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A Comparative study of the performance of the Chitungwiza, Marondera and Crowborough sewage treatment plants in Zimbabwe

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The performance of the Chitungwiza, Marondera and Crowborough Sewage treatment plants in Zimbabwe were evaluated by monitoring the levels of suspended solids (SS), dissolved solids (DS), dissolved oxygen (DO), biological oxygen demand (BOD), K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, and PO_4^{3-} ions in the period May 1994 to September 1995. The performance of the three plants were assessed by comparison to the UK conventional effluent 30:20 standard for SS, BOD, Cl^-, NO_3^- and PO_4^{3-} ions. All three plants conformed to this standard for nitrate ion, while for Chitungwiza and Marondera plants the levels of BOD, SS, chloride and phosphate ions were in excess of the Standard. In addition, the Chitungwiza sewage plant effluent contained very high levels of nitrite ion.

Keywords: Sewage effluent, Wastewater quality.

Introduction

Although the techniques for efficient water collection and treatment, as well as disposal of wastewaters, are well developed, and in the developed countries the public is always assured of good quality water, in developing countries many cities and towns are without safe water supply because of lack of adequate resources, both financial and skilled manpower, for the operation and maintenance of water and wastewater treatment plants.

In Zimbabwe water pollution caused by discharging poorly treated sewage plant effluent into public waterways has been reported (Mathuthu *et al.*, 1995; Mathuthu et al., 1997). The need to monitor the performance of sewage treatment plants cannot therefore be over emphasized. In this paper we report on a study carried out to assess the efficiency of three sewage treatment plants in the towns of Chitungwiza and Marondera and the City of Harare in Zimbabwe.

Chitungwiza town lies 25 km to the south of Harare, Zimbabwe's capital city, and has a population of about a million. The Chitungwiza sewage works plant is responsible for treating all the sewage from the town. It is a secondary treatment plant which employs the trickling filter method. The plant is designed to treat up to 32 000 cubic metres of wastewater per day. Currently the sewage effluent is used for irrigating pastures at a nearby farm. The Chitungwiza Town Council is spending about 7.5 million Zimbabwe dollars annually in running the plant.

The Town of Marondera lies 85 km to the east of Harare. It has a population of 200 000. The Elswood sewage disposal works is responsible for the treatment of Marondera's sewage and industrial wastewater. It is a secondary sewage treatment plant that utilizes the activated sludge process and biological treatment of wastewater. During the period of the study, the plant was treating about 280 000 cubic metres of wastewater per day, although it was designed for a maximum capacity of 200 000 cubic metres per day. Currently the effluent is being used for irrigating pastures. Due to domestic water shortage, the municipality authorities are considering treating and recycling the wastewater for re-use back in the community.

The Crowborough sewage works in Harare is responsible for the treatment of approximately half of Harare's sewage waste from industrial and domestic sources. It is a secondary treatment plant which uses a modified activated sludge process and biological treatment of the waste water. The plant receives 55 million cubic metres of waste water a day. Fifty two million litres of treated sewage are discharged daily into Marimba river and is carried to Lake Chivero for eventual recycling for water consumption back in Harare. The city water consumption rate is 300 000 cubic metres per day and of this, 20 percent of the water comes from recycling of waste water.

Materials and Methods

Samples were collected between June 1995 and September 1995 for the Chitungwiza and Marondera plants, and between May 1994 and February 1995 for the Harare plant. Samples were collected using 1-L polythene bottles previously cleaned by soaking in 10 percent v/v nitric acid overnight and rinsing with distilled de-ionized water. All samples were tightly sealed and immediately taken to the laboratory for analysis. Where immediate analysis was not possible, samples were stored in a refrigerator at 4°C. Temperature and pH were measured on site, while the rest of the parameters (Tables 1 to 3) were analyzed in the laboratory.

The various parameters were determined using standard methods (APHA 1975; APHA 1980). All reagents used were analytical reagent grade. Suspended solids (SS) and dissolved solids (DS) were separated by filtering the sample through a 0.45 μm cellulose acetate filter paper and both determined according to standard procedures (APHA 1975; APHA 1980). Dissolved oxygen (DO) was measured using the Winkler method (APHA 1975; APHA 1980). DO fixation was done at the sampling site. Biological oxygen demand (BOD) levels were measured by incubating the samples for five days in tightly stoppered bottles in the dark and determining the oxygen consumed (APHA 1975; APHA 1980). Sodium and potassium were determined using flame emission spectrometry, while calcium and magnesium were determined using flame atomic absorption spectrometry on a Shimadzu

AA-6401F Flame Atomic Spectrometer (Shimadzu Corporation, Japan) (Dean and Rains 1975).

The anions PO_4^{3-}, Cl^-, SO_4^{2-}, NO_3^- and NO_2^- were determined using standard methods and/or ion chromatography (IC) (Small 1983). A DX-10 IC Dionex Corporation Instrument, No. 17423 with an IONPAC AG4A-SC Guard Column (4 x 50 mm, P/N 043175) and an IONPAC AS4A-SC Analytical column (4 x 250 mm, P/N 043174), was used. An anion micromembrane suppressor AMMS-11 was used. The eluent, 1.8 mM Na_2CO_3/1.7 mM $NaHCO_3$, was prepared from the AS4A Combined Carbonate/Bicarbonate Eluent Concentrate (IDOX concentrate P/N 039513).

Results

For each sample collected, determinations were made in three replicates. The levels of the various parameters measured during the study period are shown in Tables 1, 2 and 3. Table 4 shows the mean values obtained for the study period.

Table 1: Chitungwiza sewage treatment plant: Mean levels of the various parameters for the period June to September 1995*

Parameter	18/06/95	19/08/95	18/09/95	Mean
pH	7.26	8.02	6.87	7.4±0.6
Temp. (°C)	20.8	22.3	23.5	22±1
SS	14±6	222±3	206±5	214±8
DS	754±5	749±4	762±5	755±7
DO	2.4±0.1	3.3±0.4	1.5±0.2	2.4±0.9
BOD	19±3	22±2	27±2	23±4
K	65.4±0.5	58.7±0.5	72.1±0.1	65±7
Mg	18.5±2	17.4±0.5	19.7±0.3	18.5±1.1
Na	225±10	220±11	231±11	225±6
Ca	13.9±0.4	12.9±0.2	14.9±0.4	14±1
Cl^-	106.9±0.6	107.1±0.6	106.0±0.4	106.7±0.6
SO_4^{2-}	55.7±0.7	55.0±0.4	54.6±0.4	55.1±0.6
NO_3^-	14.4±0.1	15.2±0.2	13.3±0.1	14±1
NO_2^-	85±2	79±2	78±1	81±4
PO_4^{3-}	37.6±0.1	35.7±0.3	39.8±0.6	38±2

*Units: mg/L, except for pH (in pH units) and Temperature (in °C).
SS = Suspended solids; DS = Dissolved solids; DO = Dissolved oxygen;
BOD = Biological oxygen demand.

Table 2: Marondera sewage treatment plant: Levels of the various parameters for the period June to September 1995*

Parameter	18/06	19/08	18/09	Mean
pH	7.38	6.42	7.65	7.2±0.6
Temp. (°C)	21.0	22.3	22.4	21.9±0.8
SS	173	169	175	172±3
DS	349	339	360	349±10
DO	4.1	3.7	3.5	3.8±0.1
BOD	6	9	7	7±2
K	53	55	51	53±2
Mg	7.8	7.6	9.7	8±1
Na	230	233	229	231±2
Ca	6	5	7	6±1
Cl^-	105.8	106.3	105.5	106.0±0.2
SO_4^{2-}	21.6	25.2	17.7	22±4
NO_3^-	18.3	13.9	16.1	16±2
NO_2^-	3.9	1.9	1.3	2.4±1.4
PO_4^{3-}	22.7	25.6	19.8	23±3

*Units: mg/L, except for pH (in pH units) and Temperature (in °C).
SS = Suspended solids; DS = Dissolved solids; DO = Dissolved oxygen;
BOD = Biological oxygen demand.

Table 3: Crowborough sewage works treatment plant: Levels of the various parameters for samples collected between May 1994 and February 1995*

Parameter	30/5/94	12/7/94	9/8/94	24/2/95	3/4/95	Mean
pH	7.21	7.43	7.56	7.68	7.84	7.54±0.24
Temp. (°C)	15.0	16.4	16.1	22.4	20.2	21.0±3.1
SS	4	20	4	24	24	15±11
DS	680	700	581	756	696	683±64
DO	6.3	5.7	6.7	3.9	4.4	5.4±1.2
BOD	0.8	2.5	2.7	1.3	0.4	1.5±2.3
K	11.6	12	28.3	24.4	34.3	22±10
Mg	10.9	6.8	8.6	28.1	8.9	9.7±2.4
Ca	24.2	10.6	11.8	125	33.6	21.7±10
Cl^-	28	29	32	134	138	72±58
SO_4^{2-}	198.9	189	191.3	158.2	166	181±18
NO_3^-	5.0	4.5	7.0	2.4	2.8	4.3±1.9
PO_4^{3-}	0.9	1.0	0.3	1.4	1.7	1.0±0.5

*Units: mg/L, except for pH (in pH units) and Temperature (in °C).
SS = Suspended solids; DS = Dissolved solids; DO = Dissolved oxygen;
BOD = Biological oxygen demand.

Table 4: Mean Levels of the various parameters* at Chitungwiza, Crowborough and Marondera sewage treatment plants.

Parameter	Chitungwiza	Crowborough	Marondera	UK 30:20 Std.**
pH	7.4±0.6	7.5±0.2	7.15	
Temp. (°C)	22±1	21±3	21.9	
SS	214±8	15±11	172.3	30
DS	754±5	683±64	349.3	
DO	2.4±0.9	5±1	3.8	
BOD	23±4	2±2	7.3	20
K	65±7	22±10	53	
Mg	19±1	10±2	8.4	
Na	225±6		230.7	
Ca	14±1	22±10	6	
Cl^-	106.7±0.6	72±58	105.9	100
SO_4^{2-}	55.1±0.6	181±18	21.5	
NO_3^-	14±1	4±2	16.1	20(as N)
NO_2^-	81±4		2.4	
PO_4^{3-}	38±2	1.0±0.5	22.7	6

*Units: mg/L, except for pH (in pH units) and Temperature (in °C).
**UK Royal Commission Conventional Effluent Standard of 20 mg/L BOD and 30 mg/L SS (Tebbutt 1992). SS = Suspended solids; DS = Dissolved solids; DO = Dissolved oxygen; BOD = Biological oxygen demand.

Discussion

The main goals of treating municipal wastewater are to reduce its content of suspended solids, oxygen-demanding materials, bacteria, dissolved inorganic compounds, particularly compounds of phosphorous and nitrogen, and toxicants (American Chemical Society Committee on Environment Improvement, 1978).

The performances of the three plants against the UK Conventional 30:20 Effluent Standard (Tebbutt 1992), and against each other, are discernible from Table 4. The Harare plant at Crowborough sewage works has the best performance with respect to levels of phosphate ion, chloride ion, and suspended solids, dissolved solids, dissolved oxygen and biological oxygen demand. On the other hand, the Marondera plant has the best performance with respect to sulphate ion, Ca and Mg levels.

From Tables 1 to 4, it is apparent that all three plants conformed to the UK Conventional 30:20 Effluent Standard for nitrate nitrogen. However, for Chitungwiza plant, levels are in excess of the UK Conventional Effluent 30:20 Standard for BOD, SS, chloride and phosphate levels, while for the Marondera plant levels are in excess of the 30:20 standard for SS, chloride and phosphate levels. The effluent from the Crowborough plant (modified activated sludge process) complied with the UK

Conventional effluent 30:20 standard for SS, BOD, chloride, nitrate and phosphate levels.

The levels of phosphates were far above recommended limits for eutrophication purposes in the Chitungwiza and Marondera effluents, but were removed to satisfactory levels by the modified activated sludge process at Crowborough sewage works where the averages were 4.3 mg/L and 1.0 mg/L for nitrate and phosphate respectively. The Chitungwiza plant had the highest level of phosphate (37.7 mg/L), followed by the Marondera plant (22.7 mg/L).

Levels of nitrate ion at Chitungwiza and Marondera sewage plants were 16 mg/L and 14 mg/L respectively. Although the organic loading and concentration of NH_4^+-N in the influent wastewater were not determined in the present exercise, the relatively high nitrate ion in the effluent from Chitungwiza and Marondera plants is probably due to high organic loading and high concentration of NH_4^+-N in the influent (Grady and Lim, 1980). For example, the Chitungwiza plant was designed to treat 32 000 cubic metres of wastewater per day, and in normal times receives a volume much larger than this. However, during the period spanning the present study, the plant was receiving only 15 000 cubic metres of wastewater per day, due to water rationing measures in force at the time as the country had experienced a severe drought. The reduction in volume of influent was compensated by an increased loading of organic and other substances. Water rationing measures were also in force at Marondera, and this may explain the reduced efficiency at this plant.

The high nitrite levels for Chitungwiza plant effluent could be a result of any of the following possible causes: (a) presence of substances inhibitory to the process of nitrification; (b) poor aeration of the wastewater and sewage under treatment, ie low DO concentration within flocs; (c) high levels of suspended solids reaching the trickling filters; and (d) high levels of influent loadings. Further work is underway to establish the exact cause of the high levels of nitrite in the plant.

Suspended solids were very high in Chitungwiza and Marondera effluents, but very low and within acceptable limits in the Crowborough sewage works effluent. Dissolved solids were rather high in Chitungwiza and Crowborough plants effluents (~700 mg/L), but were well within acceptable limits in the Marondera effluent.

Chloride levels were comparable in all the three plants effluents. Sulfate levels were very high in the Crowborough modified activated sludge process effluent. This could be attributed to the release of organic-bound sulfur by the more efficient bacterial decomposition of organic matter.

The oxygen demanding substances were removed very effectively by the modified activated sludge process and the DO levels were satisfactory (~5.4 mg/L). The treatment processes at Chitungwiza and Marondera were not satisfactory in the removal of oxygen demanding organic substances, with the Chitungwiza plant being the worst.

Conclusion

The Chitungwiza treatment plant seems to be too small for the volume of sewage waste that it must process and the biological processes (bacterial decomposition) are not given enough time to work on the organic matter, hen :e the poor quality of the effluent. The Marondera plant is better compared to the Chitungwiza plant overall but it is also showing signs of strain with respect to some of the parameters. The activated sludge process at the Crowborough works was very efficient with very good quality effluent.

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REFERENCES

American Chemical Society committee on Envronmental improvement, 1978 Cleaning Our Environment: A Chemical Perspective, *American Chemical Society*, Washington D.C., p 213.

APHA (American Public Health Associaiton), 1975 Standard Methods for the Examination of Water and wastewater, 14th Ed., APHA, Washington, D.C.

APHA (American Public Health Associaiton), 1980 Standard Methods for the Examination of Water and wastewater, 15th Ed., APHA, Washington, D.C.

Dean J.A. and Rains T.C., (eds) 1975 Flame Emission and Atomic Absorption Spectroscopy: Applications. Marcel Dekker, NY, Vol. **3**.

Grady C.P.L. and Lim H.C., 1980 Biological Wastewater Treatment: Theory andApplications, Marcel Dekker, NY, p 796.

Mathuthu A.S., Zaranyika M.F., Tafirenyika S. and Chibanda B., 1995 Impact Assessment of Sewage Effluent Discharges on the Quality of the receiving lower Mukuvisi River waters in Harare, Zimbabwe. *Journal of Environmental Science Health*, **A30(2)**: 281–297.

Mathuthu A.S., Mwanga K. and Simoro A., 1997 Impact Assessment of Industrial and Sewage Effluent on Water Quality of the receiving Marimba River in Harare, in Lake Chivero: A Polluted Lake, N.A.G. Moyo, ed., University of Zimbabwe Publications.

Small H., 1983 Modern Inorganic Chromatography, *Anal. Chem.*, **55(2)**: 235A.

Tebbutt T.H.Y., 1992 Principles of Water Quality Control, 4th Ed., Pergamon Press, p 221.