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Characterization of Wastewater from an Abattoir in Rwanda and the Impact on Downstream Water Quality

[1]Muhirwa D., [2]Nhapi I., [1]Wali U.G., [3]Banadda N., [4]Kashaigili J. J. and **[5]Kimwaga R.**

[1] Faculty of Applied Sciences, National University of Rwanda, Box 117, Butare, RWANDA, Email muhird@yahoo.fr, ugwas@yahoo.com

[2] Department of Civil Engineering, University of Zimbabwe Box MP167, Mt. Pleasant, Harare, Zimbabwe, Email i_nhapi@yahoo.com

[3] Uganda Industrial Research Institute, P.O. Box 7086, Kampala, UGANDA, Email banadda@uiri.org

[4] Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture, Box 3003 Morogoro, TANZANIA, Email jkashaigili@yahoo.co.uk

[4] University of Dar Es Salaam, Box 35131, Dar Es Salaam, TANZANIA, Email rkimwaga2007@yahoo.com

ABSTRACT

This study analyzed processes and products at Nyabugogo Abattoir in Kigali, Rwanda, and investigated how they can be optimized for environmental safety. The average capacity of the abattoir is 566 cattle and 1,512 goats and sheep slaughtered per week. The study assessed the quantity and quality of different raw materials, by-products and wastewater streams and the potential impacts of applying cleaner production principles in abattoir processes. The samples were collected fortnightly, and analyzed using Standard Methods. The analysis emphasized on nutrients, biologically active constituents, and receiving water impacts. 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, fat oils and grease, NO_3-N, TKN, total phosphorus, chloride, calcium and total coliforms. The findings showed that the abattoir wastewater streams' total chemical oxygen demand (TCOD) ranged from (7,533±723) for evisceration to (23,778±1,673) mgl^{-1} from slaughtering step and the discharge into Mpazi River increased its TCOD from (213±29) to (852±94) mgl^{-1}. The TSS varied between 2,452±51 from the slaughter process and 5,252±174 mgl^{-1} for the effluent from the goat and sheep slaughter section. Results from the bacteriological analysis showed that the average abattoir wastewater discharge count was (560±81)10^5 cfu/100ml of total coliforms which increased from (2.8±0.58)*10^5 to (8.2±0.86)*10^5 cfu/100 ml. It was concluded that the current effluent quality is not suitable for discharge into watercourses. It was recommended that further treatment of the effluent is required coupled with the application of cleaner production principles.*

Keywords: Abattoir effluent, cleaner production, Rwanda, sustainability, wastewater management

2000 Mathematics Subject Classification: 62- XX

JEL Classification System: Q53

1. INTRODUCTION

Meet processing industries involve massive quantities of water used for cleaning, transport, and processing of meat and meat products (EPA, 2002). Major wastewater characteristics of concern to the industry are pollutant parameters, process waste point sources, types of wastes and wastewater loading factors as influenced by production. Water usage in abattoir varies widely across plants

depending upon the type of animal slaughtered, type of processing (dry or wet), water and waste minimization practices, *etc.* Previous studies have reported that the water usage in abattoir varies from 2 to 60 m^3/tonne of meat processed (World Bank, 1998). The average water consumption for abattoir in the United States of America has been reported to vary from 2.6 to 29.2 m^3/tonne Live Weight Killed (LWK), but in Europe and the UK, the figures are lower, ranging from 0.8 to 15 m^3/tonne LWK (Johns, 1995). An Australian study suggested that the amount of water consumed in abattoirs ranged from 4.1 to 43 m^3/tonne of Hot Standard Carcase Weight produced (McNeil and Husband, 1995).

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, including abattoir wastes. One of the abattoirs, the 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 waste management strategies that would control both water and nutrients flows into the downstream Mpazi River with the added advantages of cost reduction, handling efficiency, increased food production, environmental integrity, and social benefits. This could be achieved through an integrated water resources management (IWRM) approach. The objectives of this study are: 1) to assess the quantity and quality of the water and wastewater streams at the Nyabugogo Abattoir and their impact on the receiving Mpazi River, 2) to explore the relationships between related parameters as a means of reducing monitoring costs for the Abattoir, and 3) to explore ways of improving the abattoir performance for better environmental safety.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The Nyabugogo Abattoir (Fig. 1) is located in a commercial zone of Kigali City, and discharges effluent into the Mpazi River, a tributary of Nyabugogo River. Adjacent to this area is a highly populated residential zone, whilst other industries discharge downstream of the abattoir. Besides other diffuse sources of pollution, 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 Nyabugogo abattoir is divided in two parts, one for cattle and the other for goats and sheep processing. The abattoir works seven days a week, with activities starting midnight and finishing around 10.00am. The daily average number of slaughtered cows is 81 heads, while for goats and sheep it is 216, and the daily average water consumption is 69 m^3 supplied by the Electrogaz water company. The abattoir uses water, sodium hydroxide (NaOH) and different kinds of detergents for cleaning purposes. A septic tank of 55 m^3 volume treats the wastewater but the treatment capacity is now too low. No by-products are recovered. Hide treatment involves application of salt to facilitate the drying before sending hides to the tannery for further processing.



Figure 1: An aerial view showing the Nyabugogo Abattoir and tannery, and Mpazi River (from www.googleearth.com)

2.2 Sample Collection

Fig 2 presents the process flow chart and by-products generation of the Nyabugogo Abattoir and the nine sampling sites. The figure shows the water input points, the process steps and the products at each step. Effluent from the two slaughter streams is diverted to a septic tank for preliminary treatment before discharge into the Mpazi River. The sampling points are shown by circled numbers. A weekly sampling program was conducted from 24th August 2007 to 28th September 2007. Samples were taken every Friday of each week, and for each sampling site (Fig 2), five samples were collected. Sampling procedures were done in accordance with the standard methods (APHA/AWWA/WEF, 2005).

Composite samples were collected weekly from 0400hrs – 0500hrs so that they did not include much water from abattoir cleaning. Sampling sites were fixed on each process such that the contribution of each process of the abattoir to wastewater strength and the Mpazi River could be determined. The first sampling point was for the treated water from Electrogaz (Site 1) used in the Abattoir. For the cattle processing part, samples were taken from Site 2 and Site 3, for wastewater streams from slaughtering, trimming and carcass washing, respectively. Sample 4 was collected on wastewater streams from the evisceration process. The 5th sample represented mixed wastewater streams from the cattle processing part of Nyabugogo abattoir. Sample 6 was the mixed wastewater streams from goat/ sheep processing part. Sample 8 was the wastewater from the septic tank which was directly discharged into the Mpazi River. In order to assess the impact of the discharge of Nyabugogo Abattoir

wastewater in the river, sample 7 was collected from Mpazi River at about 25 m upstream of cattle holding area so that there could be no contamination from Nyabugogo Abattoir processes or operations. Sample 9 was collected in the middle of Mpazi River at about 33 m downstream of wastewater discharge into the same river. Immediately downstream this point there were other activities discharging effluent into the River.

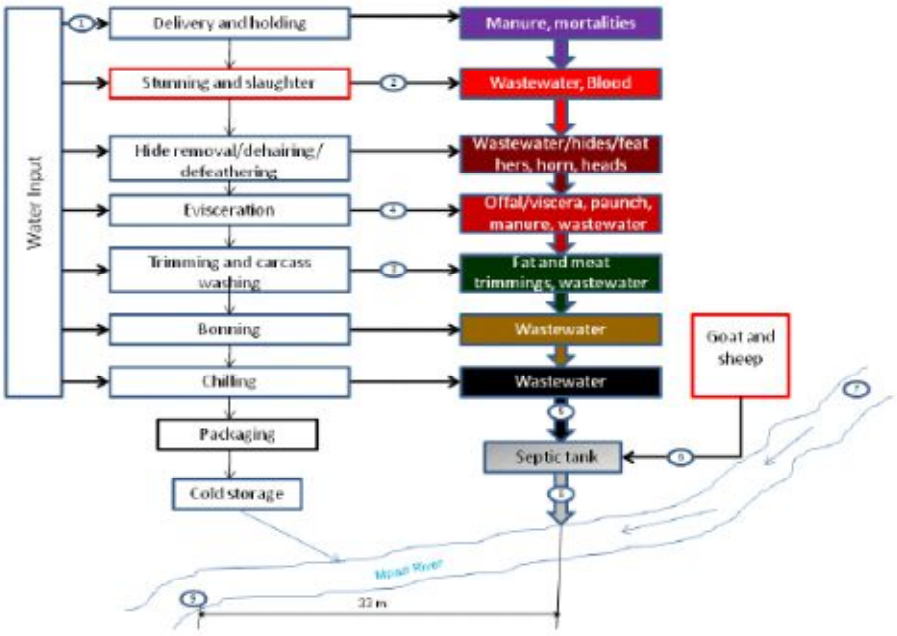


Figure 2: Nyabugogo Abattoir flow chart, by-products and sampling sites used for the current study

2.3 Quantification of Water and Wastewater Generated

To establish the quantity of raw materials, the quantification of cattle slaughtered per day is required as is also the quantity of water used in different processes and operations of the Abattoir. The average cattle slaughtered was calculated from the data of cattle slaughtered from July 2006 to July 2007. The average water consumption was calculated from daily water consumption data of the Abattoir for three months (May, June, and July 2007). This average was extrapolated to estimate water use per animal slaughtered for the period 2006 to 2007.

To estimate the wastewater volume, surveys were done to measure the quantity of blood lost per animal slaughtered (cattle, goat and sheep). The blood loss for 40 cattle and 50 goat/sheep were measured. The bleeding time was about 7 minutes. Fig 3 shows the blood flow measurement step. Blood drains before and after skinning/dressing and this was continuously recorded from a fabricated weir, the results of which were converted into flow measurements. Assuming 100% of water

consumed by the abattoir becomes wastewater, the annual wastewater produced was estimated. The total wastewater volume per year was calculated taking into account wastewater from cattle, sheep and goats plus the annual water consumption from figures collected from the Abattoir officials



Figure 3: Measurement of blood loss and rumen content during the slaughter step

2.4 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, total Kjeldhal nitrogen (TKN), nitrate, total phosphorus (TP), calcium and chloride. The bacteriological parameter analysed was total coliforms. The analyses were done according to APHA/AWWA/WEF (2005).

2.5 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 the SPSS software 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 the Mpazi River.

3. RESULTS AND DISCUSSION

3.1 Animal Slaughter and Water Consumption

Fig 4 presents the trend of animals slaughtered per month based on the data that was available at the Nyabugogo Abattoir. The number of cattle and goats/sheep slaughtered for the period July 2006 to

July 2007 averaged 81 and 216/day, respectively. Production at the Nyabugogo Abattoir varies from month to month depending on the consumption patterns of people in Kigali. Slaughtering levels are highest in December.

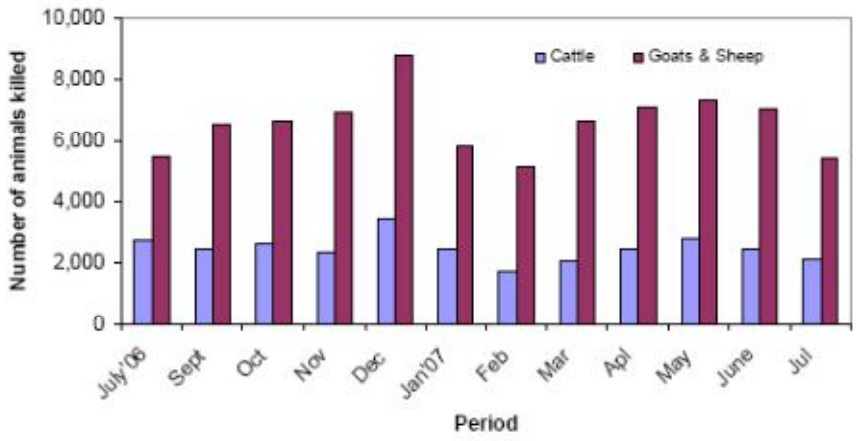


Figure 4: Number of animal slaughtered per month from July 2006 to July 2007(Source of data: Nyabugogo Abattoir officials).

The average blood loss per head killed is 8 litters and 12 litres of paunch which gives 20 litres of wastewater volume per cattle and 2 and 4 litres respectively for blood and paunch content in case of goat and sheep. Table 1 presents the water use and wastewater generated at Nyabugogo Abattoir from May 2006 to July 2007. The average water consumption was 69 m^3/day and the calculated wastewater generated was 72 m^3/ day. It was assumed that all water used ends up as wastewater. Average water consumption and animal slaughtered per day were calculated using the data obtained from Nyabugogo Abattoir officials. Water consumption is not systematically monitored in the plant so as to give water use for each process. Reliable water consumption figures were available for May, June and July 2007.

Table 1: Water use and wastewater generation at the Nyabugogo Abattoir for the period May to July 2007

Month	Cattle slaughtered	Goat and sheep slaughtered	Treated water intake (m^3)	Wastewater Generated (m^3)
May	2,785	7,319	2,278	2,399.5
June	2,455	7,039	2,078	2,190.4
July	2,089	5,418	1,959	2,049.5
Total	7,329	19,776	6,315	6,639.5

The abattoir produces effluent and a variety of solid waste. There are no records of generated and disposed solid waste. It was observed that landfill around the Abattoir is in very poor state without adequate security against scavengers. Waste was not separated and hazardous waste was stored on site or dumped near the Mpazi River. Carcasses were dumped in the same area and as it remained uncovered such that birds and people have unhindered access to it. Resource consumption and waste generation are closely associated with the production volume as measured by the number of animals slaughtered.

3.2 Quality of Water and Wastewater Streams, and Impact on the Mpazi River

Tables 2 and 3 summarize the quality of water and different wastewater streams from the Nyabugogo Abattoir for the five sampling runs under the monitoring period.

The lowest temperature recorded was 19.8 (±0.4) ˚C for wastewater discharged into the Mpazi River and the highest on the slaughtering process 25.8 (±0.9) ˚C. The temperature of the Mpazi River changed from 20.8 (±0.6) to 21.3 (±0.4) ˚C. Statistical analysis (T-Test) of samples from Mpazi River showed P (T<=t) = 0.25 which is larger than 0.05, hence, the temperature of Mpazi River before and after the discharge of wastewater from Nyabugogo Abattoir was not significant.

All the pH figures recorded were between 7.2 (±0.6) for the evisceration step and 8.9 (±0.2) for wastewater discharged into the Mpazi River. Statistical analysis of samples from sites 7 and 9 from the Mpazi River shows P (T<=t) = 0.004 (<0.05). There is therefore a significant difference between pH of the Mpazi River before and after the discharge of wastewater from the plant. It was therefore concluded that the wastewater from Nyabugogo Abattoir increases the pH of the Mpazi River.

The salinity recorded for the municipal water was 0.1. The high salinity levels were from the slaughtering and evisceration processes of 4.1 (±0.3) and 4.0 (±0.6) respectively. The salinity of wastewater discharged into the Mpazi River was 1.8 (±0.11) and the salinity of the Mpazi River increased from 0.34 (±0.02) before discharge to 0.54 (±0.13) about 30 m after discharge (Site 9). Statistical analysis of samples from the Mpazi River (sites 7 and 9) shows P (T<=t) = 0.011 lower than 0.05. Therefore, the difference between salinity of Mpazi River before and after the discharge was very significant. There is an increase of salinity of the river which is directly attributed to the abattoir effluent.

Table 2: Results for raw water and various streams of wastewater at the Nyabugogo Abattoir for Aug-Sept'07, Sampling 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)	-	-	-	-	-
DO (mgl^{-1})	-	-	-	-	-
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

N.B.

- *The results represent the mean of the 5 sampling runs for each parameter*
- *All values are Mean ± Standard Error of Mean (SEM),*
- *cfu : colony forming unit*
- *Blank entry means the parameter was not analysed for the particular station*

Table 3: Results for raw water and various streams of wastewater at the Nyabugogo Abattoir for Aug-Sept'07, Sampling Sites 6 – 9

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)	-	662.4 ± 37.0	552.2 ± 26.6	707 ± 37.6
DO (mgl^{-1})	-	0.05 ± 0.11	-	0.51 ± 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)	$(7.8 \pm 0.86)*10^5$	$(2.8 \pm 0.58)*10^5$	$(560 \pm 81.24)*10^5$	$(8.2 \pm 0.86)*10^5$

N.B.

- *The results represent the mean of the 5 sampling runs for each parameter*
- *All values are Mean ± Standard Error of Mean (SEM),*
- *cfu : colony forming unit*
- *Blank entry means the parameter was not analysed for the particular station*

The conductivity recorded for municipal water was 180 (±13) µS/cm. The high conductivity values recorded were 6,792 (±1,303) µS/cm and 5,646 (±707) µS/cm respectively from slaughtering and evisceration processes. The conductivity of wastewater discharged into Mpazi River was 3,199 (±66)

µS/cm. The impact on the Mpazi River was the increase of conductivity from 632 (±33) before discharge to 726 (±77) µS/cm after discharge. Statistical analysis gave P (T<=t) = 0.001 which was less than 0.05. The difference between electrical conductivity of Mpazi River before and after the discharge was very significant. The discharge of Nyabugogo wastewater into Mpazi River increases its electrical conductivity.

Total dissolved solids of municipal water were 100 (±5) mgl^{-1}. The high TDS recorded were 3,434 (±509) and 3,231 (±200) mgl^{-1} for the slaughtering process and wastewater from goat and sheep part of the Abattoir, respectively. The difference between total dissolved solids of the Mpazi River before and after the discharge point was not significant P (T<=t) = 0.08. The impact on the Mpazi River is not very high because the River also is already highly concentrated in total dissolved solids.

The total suspended solids for municipal water was 8.7 (±0.5) mgl^{-1}. The high total suspended solids recorded were 5,252 (±174) mgl^{-1} for the wastewater stream from goat and sheep part of the Abattoir and 4,412 (±172 mgl^{-1} from the evisceration process. The final effluent from the septic tank discharged 2,940 (±71) mgl^{-1} and the concentration in the Mpazi River was increased from 220 (±16) mgl^{-1} before discharge point to 304 (±34) mgl^{-1} after discharge. The difference between the concentration in TSS upstream of the discharge and downstream of the discharge was very significant P (T<=t) = 0.017. Wastewater from the Nyabugogo Abattoir is highly concentrated in TSS and therefore increases the TSS of Mpazi River.

The TCOD and BOD_5 of the municipal water were 30 (±7) and 18 (±3) mgl^{-1}respectively. The highest TCOD and BOD_5 measured were 23,778 (±1,673) and 15,773 (±847) mgl^{-1}, both from the slaughter wastewater stream. The TCOD and BOD_5 of wastewater discharged were 14,722 (±811) and 13,157 (±739) mgl^{-1} respectively. The impact of discharge on the Mpazi River was the increase of TCOD from 213 (±29) to 852 (± 94) mgl^{-1} downstream of the discharge. Statistical analysis showed that P (T<=t) = 0.004 which indicates that the difference between TCOD of Mpazi River before and after the discharge of wastewater into the river was highly significant. The BOD_5 of Mpazi River upstream and downstream of the discharge point was 161 (±24) and 629 (±27) mgl^{-1}. Statistical analysis t–test shows P (T<=t) 0.0006, therefore, the difference between BOD_5 of Mpazi River upstream and downstream of the discharge was very significant. Hence, wastewater from the Nyabugogo Abattoir increases the BOD_5 of the river.

The concentrations of calcium and chloride in municipal water were 7 (±1) and 42 (±5) mgl^{-1} respectively. The highest concentration of calcium was 372 (±26.1) mgl^{-1} of wastewater stream from the slaughtering process and the highest concentration of chloride recorded was 520 (±27) mgl^{-1} of wastewater stream from the evisceration process. The concentration of calcium and chloride of wastewater discharged into the Mpazi River were, respectively, 337 (±16) mgl^{-1} and 330 (±14) mgl^{-1}. The impact on the Mpazi River was the increase of the concentration of calcium from 12 (±0.4) mgl^{-1} to 18 (±0.6) mgl^{-1}. Statistically, the difference between the concentration of calcium of the Mpazi River upstream and downstream of the discharge was significant P (T<=t) = 0.005.

The concentration of chloride increased from 71 (±5) mgl^{-1} to 130 (±7.7) mgl^{-1}. The difference between the concentration of chloride in the Mpazi River upstream and downstream of the discharge was highly significant P (T<=t) = 0.003. Therefore, wastewater from Nyabugogo Abattoir increases the chloride concentration of the Mpazi.

Nitrates were very high in the Abattoir wastewater especially at the evisceration and slaughter step where the urine and undigested stomach contents are mixed in wastewater streams (Massé and Massé, 2000). This is because wastewater streams for these processes consist of mixed intestinal contents and blood which are high in nitrate content. 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 or disposal.

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 compounds 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 the Mpazi River was concentrated in nitrogen mainly in the form of nitrate. This is also due to the partial anaerobic treatment in the septic tank before discharge.

The highest concentration of TP obtained was 937 (±30) mgl^{-1} for wastewater stream from the evisceration process. The concentration of TP in discharged wastewater was 438 (±19) mgl^{-1} and the concentration of TP in the Mpazi River increased from 3.1 (±0.1) to 5 (±0.4) mgl^{-1}. Statistical analysis of samples from the Mpazi River (Sites 7 and 9) showed P (T<=t) = 0.011, showing that the Abattoir effluent is greatly impacting on the River.

The municipal water (Site 1) was microbiologically safe, with no coliforms count. The total coliform count in the discharged wastewater was 560 (± 81.2)10^5cfu/100 ml. The impact on the Mpazi River was the increase of total coliforms count from 2.8 (±0.5) x 10^5 to 8.2 (± 08) x 10^5 cfu /100 ml. The highest total coliform count was recorded in wastewater discharged into Mpazi River at 560 x 10^5 cfu/ 100 ml. The results showed that there is a multiplication of total coliforms in the septic tank as the influent levels were 33 (±2.39) x.10^5 cfu/100 ml for Site 5 and 7.8 (±0.8) x 10^5 cfu /100 ml for Site 6. It is also possible that a great quantity of wastewater is lost in the septic tank thus increasing its concentration in total coliforms compared to wastewater streams from different processes of the Abattoir. Statistical analysis of samples from the Mpazi River showed P (T<=t) = 0.008. Therefore, the difference between total coliform count of the Mpazi River before and after the discharge was very significant. For the abattoir processes wastewater streams, the highest total coliforms count was recorded in wastewater streams from the evisceration process. This was strongly associated with stomach and intestinal contents.

Dissolved oxygen of the Mpazi River was 0.05 (±0.11) mgl^{-1} upstream of the discharge (Site 7) and 0.51 (±0.18) mgl^{-1} downstream (site 9). Statistically, there was no significant difference between the dissolved oxygen of the river upstream and downstream because P (T<=t) = 0.065 which is larger than 0.05. Dissolved oxygen was very low in the Mpazi River because it is highly polluted with organic materials that consume the oxygen in their decomposition process.

As earlier indicated, the average water consumption is 69 m^3/day. When compared to the water used in the USA, UK and Australia, the water consumption at the Nyabugogo Abattoir is not high (Massé and Massé, 2000). Table 4 presents the quality of Nyabugogo Abattoir wastewater and its comparison with typical literature figures, focusing on parameters of concern as given in the Environmental Health Safety Guidelines (EHSG) for Meat Processing (EHSG, 2007).

Table 4: Comparison of Nyabugogo Abattoir wastewater quality with literature values

Parameters	Experimental value	Typical literature figures (see Table 1)	EHSG for Meat Processing (EHSG, 2007)
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

3.3 Relationships Between Related Parameters.

The linear regression analysis results obtained during the water quality analysis are shown in Table 5. The results are presented together with the corresponding equations and correlation coefficients (R^2).

The correlation coefficients of the fitted equations between total COD, BOD_5 and soluble COD were generally positive for the results for both the Nyabugogo Abattoir and the Mpazi River. The high values for the regression coefficients (R^2) in Table 6 confirm the strong linear relationship between the parameters measured. The following were deduced:

- The COD and the BOD_5 for the Nyabugogo Abattoir wastewater and the 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 BOD_5 and COD. The COD covers virtually all organic compounds, many of which are either partially biodegradable or non-biodegradable. The strong relationship between BOD_5 and COD indicate that COD could be used as an indicator of the environmental oxygen load.

- The TCOD / BOD_5 ratio lied between 1 and 2, suggesting that the organic matter of the abattoir wastewater is highly biodegradable.

Table 5: Relationship between related parameters

Related parameters	*Fitted equations*	*Regression coefficients (R^2)*
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 BOD_5 and the COD values obtained from the analysis of the effluents of the abattoir have been found to be higher than those expected from literature (Massé and Massé, 2000). 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 compounds in the abattoir effluent 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 and the Mpazi River was highly positive as revealed by the high values of the R^2. The fitted equation may, therefore, be used to facilitate rapid wastewater quality assessment or optimal process control by the abattoir once the COD is measured or *vice versa*.

The correlation analysis of the data revealed that the wastewater load for COD values correlated with values measuring the presence of TSS and BOD_5. This means that a change in one parameter could account for a certain predictable change in the other parameter. The abattoir wastewater is characterised by substantial organic matter content, resulting in an average TCOD concentration of 23,778 mgl^{-1} for the 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 quality, depending on the type of by-products generated by the processes at the time of sampling.

Some useful relationships between parameters were derived. 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 of 0.79 indicates that very little amount of COD is soluble. The SCOD of the 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 the River downstream of the effluent discharge point. The BOD_5 / SCOD 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 (Ahn *et al*., 1999). Therefore, the biodegradability of the wastewater was found to be high because the ratio was less than 3 (Ahn *et al*., 1999; Jones, 1974). 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 in waterways (Masse and Massé, 2000; Attiogbe, 2006).

As has been shown in Tables 2 and 3, 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 were respectively 130 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 process 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}) (Metcalf and Eddy, 2003). These levels of BOD_5 and COD could constitute potential pollution problems for the Mpazi River since they represent organic compounds that will require a large quantity of oxygen for degradation.

The volume of the septic tank used for treating the effluent from the Abattoir is only 55 m^3 and the wastewater produced per day was about 72 m^3, representing a hydraulic retention time (HRT) of only 18 hours. The typical HRT for anaerobic ponds is 8 days (Metcalf and Eddy, 2003). It is therefore recommended that the septic tank volume be increased to about 600 m^3 so that the organic matter is substantially reduced whilst other elements are reduced to soluble state. This would facilitate further treatment steps such as nutrient and pathogen removal. This could be achieved through commercially

available package treatment units or a combination of waste stabilisation ponds and wetlands (about 2,600 m^2 of land required). The area and volume of treatment units could be slightly reduced by applying cleaner production principles in the production processes, since water use in the Abattoir is not very high. Besides the liquid waste part, there is also a need to deal with the solid waste products such as hooves, horns and bones. This could be processed into commercial products such as fertilisers, activated carbon, buttons, etc.

4. CONCLUSIONS

From this study, it can be concluded that:

(i) The effluent from Nyabugogo Abattoir is highly loaded with degradable organics and other pollutants 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 predict the levels of others through regression equations, as derived in this study. This could greatly reduce the costs for analysis if the concentration of one of the regressed parameter is known.

(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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