) of initial concentrations (1, 3 and 6 mg/L) to the growth of the plants ($P > 0.05$), but for 2 and 4 weeks related to initial concentrations, the difference is not significant ($P > 0.05$). Xiaomei et *a*l. [15] reported that the relative growth of water hyacinth decreases when metal concentrations increase, confirming what was observed in this investigation.

Bioconcentration Factor (BCF) of zinc and chromium

The bioconcentration factor (BCF) was calculated as the ratio of the trace element concentration in the plant tissues at harvest to the concentration of the element in the external environment [16]. The pattern of the bioconcentration factor of water hyacinth plants is shown in Figures 4 and 5.

0
2
4
6
8
initial conc.(mg/L) conc.in plant tissues (mg/L)
BCF
Variation of Zinc conc.
conc. in mg/L
1 mg/L 3 mg/L 6 mg/L
0
2
4
6
8
10
I.C Conc./P.T BCF
Variation of Cr Conc. in plant tissues
BCF of Cr
1 mg/L 3 mg/L 6 mg/L

Fig.4: Variations in BCF of zinc Fig.5: Variations in BCF of chromium

A high competition between zinc and chromium accumulation by the plants and zinc was observed due to kinetics of these metals. The comparison of Zn (II) and Cr (VI) showed

that the BCF of zinc was higher than the chromium's BCF for 1 and 3 mg/L, but very low for
6 mg/L for zinc. The plant accumulated more low concentrations than the high ones. It was
reported that there is no significant difference both for zinc and chromium when comparing
initial concentrations to the concentrations in plant tissues and bioconcentration factors ($P >$
0.05) for zinc and chromium.
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Adsorption

More trace elements of zinc and chromium were removed from 5 up to 15 minutes
and the high concentration observed for 6 mg/L was around 2 mg/L, for 3 mg/L was around
1.6 mg/L and for 1 mg/L was around 0.3 mg/L. The adsorption ability of water hyacinth
plants was seemed to be different when zinc and chromium are compared.

0
0.05
0.1
0.15
0.2
0.25
5 min
10 min
15 min
20 min
25 min
30 min
35 min
40 min
45 min
Period of time for removal
conc. in mg/L
1 mg/L 3 mg/L 6 mg/L
0
1
1
2
2
3
5 min
10 min
15 min
20 min
25 min
30 min
35 min
40 min
45 min
Period of time for removal (min.)
conc.in (mg/L)
1 mg/L 3 mg/L 6 mg/L

Fig. 6: Desorption of zinc Fig.7: Desorption of chromium.

For zinc, 17.6% of 1 mg/L was adsorbed by the water hyacinth plants, 6.1% of 3
mg/L was adsorbed and the plants adsorbed 1.1% of 6 mg/L. For chromium, 9.0% of 1 mg/L,
36.4% of 3 mg/L and 54.6% of 6 mg/L were adsorbed on the roots of water hyacinth plants.
Meggo[17] has confirmed that aquatic plants are able to accumulate metal at low concentrations.

Uptake for zinc and chromium

It was reported that 56.7% of zinc was accumulated in petioles, 27.0% in leaves and 16.3% in roots. The analysis demonstrated no significant difference for different initial concentration and exposure time ($p > 0.05$) in uptake mechanisms of zinc. There was a significant difference observed in plant parts in uptake processes ($p \leq 0.05$). For chromium, 73.7% was taken up in roots, 14.1% in petioles and 12.2% in leaves, demonstrating the preference of plants to store chromium in roots. The trend was the same for zinc; no significant difference existed between plant parts ($p > 0.05$) and also between initial concentrations in uptake processes ($p > 0.05$).

Translocation ability (TA)

The quantities of trace elements accumulated in the petioles exceeded those in the shoots. Roots of water hyacinth accumulated about 3 to 15 times more trace elements than did the shoots. It appears that chromium translocation is compared to zinc as shown in Table 3. The ability of plants to translocate trace elements of chromium increased for roots/leaves (5.3 times for 1 mg/L, 6.5 times for 3 mg/L and 6 times for 6 mg/L). The number of times for roots/petioles decreases (4 times for 1 mg/L, 4 times for 3 mg/L and 7 times for 6 mg/L) because the order of storage was leaves<petioles<roots.

Table 2: TA of zinc Table 3: TA of chromium

	Zn (II) conc.			
	Roots/ Shoots	1 mg/L	3 mg/L	6 mg/L
1 week	Roots/petioles	0.382_a	0.255_a	0.383_a
	Roots/leaves	1.114_a	0.732_a	0.164_a
2 weeks	Roots/petioles	0.478_a	0.485_a	0.439_a
	Roots/leaves	0.461_a	0.564_a	0.993_a
4 weeks	Roots/petioles	0.171_a	0.510_a	0.109_a
	Roots/leaves	0.241_a	1.041_a	0.255_a

a: times of storage in roots compared to shoots.

I.C$_a$ of chromium (VI)			
Roots/shoots	1 mg/L	3 mg/L	6 mg/L
roots/petioles	4.104_b	3.663_b	6.831_b
roots/leaves	5.288_b	6.487_b	5.965_b

a: initial concentration; b: times of storage in roots compared to shoots.

The ANOVA shows the variability in translocation ability. It can be seen that the difference is not significant between metal concentration ($p > 0.05$) and no significant difference between roots and shoots translocation ($p > 0.05$). Stratford and co-workers [18] found that metal accumulations in water hyacinth increased linearly with solution metal concentration in order ***leaves<petioles<roots.*** In this research, the following order was observed: ***leaves<roots<petioles***. When the concentration is high, the water hyacinth plant can only accumulate a low concentration in plant cells. This is in agreement with the results of this study in the case of chromium concentration accumulation in water hyacinth plants, where the high concentration was accumulated in roots followed by petioles and then leaves.

Water hyacinth materials were burned after all experiences to avoid the contamination.

CONCLUSIONS

From the above results, it is evident that water hyacinth when grown over wastewaters in controlled environment/closed systems such as constructed wetlands can efficiently remove zinc and chromium in wastewaters, provide fresh water, and possibly clean up the air environment by removing CO_2 and releasing O_2. The removal mechanisms of zinc and chromium by water hyacinth plants showed that the plant concentrated a high quantity of metals. The aquatic plant water hyacinth have shown promising potential for the removal of Cr (VI) and Zn (II) from industrial synthetic wastewater of three different concentrations (1, 3 and 6 mg / L).

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Characterization of abattoir wastewater of Kigali, Rwanda

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Abstract

The rapid pace and scale of urbanization in Rwanda represents a considerable challenge for water resources management particularly the delivery of essential water, sanitation services and environmental protection. The main objective of this study was to analyze processes and products at Nyabugogo abattoir in Kigali, and to investigate how they can be optimized for environmental safety. The effluent characteristics of the abattoir were analyzed, with emphasis on nutrients, biologically active constituents, and receiving water impacts. The study focused on establishment of the quantity and quality of different raw materials, by-products and wastewater streams and assessment of potential impacts of the application of cleaner production principles in abattoir processes. The samples were collected fortnightly, preserved and analyzed in each case using Standard Methods. The data were processed for trends and variance using SPSS computer package. The wastewater parameters analyzed are temperature, salinity, conductivity, turbidity, dissolved oxygen pH, TSS, TDS, BOD_5*, COD, FOG,* NO_3*-N, TKN, total phosphorus, chloride, calcium and total coliforms. The capacity of the abattoir is on average 566 cattle and 1512 goats and sheep slaughtered per week.*

Results show that the current effluent quality is not suitable for discharge into the watercourse. The abattoir wastewater streams' total chemical oxygen demand (TCOD) ranged form 7533 (± 723) from evisceration to 23,778 (± 1,673) $mgl^{-1}$from slaughtering step and the discharge into Mpazi River increases its TCOD from 213 (± 29) to 852(± 94) mgl^{-1} TSS varied between 2,452 (± 51) from slaughter process and 5,252 (± 174) mgl^{-1}. Results from the bacteriological analysis indicate that abattoir wastewater discharged count (560 ± 81)10^5 cfu/100ml of total coliforms which increases from (2.8 ± 0.58) 10^5 to (8.2 ± 0.86)10^5 cfu /100ml.

Keywords: abattoir effluent, cleaner production, sustainability, wastewater management

Introduction

The rapid pace and scale of urbanization in Rwanda represents a considerable challenge for water resources management particularly the delivery of essential water, sanitation services and environmental protection. In the last ten years, the city of Kigali has experienced a spectacular growth in population leading to large volumes of domestic and industrial wastes.

Nyabugogo Abattoir uses large quantities of water and generates equally large quantities of biodegradable wastewater with a high strength, and complex composition. There is, therefore, an urgent need to develop sustainable management strategies that would control both water and nutrients flows in Kigali city with the added advantages of cost reduction, handling efficiency, increased food production, environmental integrity, and social benefits. This could be achieved by of application of IWRM approach. This entails a holistic approach with waste being seen as resource, and its management linked to that of water resources and nutrients

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and this could be addressed from a 'cleaner production' angle [1], [2]. The cleaner production concept has brought some innovative environmental thinking into the industrial sector, especially in terms of waste avoidance/reduction and use of substitutes [3]. In this framework, this study seeks to:

i.To assess the quantity and quality of the water and wastewater streams at the Nyabugogo Abattoir and their impact r on the receiving Mpazi River;

ii.To explore the relationships between related parameters as a means of reducing monitoring costs for the Abattoir;

iii.To explore ways of improving the abattoir performance for better environmental safety.

Description of the Study Area

The Nyabugogo Abattoir (Figure 1) is located in commercial zone and discharges effluent into the Mpazi River. Adjacent to this area is a highly populated residential zone whilst other industries discharge downstream of the abattoir. Besides the diffuse source of pollution from the population, the main point source polluters of the Mpazi River are Centre Hospitalier Universitaire de Kigali, the central prison of Kigali, Muhima police station, hotels and the Nyabugogo Abattoir. The Mpazi River discharges into Nyabugogo River, a tributary of the Nile River.

Figure1: An aerial view showing the Nyabugogo Abattoir and tannery, and Mpazi River

Figure 2: Abattoir flow chart, by-products and sampling sites

Analytical methods

Samples were analyzed for the following physico-chemical parameters: pH, temperature, electrical conductivity, salinity, turbidity, TDS, TSS, dissolved oxygen measured *in situ* using conductivity meter model HACH sinsion$_{TM}$5, turbidity meter model wag-WT3020. The analysis of BOD_5, total COD, soluble COD, Oil and Greases, TKN, Nitrate, TP, Calcium, and Chloride were done using standard methods. The bacteriological parameter analysed was

total coliforms. The analyses followed APHA’s Standard Methods for the Examination of Water and Wastewater [4].

Data analysis and presentation

The means and standard error of the mean were calculated using 5 different samples taken within 5 weeks during the experimental period. The data obtained from sites 7 and 9 respectively upstream and downstream of the discharge into Mpazi River were compared using t-Test. The coefficient of correlation between related physicochemical parameters was calculated by Pearson correlation test using SPSS package. Statistical significance was set at $p < 0.05$ for t-Test (t-Test: Paired Two Sample for Means) analysis in the comparison of means of samples from Mpazi River.

Results and discussion

Tables 1 and 2 summarize the quality of water and different wastewater streams from the Nyabugogo Abattoir for five sampling runs under the monitoring period. The results were split into two tables for clarity.

Table 1: Analysis results for water and various streams of wastewater, Sites 1 - 5

Parameters	***Site 1***	***Site 2***	***Site 3***	***Site 4***	***Site 5***
Temperature (° C)	23.5 ±0.6	24.2 ± 0.5	22.3±0.3	25.8 ± 0.9	22.9 ± 0.2
pH	7.4 ± 0.6	7.7 ± 0.4	8.2 ±0.5	7.2 ± 0.6	8.15± 0.1
Salinity	0.10 ± 0	4.1 ± .36	0.62 ± 0.15	4.0 ±0.65	1.70 ± 0.09
EC (μScm^{-1})	180.3 ±13.9	6,792.4 ±1303	1,890 ± 86.2	5,646 ± 707.9	3,137 ± 130.7
TDS (mgl^{-1})	100 ± 5	3,434 ± 509	603 ± 149	2,657 ± 472	1,800 ± 289
TSS (mgl^{-1})	8.7 ± 0.5	2,452 ± 51	3,492 ± 343	3,504 ± 143	4,412 ± 172
Turbidity (NTU)	NA	NA	NA	NA	NA
D.O (mgl^{-1})	NA	NA	NA	NA	NA
Nitrate(mgl^{-1})	3.2 ± 0.23	648 ± 66.1	208.2 ± 23.1	676.6±53.3	205.8 ± 23.1
TKN (mgl^{-1})	1.1 ± 0.1	714 ± 13	244 ± 24.5	565 ± 43	423 ± 15
TP (mgl^{-1})	0.71± 0.16	693 ± 21	83 ± 7	937 ± 30	396 ± 55
O&G (mgl^{-1})	1	58	56	36	49
Chloride(mgl^{-1})	42 ± 5	190 ± 8	113 ± 4	72 ± 5	520 ± 27
Calcium(mgl^{-1})	7.6 ± 0.9	372 ± 26	54.9 ± 2	40 ± 3	218 ± 10
TCOD(mgl^{-1})	30 ± 7	23,778 ± 1673	17,019 ± 878	7,533 ± 723	13,126 ± 406
SCOD(mgl^{-1})	22 ± 4	7260 ± 1015	5,774 ± 806	1,445 ± 295	5,270 ±1187
SCOD/TCOD(%)	78 ± 6	29 ± 2	33 ± 3	18 ± 2	44 ± 6
BOD_5 (mgl^{-1})	18 ± 3	15,773 ± 847	10,989 ± 814	5,018 ± 180	10,801 ± 456
COD/ BOD_5	1.67	1.51	1.54	1.50	1.21
TC (cfu/100ml)	0 ± 0.00	(9.4 ± 0.92) 10^5	(1.6 ± 0.40) 10^5		

(29.6 ± 2.8)10^5 (33 ±
2.39).10^5

Table 2: Analysis results for water and various streams of wastewater, Sites 6 - 9

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Parameters	***Site 6***	***Site 7***	***Site 8***	***Site 9***
Temperature (° C)	21.0 ± 0.3	20.8 ± 0.6	19.8 ± 0.4	21.3 ± 0.4
pH	8.1 ± 0.1	7.5 ± 0.1	8.9 ± 0.2	8.1 ± 0.1
Salinity	3.54 ± 0.31	0.34 ± 0.02	1.82 ± 0.11	0.54 ± 013
Conductivity (μScm^{-1})	5,761 ± 361	632 ± 33	3,199 ± 66	726 ± 77
TDS (mgl^{-1})	3,231 ± 200.6	328.4 ± 15.2	1,833 ± 131.0	358.6 ± 10.7
TSS (mgl^{-1})	5,252 ± 174	220 ± 16	2,939 ± 71	304 ± 34
Turbidity (NTU)	NA	662.4 ± 37.0	552.2 ± 26.6	707 ± 37.6
D.O (mgl^{-1})	NA	0.053 ± 0.11	-	0.509 ± 0.18
Nitrate (mgl^{-1})	702.4± 101.4	114 ± 10.7	224.0± 37.2	176.6 ± 13.3
TKN (mgl^{-1})	735 ± 30	63 ± 1.9	198 ± 16	82 ± 8
TP (mgl^{-1})	475 ± 73	3.1 ± 0.1	438 ± 19	5 ± 0.4
O&G (mgl^{-1})	61	26	59	31.8
Chloride (mgl^{-1})	275 ± 16	71 ± 5	330 ± 14	130 ± 7
Calcium (mgl^{-1})	139 ± 10	12 ± 0.4	337 ± 16	18 ± 0.6
TCOD (mgl^{-1})	20,271 ± 1552	213 ± 29	14,722 ± 811	852 ± 94
SCOD (mgl^{-1})	7,001 ± 727	133 ± 4	6,100 ± 416	272 ± 24
%SCOD/TCOD	34.2 ± 1.4	67.4 ± 9.6	41.7 ± 3.1	33.5 ± 4.9
BOD_5 (mgl^{-1})	12,786± 1230	161 ± 24	13,157 ± 739	629 ± 27
TCOD/ BOD_5	1.58	1.32	1.11	1.35
Total coliforms (cfu/100ml)	(7.8 ± 0.86)10^5	(2.8 ± 0.58)10^5	(560 ± 81.24)10^5	(8.2 ± 0.86)10^5

In a further step, linear regression of analysis results obtained during the Nyabugogo Abattoir wastewater and the Mpazi River water quality analysis are shown in Table 3. The results are presented together with the corresponding equations and correlation coefficients (R^2).

Table 3: Relationship between related parameters

Related parameters	***Fitted equations***	***Regression coefficients***
Salinity and conductivity	y = 0.0006x − 0.15	0.97
TDS and Salinity	y = 0.012x − 0.07	0.94
Conductivity and TDS	y = 1.8703x + 125.8	0.97
TCOD and BOD_5	y = 1.411x−36.0	0.95
SCOD and BOD_5	Y = 0.501x − 98.8	0.97
TCOD and SCOD	y = 1.8703x + 125	0.97
TCOD and TSS	y = 3.620 x + 1753	0.61
TCOD and TKN	y = 0.89 x + 29	0.87

The average water consumption was 69 m^3/day for an abattoir of average of 81 cattle and 216 goat and sheep slaughtered per day. Compared to the water used in the USA, UK and Australia, water consumption in Nyabugogo Abattoir is not high [7]. Table 4 presents the

quality of Nyabugogo Abattoir wastewater and its comparison with typical literature figures,
Environmental Health Safety Guidelines (EHSG) for Meat Processing.

Table 4: Comparison of Nyabugogo Abattoir wastewater quality with different guidelines

Parameters	***Experimental value***	***Typical literature figures (Table 2.1)***	***EHSG for Meat Processing (6)***
pH	8.95 ± 0.26	6.5	6 - 9
COD	14,722 ± 811	9,790	250
BOD	13,157 ± 739	6,433	50
TSS	2,940 ± 71	1,886	50
TP	439 ± 19	128	2
O&G	56	46 ± 9	10
Total coliforms	(560 ± 81) x 10^5	-	MPN 400/ 100 ml

Nitrates are very high in the abattoir wastewater especially at the evisceration and slaughter step where the urine and undigested stomach content concentrated in nitrate was mixed in wastewater streams [7]. This is because wastewater streams for these processes consist of mixed intestinal contents and blood with a high content of nitrates. The levels of nitrates in the abattoir wastewater show that the wastewater could be treated by biological processes if other inhibiting parameters, such as chloride, are reduced. The BOD_5: N: P ratio was 31: 1: 1, which makes it attractive to reduce the organic matter content first through such technologies as anaerobic decomposition, and then further stabilisation before reuse. Conventional waste stabilisation ponds or other natural treatment systems could be used for further stabilisation and reduction of coliforms.

The concentration of TKN was very high in wastewater streams from slaughtering and evisceration processes because of blood and intestinal contents. In the slaughtering area, nitrogen is mainly in the form of TKN because nitrogen is maintained in organic compound in the form of organic nitrogen and ammonia. For the wastewater from the evisceration process nitrogen was mainly in the nitrate form the end product of nitrification because wastewater was mixed with intestinal content and digested organic materials. The wastewater discharged into impact on Mpazi River was concentrated in nitrogen mainly in the form of nitrate.

The correlation coefficients of the fitted equations between total COD, BOD_5 and soluble COD were generally positive for the results for both Nyabugogo Abattoir and Mpazi River.

The high values of R squared (Rsq), and the significant value in the analysis of variance table confirms the strong linear relationship that can be seen on the graph. The following can be deduced:

· The COD and the BOD_5 for the Nyabugogo Abattoir wastewater and Mpazi River showed that the degree of common variation between the two variables was highly positive; thus, the COD and the BOD_5 are said to be highly correlated.

· The correlation coefficients were highly positive hence, they are very strong and indicate a significant relationship between chemical oxygen demand and a five day biochemical oxygen demand. The COD covers virtually all organic compounds, many of which are either partially biodegradable or non-biodegradable. The strong relationship between BOD and COD indicate that COD is could be used as an indicator of the environmental oxygen load.

· The TCOD / BOD_5 ratio was situated between 1 and 2, suggesting that the organic matter of this wastewater is highly biodegradable.

The BOD_5 and the COD values obtained for the analysis of the effluents of the abattoir have been found to be higher than those expected from literature [7]. These levels of BOD_5 and COD could constitute potential pollution problems for the Mpazi River since they contain organic compounds that will require a large quantity of oxygen for degradation. The COD / BOD_5 ratios have been found to be less than 3. This implies that the compound in the wastewater of the abattoir were relatively degradable, thus, a possible depletion of the dissolved oxygen in the receiving rivers and a potential effect on aquatic life. The COD correlates positively with the BOD_5 of the wastewater. The correlation equations could be used to estimate the BOD_5 for reporting and treatment process control. The degree of common variation between the COD and the BOD_5 of the abattoir wastewater from Nyabugogo and Mpazi River was highly positive the strength or magnitude of the relationship is represented by the high values of the R^2 and the significance of the correlation.

The correlation coefficient of the fitted equation for the prediction for Nyabugogo Abattoir and Mpazi River may, therefore, be used to facilitate rapid wastewater quality assessment or optimal process control by the abattoir once the chemical oxygen demand (COD) is measured or *vice versa*.

The TCOD of Nyabugogo Abattoir wastewater was mainly in the form of suspended solids as it is shown by the significant correlation between TCOD and TSS (R^2= 0.75). The high suspended solids concentration in wastewater discharged into the Mpazi River (Site 8) compared to the septic tank influent (Site 5), also suggested some multiplication of biomass.

The high level of TDS and TSS values obtained for the wastewater streams support some of the high values obtained for other parameters determined in this study.

Statistical correlation analysis of the data revealed that the wastewater load COD values correlated with values measuring the presence of TSS, BOD_5. This means that a change in one parameter could account for a certain predictable change in other parameter. The abattoir wastewater is characterised by substantial organic matter content, resulting in an average TCOD concentration of 23,778 mgl^{-1} for abattoir wastewater stream from the slaughtering area and 14,722 mgl^{-1} for the mixed wastewater stream discharged into the Mpazi River. The wastewater stream from the evisceration process had a TCOD of 7,533 mgl^{-1}which is low compared to other sources of wastewater streams in the abattoir. The main contributors of organic matter are blood, fat and paunch content from the evisceration step. Results show great variability in the quality of wastewater streams, reflected by high standard error values on the means. Great variability was observed with respect to the wastewater, depending on the type of by-products generated on process, at the time of sampling.

Some useful relationships between parameters were calculated. According to the calculated percentages soluble COD averaged 44.8% (± 6.8 %) and 18.9% (± 2.1%) of TCOD for influent of septic tank and evisceration process respectively, and the significant correlation between TSS and TCOD which is 0.79 indicate that very little amount of COD is soluble.

The SCOD of Mpazi River was 67.4 % (± 9.6 %) of TCOD before discharge and becomes 33.5 % (± 4.9 %) of TCOD after discharge. Most of it must be included in the paunch content, coagulated blood and fat which increase particulate COD in downstream of the discharge. The BOD_5/ COD ratio range was 1.1-1.5, which was very high in comparison with domestic wastewater, which has a range of 0.3-0.8 (8). Therefore, the biodegradability of the wastewater was found to be high because the ration was less than 3 [8], [9]. In general, organic contaminants entering the wastewater streams are from slaughtering and evisceration processes. Blood and undigested materials are some of the major sources of organic wastes entering wastewater streams, which end up waterways [7], [10].

Tables 1 and 2 show that the Nyabugogo Abattoir increases the organic pollution of Mpazi River especially for TCOD and SCOD which were 213 mg/l and 133 mg/l respectively before discharge and 852 mg/l and 272 mg/l respectively after discharge. The main contributor of that organic material is the wastewater from the slaughtering area especially blood, as it is represented by 23,942 mg/l of TCOD. The nutrients nitrogen and chloride are respectively 130.2 mg/l and 74 mg/l before discharge and 165 mg/l and 123 mg/l respectively after discharge of the Nyabugogo Abattoir effluent. The BOD_5 and the COD values obtained from the analysis of the Nyabugogo processes streams have been found to be higher than expected from Environmental Protection Agency standards guideline for discharge (BOD_5 of 50 mgl^{-1} and the COD of 250 mgl^{-1}) [11]. These levels of BOD_5 and COD could constitute potential

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pollution problems for the Mpazi River since they contain organic compounds that will require a large quantity of oxygen for degradation.

The volume of the septic tank is 55 m^3 and the wastewater produced per day was about 72 m^3. The hydraulic retention time for anaerobic ponds is 8 day [11]. The quantity of wastewater produced in 8 day is about 8000 m^3.

Conclusions

From this study, it can be concluded that:

i. The effluent from Nyabugogo Abattoir is highly loaded with degradable organics and other pollutant that pose an environmental risk to the receiving Mpazi River. The existing septic tank is no longer sufficient to achieve any meaningful treatment, thus allowing high loads of pollutants to enter the Mpazi River. Significant pollution of the Mpazi River was observed for COD, BOD_5, nutrients, chloride, calcium, total coliforms and TSS.

ii. The inter-relationship between some parameters monitored could be used to deduce the levels of others through certain equations, as derived in the study. This could greatly reduce the cost of analysis.

iii. There are opportunities for improving the operations and processes at the Nyabugogo Abattoir, thereby reducing environmental impacts and saving on costs. The application of cleaner production concepts: good housekeeping practices, processes optimisation and efficient use of resources by-products recovery and rendering, together with the establishment of appropriate treatment systems, would greatly improve the environmental performance of the Abattoir.

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USING TRADITIONAL KNOWLEDGE TO COPE WITH CLIMATE CHANGE IN RURAL GHANA

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Abstract

Indigenous or traditional people often inhabit economically and politically marginal areas.
Their livelihoods depend on natural resources which are directly affected by climate change.
Such people have immense knowledge of their micro-environment but are usually neglected in academic, policy and public discourses on climate change and adaptation. Coping with increasing climate change/variability is a major challenge in less resourced, natural resource dependent, low technology communities. This paper assesses coping strategies by rural communities in the Offin River basin in Ghana to changing climate. Data was collected in 2007 through questionnaires, focus group discussions, interviews and field observations in 20 rural communities. Key issues examined include observation of changes in local climate, effects of the changes on livelihoods, strategies adopted to live with the changes, viability of and challenges in implementing strategies, and what the people think is the way forward.
Identified coping strategies include water rationing, rainwater harvesting, indigenous knowledge in agriculture and water management, and traditional taboo/forbidden days.
These strategies are based on traditional norms and practices, less expensive and easy to implement but faces serious challenges due to modernisation. This calls for support and

integration of modern scientific and traditional knowledge in coping with effects of climate change.

INTRODUCTION

As calls multiplied for high-tech solutions (installation of early warning systems using cutting-edge satellite and ocean buoy technologies) as a means of preventing similar disastrous occurrences like the 26th December 2004 tsunami off the coast of Indonesia, news began to circulate about how indigenous communities escaped the tsunami's wrath due to their traditional knowledge. Unlike numerous persons who were attracted to the shoreline by the unusual spectacle of fish flopping on a seafloor exposed by the sea's withdrawal, the Moken and Urok Lawai peoples of Thailand's coasts and islands, the Ong of India's Andaman Islands and the Simeulue community of Indonesia all knew to head rapidly inland to avoid the destructive force of the sea. The small villages of the Moken and Ong were completely destroyed, but their inhabitants escaped unscathed. Even more striking was the displacement of more than 80,000 Simeulue peoples beyond the reach of the tsunami. Only 7 persons died. This surprisingly efficient response, striking in its contrast with the frightening losses suffered elsewhere in Indonesia, was acknowledged by the granting of a UN Sasakawa Award for Disaster Reduction to the Simeulue peoples [1]. This drew world attention to the

traditional knowledge of indigenous people and its relevance to the emerging priority domain of natural disaster preparedness and response.

Traditional knowledge, defined by [2] as a changing system, where western knowledge has a place, has over the years played significant roles in solving problems including climate change. Indigenous people, who live close to the natural resources, observe the activities around them and are first to identify any changes and adapt to them. Appearance of certain birds, mating of certain animals, or the flowering of certain plants are all important signals of changes in time and seasons that are well understood by traditional knowledge.

Biodiversity have been used as a buffer against variation, change, and catastrophe; in the face of plague, if one crop fails, another will survive [3]. In coping with risk due to excessive rainfall, low rainfall, drought and crop failure, some traditional people grow many different crops and varieties with different susceptibility to droughts and floods and supplement these by hunting, fishing and gathering wild food plants. Diversity of crops and food resources are often matched by a similar diversity in field location, some which are more prone to flooding, others more prone to drought, so that in extreme weather some fields are likely to produce harvestable crops.

Adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system [4]. This is important when considering climate change and variability because the impacts of climate change, and hence its seriousness, can be modified by adaptations of various kinds (e.g., [5] and [6]). The ability to, and for how long one can adapt, however, depends on the resources available.

Africa is clearly the most vulnerable and at the same time very far behind in adaptation to effects of climate change because it is the least resourced to withstand the effects without significant changes to its fundamental structures.

It is estimated that Africa has been warming through the 20th century at a rate of between 0.26 and 0.50$_o$C per century. This trend is expected to continue and even see a significant increase in the rate of warming with its attendant negative effects on livelihoods. According to the IPCC Fourth Assessment Report [7], a medium-high emission scenario would see annual mean surface air temperatures expected to increase between 3_{o}C and 4_{o}C by 2080 (IPCC, 2007). This implies difficult times ahead for the local people who depend directly on the natural resources for their livelihoods and their main and/or only weapon to cope with the changes that are yet to come is their traditional knowledge and practices.

Over the last 40 years, Ghana has recorded temperature rise of over about 1_{o}C as well as reductions in rainfall and runoff of approximately 20 and 30% respectively. For a country which depends mainly on rain-fed agriculture, Ghana's vulnerability to changes in climate variability, seasonal shifts, and precipitation patterns can not be over-emphasised. Over the years, farmers and other natural resource dependent communities in Ghana have found ways of coping with changes in climate as is being observed. Such coping strategies have been based on traditional knowledge and practices and this varies from community to community since the country has no climate change adaptation policy. The coping/adaptation strategies, however, show some similarities among communities within one agro-climatic zone.

The evidence and impacts of climate change may be most felt in Africa than any other continent but this does not mean that the continent sits down, looks on helplessly and waits to be consumed by the changes in climate. Traditional knowledge has played a significant role in Africa's adaptation efforts, in the face of low technology. This paper critically looks at use of traditional knowledge to cope with climate change in rural Ghana.

METHODOLOGY

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Study Area

The study was carried out in 2007 in twenty (20) communities in the Offin River basin in the Ashanti Region of Ghana. This region falls in the moist semi-deciduous forest category with a semi humid tropical climate. The rainfall distribution of the basin is weakly bimodal with a main peak between May and June and a secondary peak in September to

October.
Communities covered in the study are rural and predominantly subsistence crop farmers. Some are also into cocoa farming. Agriculture in this region, like most parts of Ghana is rain-dependent and planting seasons are along the two rainy seasons: main season from April-July and the minor season from September-October. Livestock rearing is limited in this region. Economic activity is very low though most of the people engage in petty trading to augment the little income from agriculture. About 90 percent of the communities covered have no pipe-borne water, and depend on the rivers/streams and rainfall for their water needs.

Data Collection

Interviews, questionnaires and focus group discussions (FGD) were used in the data collection. Four (4) focus group discussions were held in four communities to collate their views on climate change and how they are coping with the changes. Semi-structured questionnaires were administered to people in the communities studied, who are forty years and above. The assumption was that younger people may not have observed and experienced enough change in the climate to make good judgement. A maximum of ten (10) questionnaires were administered per community. The questionnaires and FGD helped to identify current observed climate changes and impacts of such changes particularly on local livelihoods; livelihood resources, i.e., natural, physical, social, financial, and human resources of communities in the Offin river basin; and the extents to which these resources help the people to conduct their livelihoods and cope with the impacts of climate change. The responses from the questionnaires were also used to cross-check with each other to get a very good view of the situations prevailing in the communities.
Through the focus group discussions and questionnaire administration, individuals who showed appreciable knowledge in environmental changes around them and their faming

operations were selected for in-depth interviews. They were mainly local farmers who were directly affected by climate change and showed remarkable knowledge of the changes and its effects on their farming; traditional leaders and opinion leaders who were usually old, well respected personalities and involved in decision making and administration of the communities.

RESULTS AND DISCUSSION

Local knowledge, perception and effects of climate change in Offin river basin

The indigenous people may not understand the concept of global warming or climate change but they rightly observe and feel its effects: decreasing rainfall, increasing air temperature, increasing sunshine intensity and seasonal changes in rainfall patterns. This is corroborated by a study in 2007 which recorded a remarkable reduction in mean annual rainfall of 22.2% and a gradual rise in average maximum temperatures of $1.3^{o}C$ or 4.3% rise in temperature from the 1961to 2006, [8]. Gradually, there is increasing realisation that indigenous groups are an important source of information on climate change. Most published reports on indigenous observations of climate changes, however, have come from Arctic regions where the co-operation between scientists and indigenous peoples is strongest [3].

Observed climate changes have resulted in serious effects on natural resources in the Offin river basin. There have been low discharges in all the waterbodies in the Offin basin with some streams becoming extinct. This is mainly in response to the reduction in rainfall since it is the source of water for the streams/rivers in the basin. River Offin which is the biggest river in the basin has been experiencing very low flows in the dry seasons to the extent that the river bed could be seen during recent dry seasons. Generally, from 6.941 m^3/s of discharge in 1957, the discharge of River Offin at 2006 was 3.797m^3/s indicating a 3.144

m^3/s (45.3%) reduction in river discharge [8]. As a measure to ensure availability of water all year round, wells have been dug by the communities but some of theses wells dry up during recent dry periods, indicating a possible reduction in ground waters.
Recent crop failure in the basin has also been attributed to low rainfalls, prolonged rainfall shortages and changes in rainfall patterns. Agriculture in the basin is rain-fed and farmers have over the years perfected the art of predicting the onset of the rainy season.
Farmlands are cleared and prepared in anticipation for the rains to start the cropping season.
This has, however, become difficult during recent years due to significant changes in the rainfall pattern. The beginning of the rainy season is no longer predictable, and during times that it has started on time, there may be an unexpected long break before the rains resume.
This is making it difficult for farmers to plan their cropping seasons to coincide with the rains to ensure maximum crop yield. The result is crop failure and low crop yield. Prolonged rainfall shortages cause a drought situation and a reduction in the water available in the soil for crop growth. This results in crop failure. Due to crop failure/loss, money spent on land preparation and planting, as well as income from the sale of farm produce is lost and household savings are spent to replant farms. People can withstand bad harvests at one time or the other but when it becomes consistent, then things begin to go very wrong.
Another effect of climate change on agriculture in the River Offin basin is the effects of intense sunshine and increasing temperature on crops. These changes coupled with prolonged rainfall shortages causes the wilting of crops. Sunshine is increasingly becoming very intensive and for long hours. Some farmers, notably cocoa growers, narrated incidence of cocoa trees withering as a result of exposure to intense and prolonged sunshine. This

situation was also reported by other farmers such as vegetable growers who claim that the high temperatures causes their vegetables to ripen prematurely and as such not getting the expected income from the sale of their produce. This is a major loss to the farmers and puts a big drain on their financial resources.

Heat and water related diseases such as malaria; diarrhoea, bilharzias, shingles and other skin debilitations are becoming common the basin. Malaria has been mainly due to the people sleeping in the open or with windows open due to high temperatures at night. This situation exposes the people to mosquitoes and eventually malaria. During dry seasons and prolonged rainfall shortages, water sources become scarce, stagnant and contaminated.

During such periods, cases of diarrhoea and bilharzias are common. Shingles and other skin debilitations are also common during periods of high temperatures. Previously, according to the communities, some skin diseases were rare in the communities but such diseases are becoming predominant in recent years.

Local coping strategies and challenges in the Offin basin

The people realize that water shortages are a major threat to their survival and there are several strategies to adapt to this new phenomenon. One of such strategies is water rationing. For example, "waste water" from washing cloths, utensils and other activities are also used for watering backyard gardens and nurseries. Households also try to reduce the

water use per person per day in an attempt to conserve water. This strategy needs to be part of a behavioural change and not during periods of water shortage. Adaptation is not just a climate change issue [9], and education on water conservation should be an on-going process.

Rainwater harvesting, an old traditional way of collecting and storing water where every household had at least two big barrels placed at strategic places in the house where rainwater is directed from the roof of buildings into those barrels for storage, is actively being revived and advocated in most communities. This has become necessary following prolonged rainfall shortages and drying of previously perennial streams that provided water all year round, at a time where more water is needed by the communities due to increase in population. But in all the communities covered under the study, not enough rainfall is harvested because the harvesting technology is not good, i.e. outdated and not inefficient under the current climate regime. The type of houses constructed and the roofing system does not support efficient rainwater harvesting. Only a small percentage of the rains can be harvested with the majority going waste.

The traditional and local authorities identifies clearing of riparian vegetation along their river banks as a major factor affecting their streamflows and are putting on measures to remedy the situation. Some of the measures are creating awareness on the effects of deforestation around water bodies, sensitizing the communities to prevent bush fires, community based management of forests, imposition of fines, etc. These measures by the traditional authorities are not yielding much because the communities, though still rural in terms of development and infrastructure, have become very cosmopolitan or heterogeneous in composition and allegiance to traditional authority is not absolute. There have been settler farmers who have moved into some of these communities and the communal nature of the communities is breaking down and people now think more of themselves than of their collective well-being.

There are also forbidden days or taboo days when nobody is expected to go to the riverside. Previously, the use of taboos was very effective in controlling community behaviour and the traditional leaders see it as an effective alternative in protecting their waterbodies. The question then is, why does it need a re-introduction since such tradition has not at any point been abolished? These taboos have been dormant for several reasons including modernisation, heterogeneity of the communities, and even Christianity. Since most of the people are now Christians, compared to previous years when almost everyone adhered to traditional way of worship, traditional authority has been undermined and its directives are seen as fetish and not adhered to. Although some do believe in the reintroduction and strict enforcement of taboos and forbidden days, they may not have the desired impacts under the current dispensation. Religion is a very delicate issue in these communities and although re-introduction and enforcement of some of the traditional laws will be very useful, it needs a very cautious.

Indigenous knowledge in agriculture and water management, acquired over many years of practice, has helped the communities to cope very well with water shortage, droughts, and crop damage/losses. The farmers are able to predict, quite well, when the rains will come and plan their planting season to coincide with the rains. This has, however, become difficult in recent years due to changing rainfall pattern. To this, the farmers are adapting by changing the type of crops they used to grow. Crops which thrive well under the current prevailing conditions are increasingly being planted in areas which, hitherto, did not support their cultivation. A case in point is shifting from cocoa cultivation to drought resistant crops such as cassava. Vegetable growers are also gradually moving into the river plains to grow their crops since they do not get enough water in the places they previously grew their vegetables. This is a form of adaptation but obviously not sustainable. The money which they previously earned from the sale of cocoa, for example, was a major source of

income which supplemented the upkeep of families and even in buying agricultural inputs and expanding their farms. Clearing of the riparian vegetation and use of chemicals so close to the rivers/streams, as is being done by the vegetable growers has its own hazards.
Farmers, especially cocoa farmers, who complained most about the effects of intense sunshine on their crops see the best way to adapt is to have trees on their farms to provide shade for the crops. Though some farmers already have trees on their farms or are planting trees to provide shade, the practice does not seem appealing to most farmers. In Ghana, all timber trees found on any land belong to the Government and the Government decides when an area of land is given as concession to a timber company for felling. This has resulted in some farmers, having in the past, deliberately killed trees on their farms to prevent timber merchants from coming to fell their trees, destroy their farms and pay little or no compensation. This policy has been a major disincentive to adaptation. Although the Timber Resource Management Amendment Act, (ACT 617), 2002, provides that the right to harvest trees and extract timber from a specified area of land shall not be granted if there are farms on the land unless the consent of the owners of the farms has been obtained or if there is timber already grown or owned by any individual or group of individuals on the land, not much has changed in terms of the relationship between timber merchants and farmers. Due to inability of farmers to show clear proof of ownership of trees on their farms (either planting the tree or tending the tree till maturity), lack of education in forest laws and the financial strength of the timber merchants, the farmers are still being exploited. To stop this exploitation and enhance adaptation of rural farmers, there must be sustained education programmes to get the farmers

informed of their rights and empower them to protect their farms and most importantly, plant more trees.

The way forward

The growing importance of traditional knowledge in coping with climate change leads to the conclusion that there must be a healthy relationship between scientific knowledge and traditional or indigenous knowledge especially in developing countries where technology for prediction and modelling is least developed. Both scientific knowledge and traditional knowledge have their limitations and a good merger will provide the desired results to help cope with climate change. Whereas models and records of precipitation mainly focus on changing amounts of precipitation with climate change indigenous peoples also emphasize changes in the regularity, length, intensity, and timing of precipitation. While scientific explanations of climatic changes have mainly concentrated on anthropogenic greenhouse gas emissions, local interpretations of observed climate changes are often much more varied and encompassing. Whether or not scientific models are incorporated into local explanations, according to [3], depends on the status and accessibility of science within a culture and on the influence of media.

In order to capitalize, develop, expand and mainstream indigenous adaptation measures into global adaptation strategies, attempts by indigenous people to cope with climate change using traditional knowledge should be studied, supported and integrated into scientific research. This is less expensive compared to bringing in aid to salvage catastrophes and disasters or "importing" adaptive measures which are usually introduced in a "top-down" manner – which is difficult to implement due to several factors including financial and institutional constraints. Main findings of the Stern review commissioned by the UK

Treasury to assess the economic impacts of climate change as well as the cost of mitigating climate change were that mitigation costs are relatively moderate, while climate change related losses are likely to be much larger than previously thought, [10]. The Stern review was partly an attempt to counter claims that it would be too costly to try to mitigate climate change compared to any damages that might arise from climate change.

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The Moken, Urok Lawai, Ong and Simeulue surprised the world with their resourceful and life-saving response to the destructive force of the Indian Ocean tsunami.

There is much to learn from indigenous, traditional and community-based approaches to natural disaster preparedness. Indigenous people have been confronted with changing environments for millennia and have developed a wide array of coping strategies, and their traditional knowledge and practice provides an important basis for facing the even greater challenges of climate change. While indigenous communities will undoubtedly need much support to adapt to climate change, they also have much expertise to offer on coping through traditional time-tested mechanisms.

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