IMPACT OF ANTHROPOGENIC ACTIVITIES AND CLIMATE CHANGE ON RAW WATER QUALITY IN UGANDA – CASE OF RIVER NABAJJUZI WETLAND SYSTEM

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ABSTRACT
Development in many urban areas especially in the developing countries has impacted on the quality of the water resources on which such areas depend for water supply. Pollutants transported by runoff from neighbourhood streets or discharged directly from commercial and industrial centres end up in the nearby water sources. The situation becomes complicated where the population growth rates are high leading to increased demand of the available resources. In this study, the impact of rainfall and temperature patterns on the quality of raw water from River Nabajjuzi wetland system was assessed. In addition, the contribution of pollutants from Masaka drinking water treatment was investigated. There was a slight drop in monthly total rainfall between 2002 and 2006; and an increasing trend of maximum temperatures from 1998 to 2008. During the same period, the apparent colour and turbidity of the raw water increased significantly (at 5% significant level). The water treatment residues did not also satisfy the National Standards for effluent discharge as indicated.

INTRODUCTION

Many urban areas that have undergone or are undergoing extensive growth find that development can severely impact water resources. Massive non-point pollution loading enter urban and suburban streams from neighbourhood streets and industrial facilities. The situation becomes troubling and complex in many developing countries where population growth rates are high coupled with rapid rural-urban migration. The impacts of land-use change, climate changes naturally through time, and incremental pollution loading usually occur in a manner that is gradual, delayed and clandestine and thus do not grab attention in the same way that the impacts of a ruptured main or water-borne disease outbreak would. Among the sources of pollutants that are in most cases ignored are water treatment plants (WTPs). WTPs produce waste streams that can lead to pollution of water sources if not managed well. Most of the wastes generated are produced from the coagulation or softening or oxidation processes (Cornwell, 1999). Other wastes produced in the water industry include sludge from iron or manganese removal processes and filter backwash water. Therefore, if activities that impact negatively on raw water sources are not controlled, running costs of water supply will systematically increase as simple treatment must be replaced by more sophisticated and expensive technologies as water quality deteriorates or as the costs of additional treatment units (for example filters) and chemicals for coagulation and disinfection rise. There might also be increased social and economic costs imposed by water contamination with constituents such as organic materials like pesticides and metals introduced to the watershed and recharge areas from anthropogenic sources which cannot easily be removed by water treatment plants.

This study investigated the impact of anthropogenic activities and climate change on Nabajjuzi wetland system as a raw water reservoir for Masaka waterworks. Residues from the coagulation process and filter backwash water at the waterworks and anthropogenic (man-made) sources of organic matter were the main focus.

MATERIALS AND METHODS

Study area

Nabajjuzi wetland system lies south west of central Uganda in Masaka district, parts of Sembabule district and Mpigi district. The system is a long narrow stretch of swamp from the periphery of Masaka Municipal Council to the major Katonga River system. It is the source of water supply for Masaka Town Council and the immediate townships such as Kyabakuza-Kimanya. It also acts as a drainage sink for Masaka Town.

Sampling and sample handling

Raw water samples were collected weekly from the River and the water treatment plant. The samples were delivered into the laboratory within 2 h and were refrigerated at 4°C for subsequent experiments. 500-ml sample bottles with solid ground glass stoppers were used to collect the samples for trihalomethanes (THM) analysis. The bottles and stoppers were put in a furnace for 3 hours at 105°C ± 5°C and thereafter allowed to cool to room temperature. A small amount (spatula full) of sodium thiosulphate was added in each bottle to react with the chlorine present in the water, and thereby prevent further THM formation. Sample bottles were filled and sealed carefully so that no air bubbles were entrapped. In the assessment of impacts of the Masaka waterworks plant, the samples of backwash water from filters and sludge from the clarifiers were taken.

Rainfall and temperature data

Rainfall and temperature data was obtained from the Uganda Department of Meteorology, under the Ministry of Water and Environment. It plays the role of providing climate and weather services to Government and other stakeholders.

Laboratory analysis

The water quality parameters measured were: colour, turbidity, THM, total organic carbon (TOC), dissolved organic carbon (DOC), total iron, total suspended solids (TSS) and aluminium. Colour was used as a surrogate measure for organic matter. Colour, iron, aluminium and turbidity were measured using Hach DR 4000 spectrophotometer methods. Historical colour and turbidity data obtained from National Water & Sewerage Corporation was also used for comparison. Analysis of THMs was done by gas chromatography (GC) with an Electron Capture Detection (ECD). GC/MS analysis was done to get an idea of the kind of organic material in the raw water. Samples (1 L each) were extracted with methylene chloride (150 mL) and concentrated at 35°C under vacuum to a final volume of 1 mL. One microlitre of the sample was injected into the HP 6890 series Gas Chromatograph interfaced to an HP 5973 Mass Selective Detector (MSD) and controlled by HP Chemstation software (version b.02.05, 1989-1997). The chromatographic separation was achieved using a DB-5 MS capillary column (30.0 m x 250 µm x 0.25 µm). The column stationary phase comprised of 5%-Diphenyl-95% Dimethylpolysiloxane. The instrument parameters are shown in Table 1.

Quality control

Samples for total iron and aluminium were analysed in triplicates and the average taken for every sampling routine. All glassware was rinsed with a 1:1 Hydrochloric Acid Solution and finally with deionized water. For spectrophotometer measurements, blank sample reading was checked every after 5 samples where a non-zero for the blank indicated need for cell cleaning, or variations in the spectrophotometer response caused by heating since it was being used over a long time.

Table 1: Gas chromatograph conditions

Oven Temperature Programme:	
Initial Temperature:	50°C
Initial Time:	2 minutes
Ramp Rate:	10°C/min
Final Temperature:	300°C
Final time:	3 minutes
Injector Conditions:	
Injection mode:	Splitless
Injector Temperature:	250°C
Injector volume:	1 µL

RESULTS AND DISCUSSION

Rainfall and temperature trends

The general trend of precipitation and temperature from year 1998 up to 2008 is shown in Figure 1. There was a significant variation of rainfall between months ($p = 0.000 < 0.05$) and this is explained by the two rain seasons experienced between March – May and October – November. However, there was no significant annual variation ($p = 0.453 > 0.05$). Despite the global climate change, the annual monthly total rainfall did not change significantly (Table 2). There was a slight drop in monthly rainfall totals between 2002 and 2006. Mean monthly maximum temperatures were significantly variable over the months and years (Table 3) with an increase in temperature from 1998 to 2008 as indicated in Figure 1. However, the mean monthly minimum temperatures were not as variable as the maximum temperature.

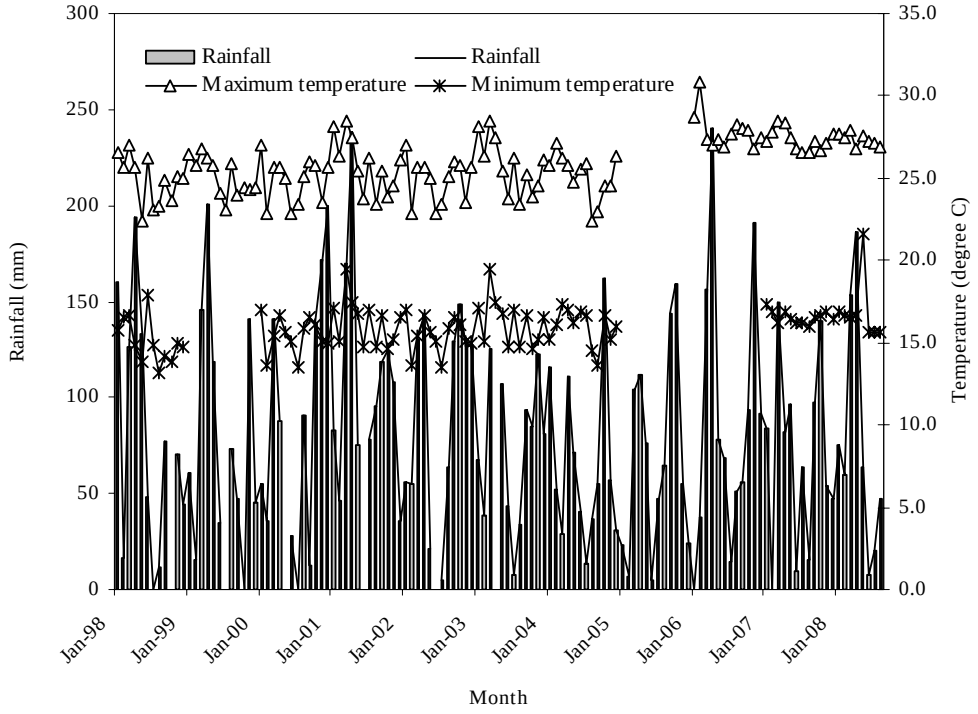

Figure 1: Trends of total monthly rainfall and temperature from 1998 to July 2008

Table 2: Tests of between-subjects effects: dependent variable: Rainfall

Source	Degree of freedom	F-value	Probability (*p*)
Month	11	6.814	0.000
Year	7	0.981	0.453
Tmax	1	0.139	0.711
Tmin	1	0.285	0.595
Error	66		

Table 3: Tests of between-subjects effects: dependent variable: Tmax and Tmin

	Tmax			Tmin		
Source	**Degree of freedom**	**F-value**	**Probability (*p*)**	**Degree of freedom**	**F-value**	**Probability (*p*)**
Month	11	4.546	0.000	11	1.701	0.092
Year	9	12.142	0.000	7	2.330	0.034
Rainfall	1	0.000	0.996	1	0.148	0.702
Error	88			67		

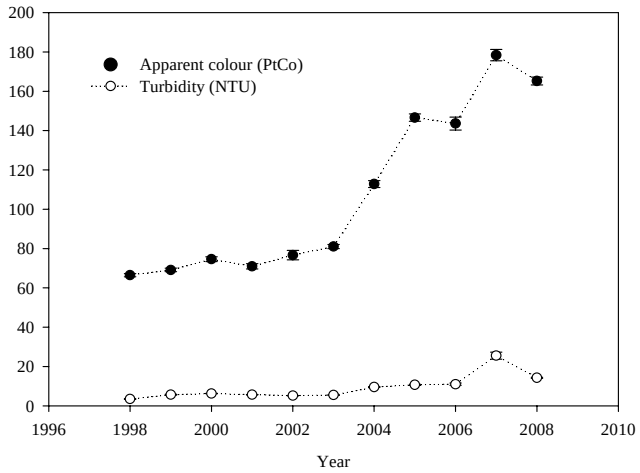

Figure 2: Trend of mean annual water quality from 1998 to 2008

Water quality trend

There was a significant change in the raw water quality (at 5% significant level) with respect to colour and turbidity (Figure 2) with an increase in the colour of raw water of about three fold from 2002. This increase in colour and turbidity occurred during the same period when the rainfall reduced. This implies that deterioration of the water quality was mainly due to the concentration effect and thus the rainfall did not have a significant impact on the rise in colour and turbidity as indicated in Table 4. The system experiences an evapotranspiration ranging between 1450 – 1600 mm (Byaruhanga & Kigoolo, 2005).

Table 4: Tests of between-subjects effects with dependent variables: colour and turbidity

Colour				Turbidity			
Source	**Degree of freedom**	**F-value**	**Probability (p)**	**Source**	**Degree of freedom**	**F-value**	**Probability (p)**
Year	6	8.244	0.000	Year	6	7.667	0.000
Month	11	3.490	0.001	Month	11	1.903	0.063
Rainfall	1	0.123	0.727	Rainfall	1	2.291	0.137
Tmax	1	0.411	0.524	Tmax	1	0.359	0.552
Tmin	1	0.192	0.663	Tmin	1	0.025	0.876
Turbidity	1	26.362	0.000	Colour	1	26.362	0.000
Error	47			Error	47		

Water treatment plant operation and residues

The deterioration of water quality has a direct impact on water treatment and thus the characteristics of residues generated. The Masaka WTP is composed of an old water works (Bwala) with a water treatment capacity of 3,000 m^3 per day and a new water works (Boma) built in 1997 with a capacity of 5,000 m^3 per day making the total capacity of Masaka water treatment works 8,000 m^3 per day, though only 35% of that capacity is utilized. It has no system for water treatment residual in place. The backwash water from Bwala WTP is discharged about 20m upstream of the raw water intake point while the sludge from all clarifiers and backwash water from Boma are discharged about 50m downstream of the raw water intake point. The filters are backwashed twice a day while the sludge from the clarifiers is removed once in every three months.

Figure 3 and 4 indicate the removal of organic carbon and trihalomethanes at the different stages of the treatment train. Most of the organic carbon (about 63%) is removed at the clarification stage while less than 15% is removed at the filtration stage. This implies that filter backwash water contains less of the organic material. The water treatment residues do not satisfy the National Standards for effluent discharge as indicated in Table 5. Given that the backwash water is discharged upstream of the water intake point, it also has direct implications on the raw water quality and treatment costs.

Table 5: Quality of residue from the coagulation and filtration processes at Masaka WTP

Parameter	Unit	Filter Backwash Water	Supernatant from Clarifier Sludge	Sludge from Clarifiers	National Standard for Effluent Discharge
TSS	mg/L	156	92	712.5	100
Total Iron	mg/L	7.325	7.525	20.925	10.0
Aluminium	mg/L	0.773	0.077	0.908	0.5

From Figures 3 and 4, the major concern should be on the clarification sludge where 63% of the organic carbon and TTHM are removed. Coagulant sludges are essentially biologically inert, having low biodegradable organic content and a near-neutral pH (Peck & Russell, 2004). The sludge also has high concentrations of TSS, iron and aluminium (Table 5). The discharge of this sludge into the raw water course probably explains the TTHM concentration in the raw water.

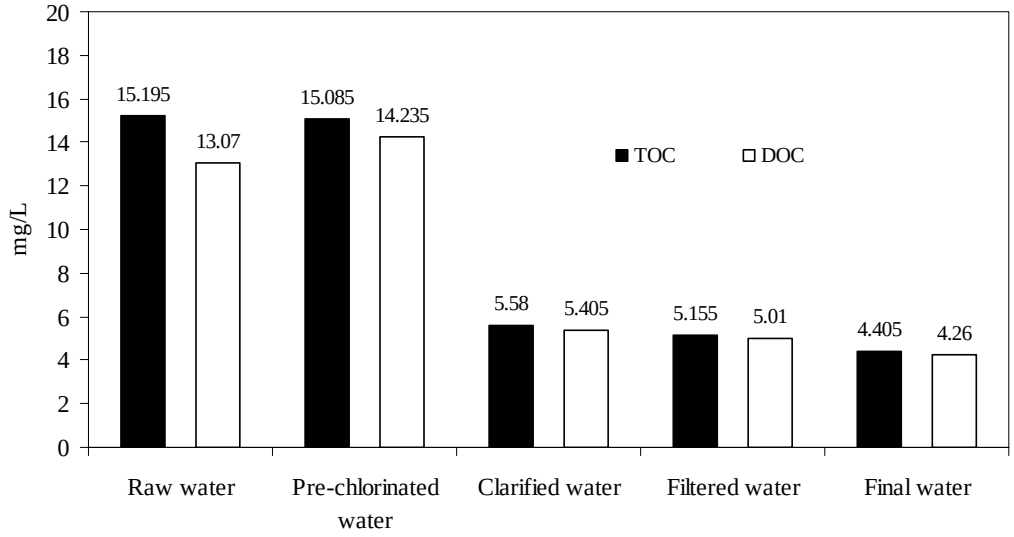

Figure 3: TOC and DOC concentrations at different treatment processes at Masaka water treatment plant

Other pollutants identified in the raw water included n-Decanoic acid, phenol, 2,4-bis1,1-dimethylethyl, dodecanoic acid, diethyl phthalate, bis (2-ethylhexyl) phthalate (DEP), 1-undecanol, tetradecanoic acid, 1,2-Benzenedicarboxylic acid, bis (2-methylpropyl) ester, n-hexadecanoic acid, dibutyl phthalate and clofenvifos. Decanoic acid, or capric acid, is a saturated fatty acid. It is used in organic synthesis and industrially in the manufacture of perfumes, lubricants, greases, rubber, dyes, plastics, food additives and pharmaceuticals.

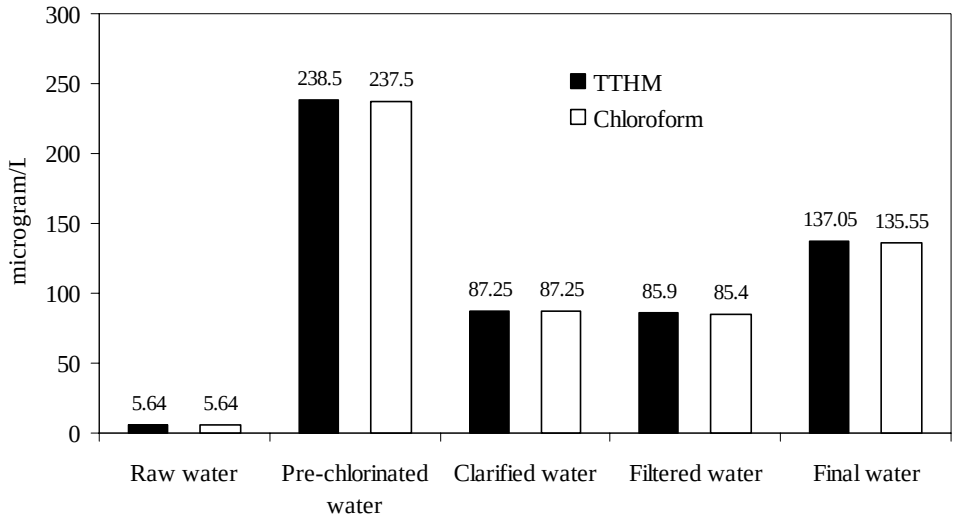

Figure 4: TTHM and Chloroform production at Masaka water treatment plant

Diethyl phthalate (DEP) is a plasticiser widely used in tools, automotive parts, toothbrushes, food packaging, cosmetics and insecticide. 1-Undecanol is an alcohol resulting from fermentation of natural organic matter while tetradecanoic acid is a saturated fatty acid occurring naturally in animal and vegetable fats. Dibutyl phthalate is a man-made chemical that is added to plastics and other chemicals. It is also used in printing inks, resin solvents, perfume oil solvents, paper coatings, adhesives, and nail polish. Diethyl phthalate (DEP) may enter the environment in air emissions, aqueous effluents, and solid waste products from manufacturing and processing plants. Plastic materials containing DEP in waste disposal sites constitute the major reservoir of this compound in the environment. If released to the aquatic environment, DEP is expected o biodegrade (aerobic biodegradation half-life approximately 2 days to > 2 weeks) (Howard, 1989). These kind of organic materials indicate contribution of organic pollutants from the urban centres probably brought by runoff into the River Nabajjuzi wetland, from the activities within and around the wetland itself including waste disposal in the watershed.

CONCLUSIONS

The reduction of rainfall and an increase in temperature could have resulted into an increase in colour and turbidity of the raw water at the River Nabajjuzi wetland system. In addition, water treatment residues did not satisfy the National Standards for effluent discharge thus impacted negatively on the water quality. The nature of organic pollutants also indicated interference of activities in the neighbouring areas on the water quality.

ACKNOWLEDGEMENTS

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REFERENCES

Peck B. E. & Russell, J. S. (2004). Chapter 17: Process residuals. In: Water treatment plant design. By Edward E. Baruth, Ameican Society of Civil Engineers, American Water Works Association, 4th edition, pp 896.

Byaruhanga, A. & Kigoolo, S. (2005). Nabajjuzi Wetland System Ramsar Information Sheet. Nature Uganda.

Cornwell, D. A. (1999). Water treatment plant residuals management. Chapter 16 in: Water Quality and Treatment: A Handbook of Community Water Supplies. American Water Works Association. Letterman, R. D. (Technical editor). Fifth edition, ISBN 0-07-001659-3. Pages 16.1 – 16.51.

Howard, P. H. (1989). Handbook of Environmental Fate and Exposure Data for Organic Chemicals. Volume 1. Published by CRC Press, ISBN – 13: 9780873711517, 604pp.

Standard Methods for the Examination of Water and Wastewater *(*2000). 20th edn, American Public Health Association/ American Water Works Association/ Water Environment Federation, Washington, DC, USA.

NWSC (2005). Annual Report 2004 –2005 Also available to download at: www.nwsc.co.ug/reports.php

NWSC (2005). Quarterly report – July – December 2005 Also available to download at: www.nwsc.co.ug/reports.php