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Urban expansion and its implication on domestic wastewater treatment in a typical small town of a developing country: case of Masvingo, Zimbabwe

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DEDICATION

This dissertation is dedicated to my parents

ACKNOWLEDGEMENTS

I observe and honour the unwavering support and knowledge of my family. I owe the successful compilation of this report to the Lord Almighty. I wish to acknowledge the valuable contribution of my supervisor who ensured efficient coordination of this dissertation.

Abstract

Background: Rapid urbanisation and overpopulation influence the efficiency of the wastewater treatment plants particularly in small towns of developing countries.

Objectives: The study investigated the impact of urban expansion on the efficiency of wastewater treatment in Masvingo town, Zimbabwe.

Methods: Eight wastewater quality parameters (temperature, pH, TDS, NH_3, PO_4^{3-} turbidity, NO_3^-, BOD) were measured at three sampling sites (inlet, cascade and holding pond) for a period of 1 month from 27 May to 4 June 2022. Parameters were analysed using standard methods for water and wastewater analysis. Secondary data were used to augment primary data to determine whether the wastewater treatment plant (WWTP) was still working along design parameters. The variation of wastewater quality parameters across sampling sites were determined by one-Way ANOVA with GLM post hoc. Measured values were compared to national discharge limits using a one sample student t-test. The efficiency of the WTP was determined by the effluent removal efficiency and population equivalence. Analyses were performed in SPSS version 16.0, and variations considered significant at $p < 0.05$.

Key results: The WWTP was designed to treat 21 Ml/day of wastewater from a population of 110 000 as ta 2022 to meet national wastewater discharge standards. By 2022, the WTP was receiving of wastewater from an estimated population of of 110 000 which produced $282.86 mg BOD/l$ It was overloaded. The quality of effluent disposed of into xxx River did not meet national limits. These included TDS, Ammonia, phosphates, and turbidity significantly exceeded national limits at all sites ($p < 0.05$). Nitrates significantly exceeded the national limit at the holding pond and the cascade ($p < 0.05$). The efficiency of the WTP with respect to BOD in the disposed effluent was Mean%.

Conclusion:

Masvingo WTP had a treatment efficiency of 88% for BOD. The plant is overloaded by 10%. There is poor operation and maintenance characterised by higher concentration of nutrients being discharged into Mucheke which exceed EMA standards. Alternative wastewater treatment techniques requiring less technical expertise and operational costs may curb the problem of partially treated effluent into our waterways.

Key terms: **BOD_5, EMA , Mucheke , Wastewater Treatment Plant (WWTP**

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

Wastewater treatment in small towns of developing countries is increasingly becoming a priority issue (Add source). This is caused by accelerating urbanisation, and rapid population growth (Sperling, Verbyla and Oliveira, 2020). Generally a wastewater treatment plant consists of mechanical treatment, biological treatment and sludge treatment sections.(Mara, 2020). There are specific processes and unit operations in wastewater treatment which are chemical, physical or biological. Mainly in low-income areas of cities and towns within developing countries, a large proportion of wastewater is discharged directly into the closest surface water drain or informal drainage channel, sometime without or with very little treatment (Hernández-Sancho *et al.*, 2015). In addition to household effluent and human waste, urban-based hospitals and industries such as small-scale mining and motor garages, often dump highly toxic chemicals and medical waste into the wastewater system.

Urbanisation process generally leads to increasing loads of pollutants discharged into rivers by human activities, causing serious deterioration of the quality of the water in the river (which could turn black and odourous), and harming the surrounding environment as well as human health. Sewer systems, consisting of sewer collecting networks and wastewater treatment plants (WWTPs) are essential components of urban environmental infrastructure, for collecting, transporting and treating wastewater. Thus, the construction of sewer systems, especially sewer collecting networks, is important to control river pollution and to protect the water environment.

Developing countries are at different stages of urbanization, leading to many challenges in the development of sewer systems and river pollution control. In most of the least developed countries, the main challenge is that sewer systems are often absent, resulting in direct discharge of wastewater into rivers. In countries with rapid economic growth and industrialization, the challenges associated with the development of sewer systems and river pollution control are more complicated. For example, since the reform and opening up of China policy, the past four decades have witnessed rapid urbanization and sewer systems have been constructed, but the rehabilitation of urban rivers still faces huge challenges

Even in cities where wastewater is collected and treated, the efficiency of treatment may vary according to the system used. Traditional wastewater treatment plants may not remove certain pollutants, such as endocrine disruptors, which can negatively affect people and the ecosystem (Manhokwe *et al.*, 2018).Therefore, utilization of appropriate wastewater treatment systems tailored to a variety of microbial agents is essential to achieve as complete as possible elimination of biological agents. Wastewater is both a resource and a problem in an urbanising world (Bartram *et al.*, 2019). Unmanaged wastewater is an important source of pollution and a hazard for human health and ecosystems services (add source).

Centralised wastewater treatment systems do not meet local sanitation needs, are costly to maintain and requireexpertise (Manhokwe *et al.*, 2018). Existing WTPs in Zimbabwe, specifically Harare, are overloaded

1.2 Problem statement

Small towns of developing countries are faced with centralised wastewater treatment challenges (Beagles *et al.*, 2016). Aged wastewater treatment plants (WWTPs) are overloaded resulting in inefficient treatment (Mara, 2020).With the changing lifestyles, new resources are used to generate products and waste which may pass through the wastewater treatment system untreated, such as contaminants of emerging concern (Oliveira, 2020) Effluent laden with pollutants is often disposed of into nearby rivers . The Masvingo WWTP was commissioned in 1976 with a capacity to treat 7.5 mega-litres of wastewater per day (Manhokwe *et al.*, 2018). With increasing population and urban expansion, the plant currently generates nutrient-rich effluent (Tull, 2017). Its efficiency in treating wastewater in the face of urban expansion, growing human population and operational challenges were investigated.

Aim of the study

To assess the impact of urban expansion on wastewater treatment for Masvingo town, Zimbabwe.

1.3.2 Objectives

- To determine the treatment efficiency of Masvingo town WWTP using selected wastewater quality parameters
- To determine the suitability of surface disposal of effluent from Masvingo wastewater treatment plant using selected parameters.
- To compare the design and current wastewater treatment plant conditions for Masvingo WWTP

Significance of the study

Most studies have focused on the impact of rapid urbanisation on waste water treatment. Hence few studies have focused on the efficiency of removal of pollutants by the WWTPS in small towns such as Masvingo. Thus, sewer systems, especially sewer collecting networks, are overwhelmed by overpopulation that outstrips the capacity of WWTPs, are essential components of urban environmental infrastructure, for collecting, transporting and treating wastewater. The availability of data on wastewater generation is critical policy formulation and implementation for small cities like Masvingo. It also essential in crafting local environmental plans.

1.5 Hypothesis

H_O There is no significant difference between design and operating conditions, -treatment and surface disposal requirements

H_1 There is significant difference between design and operating conditions, treatment and surface disposal requirements

H_1 There is no significance different between treatment efficiency and current treatment efficiency

H_0There is a significance different between treatment efficiency and current treatment efficiency

H_1There is no significance difference between Effluent quality and national disposal limits

H_0There is a significant difference between effluent quality and national disposal limits

CHAPTER 2: REVIEW OF LITERATURE

2. Literature review

2.1 Introduction

Urban expansion is a multifaceted concept which includes the spreading outwards of a city and its suburbs to its outskirts in low-density and auto-dependent development. It has several direct or indirect environmental effects such as land occupation, car dependency, high per-capita use of energy and water, loss of time and productivity for commuting. This work intends to assess the impact of urbanisation on wastewater treatment, an additional environmental effect of urban sprawl on sewer infrastructure (as a first step for small and medium communities). This effect is discussed in relation to land topography and population density in terms of urban planning issues.

2.2 Wastewater infrastructure and urban growth

When and where sewer infrastructure is located is thought to influence growth patterns and thus the size, location and extension of sewer service areas are critical(Desye *et al.*, 2021). Recent examinations of land conversion processes suggest that sewer service area expansion greatly influences urbanization. Tian et al., (2018) in their study of suburban and rural residential development in Sonoma County, California, developed a spatially explicit model that emphasizes the role of municipal services (e.g. water and sewer) and zoning on land use change. They found that when water and sewer service areas were extended, the average probabilities that urban development would occur were very high, and there was an increase in the likelihood that development would be high-density. In the Maryland context, the presence of public sewer had a very positive effect on the hazard rate of conversion for developable parcels in Calvert County (Eerikäinen *et al.*, 2020).

Based on estimated hazard ratios, Eerikäinen et al., (2020)state, “the mean hazard rate of those parcels with public sewer, holding all other variations constant, was 363% greater than those without public sewer. Thus, just the provision of public sewer to a parcel increases the hazard rate of conversion by almost fourfold.” Similarly Roy et al., (2011), in their study of the effectiveness of Maryland’s Smart Growth policies, found that land inside the sewer service areas of selected counties in the state was more likely to be developed than land outside these areas. These studies suggest that growth is inextricably tied to sewer infrastructure. Akin to the connection between public sewer infrastructure and urban growth, some of the same land conversion studies have also found that utilization of on-site septic systems can lead to low-density, sprawl-like development. For instance, the McGrane, (2016)study found rural and exurban areas in Sonoma County received growth typically at lower densities than those areas close to the urban core. According to their findings, this lower density development was the result of the expansion of large lots with on-site septic systems and private residential wells.

The installation of on-site septic systems requires that residents set aside enough space to provide adequate drain field size for effective effluent treatment and disposal. These systems also need to be a safe distance from any nearby residential groundwater wells. Large lot sizes are the result. So, while urban development is likely to occur within sewer service areas, the lack of sewer does not necessarily thwart growth, especially the sprawl-like development government planners seek to prevent. This sprawl-like development can even occur within designated sewer service areas. For example, Deeba et al., (2020) found that large-lot residential development occurred within the Minneapolis Metropolitan Urban Service Area (MUSA) because of the availability of private septic systems and pre-existing groundwater wells

Centralised wastewater treatment.

Large-scale systems that gather wastewater from many users for treatment at one or a number of sites (Hernández-Sancho *et al.*, 2015).The treatment process (physical, chemical and biological) removes pollutants and organic matter from wastewater. The aim of this treatment is to produce an effluent (and sludge) with the appropriate quality to be released to the environment or re-used. The requirements for the treatment and effluent quality are established in the legislation of each country. WWTPs can include different levels of treatment: preliminary, primary, advanced primary, secondary and tertiary (Chirisa *et al.*, 2017).

In preliminary treatment, gross solids such as grit are removed since these materials may cause operational problems. In primary treatment, physical operations such as sedimentation remove floating and settleable suspended materials and a portion of organic matter. Primary treatment is intended to reduce oils, grease, fats, sand, grit, and settle-able solids. This step is done entirely mechanically by means of filtration and sedimentation. Chemicals can be added to enhance the removal of suspended and dissolved solids.

The secondary treatment is designed to substantially degrade the organic content of the sewage. In this secondary or advanced treatment step, very often microorganisms are used in the purification step. This biological treatment is an efficient method for the removal and reduction of both organic contaminants as well as for the reduction of the nutrient load. In this purification step, dissolved organic matter is progressively converted into a solid mass by using indigenous, waterborne bacteria. Several methods are being used in modern WWTP's, but the most common method in the Netherlands is conventional activated sludge (CAS). Activated sludge plants use a variety of mechanisms and processes to use dissolved oxygen to promote the growth of a biological floc that substantially removes organic material. It also traps particulate material and can, under ideal conditions, convert ammonia to nitrite and nitrate and finally to nitrogen gas.

In the final (tertiary) treatment step, the organic solids (sludge) are neutralized and then disposed or re-used. The treated water may finally be disinfected chemically or physically for example by micro-filtration or clarifier. The final effluent can be discharged onto a natural surface water body (stream,

Wastewater Treatment removal efficiency

The efficiency of waste water treatment process is defined as the ratio between removed concentration of polluting and their initial concentration(Garcia *et al.*, 2013). The removed efficiency of component in the system is given by the equation as

$$E_A = \frac{C_{A1} - C_{A2}}{C_{A1}} \cdot 100, \quad [\%]$$

where: CA1 is the mass concentration of component A at the system input [mg/l] and CA2 is the mass concentration of component A at the system output [mg/l] (Chinyama, etal 2016).Removal refers to the physical elimination of pathogens from water or wastewater. Often, pathogens removed are simply transferred to sludge or sediments, where they may still remain viable. The efficiency of waste water treatment is basic indicator of wastewater treatment plant (Beagles *et al.*, 2016). It depends on the amount and composition of waste water, on condition and type of sewer network, on producers, on used technical equipment and climatic and other conditions Von Sperling, (2015) focused on primary, secondary, and total efficiency evaluation of the wastewater treatment process for chosen small wastewater treatment plant (WWTP) located near the Moravian Karst. The results shows that the average value of BOD during the monitored period was 8.6 mg/l at the inflow to the primary level of WWTP and 5.6 mg/l at the outflow. The measured values do not exceed the allowable (25 mg/l) and maximum (62 mg/l) values at the outflow from the WWTP. The total efficiency of WWTP for BOD reducing was 34.1%. The permissible minimum treatment efficiency, determined for the discharge of waste water, must be at least 80% in the case of BOD (Rozkosny *et al.*, 2014).

EFFLUENT DISPOSAL AND DISCHARGE STANDARDS

Discharge of wastewater effluent to a water course or by irrigation is controlled by Government legislation, namely Section 39 of the National Water Act, 1998 (Act No. 36 of 1998). This is available from the Department of Water Affairs website and as it is periodically revised, it is advisable to access the latest version from the website. The latest version at the time of publishing this guide is provided below for ease of use. The Act specifies the volumes of wastewater effluent that can be irrigated to land, or discharged to a water resource daily, the volume being limited by the quality of the effluent and its impact on affected water resources, land, and health and safety of the population. Tables listing chemical, physical and bacterial limits are provided, together with a table of listed water resources. The special wastewater limits apply when discharging wastewater effluent to a listed water resource The Act also specifies monitoring frequency, analytical and record-keeping requirements, precautionary procedures and procedures for registering as a user with the Department of Water Affairs.

Wastewater parameters and the risk factors in urban environments

Wastewater treatment is designed to improve water quality to meet the specific safety and safety requirements of the wastewater after treatment. Different treatment processes reduce the concentration of pollutants in water. It reduces the content of suspended solids, whose molecules can contaminate the rivers and impede the movement of water in the channels and pipes after deposition. It also reduces the content of biodegradable organic matter, measured by the

Biological Oxygen Demand BOD (BOD) index. Treatment processes can also remove or neutralize many industrial pollutants and toxic chemicals. In principle, processes of industrial waste and toxic chemicals treatment should be carried out in the same industrial establishments, and should not be dumped in sewage sewers without treatment, and without complying with the regulations on the specifications of industrial effluents allowed in sewerage. In the area of wastewater management and treatment, we talk about three main levels of treatment, each of which involves a range of processes and targets a specific type of contaminant present in the water. There are those who talk about two additional processes, one at the beginning and one at the end, and the number of treatments becomes five.

Composed principally of proteins, carbohydrates, and fats, biodegradable organics are measured most common in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand). If discharged untreated to the environment, their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions. Pathogens are disease-causing organisms including bacteria and viruses that can be deposited in the wastewater through human or animal wastes, or from improperly handled hospitals wastes. Proper hygiene is extremely important when working around wastewater. Because the potential disease is so great, it is important that wastewater be treated and disinfected to inactivate the pathogens prior to discharge to the receiving stream. It is particularly important if the receiving stream is used for recreational purposes (e.g., boating, swimming and fishing) or as a drinking water source.

Waste water regulation in Zimbabwe

The Environmental Management Act (Chapter 20:27) and Statutory Instrument 7 of 2007 Environmental Management (Effluent and Solid Waste Disposal) Regulations govern effluent discharge in Zimbabwe. The Agency is guided by the licence classification criteria contained in the Third Schedule of Statutory Instrument 6 of 2007 Environmental Management (Effluent and Solid Waste Disposal) Regulations in issuing the effluent discharge licences and testing the parameters of the discharge as outlined in the Fourth Schedule of the Statutory Instrument. as follows.

Table 2.1 showing the S1 68 OF 2007 regulations by EMA in full

Classification of discharge	Risk associated with Environmental Hazard
Blue	Safe
Green	Low hazard
Yellow	Medium Hazard
Red	High hazard

: A blue licence in respect of a disposal which is considered to be environmentally safe;a green licence in respect of a disposal that is considered to present a low environmental hazard. A yellow licence in respect of a disposal; which is considered to present a medium environmental hazard; and a red licence in respect of a disposal that is considered to present a high environmental hazard.

Population Equivalent

Population equivalent (PE) is a measure of important parameter for characterising domestic wastewater. PE reflects the equivalence between the polluting potential of a municipal area in terms of the biodegradable organic matter and a certain population, which produces same polluting load. The formula for the calculation equivalent based on BOD is

$$PE(population\ equivalent) = BOD\ load\ from\ domestic\ sewer\ (kg/d)/percapita\ BODload(kg/inhab.d)$$

The pollutants per capita values can be used to estimate the present and the future pollution loading of wastewater produced from a population. These also are useful to estimate the equivalent population of an urban or industrial wastewater flow. By expressing the wastewater pollution in terms of per capita values, the concept of pollution would be more understandable for the citizens and policy makers

Summary

This chapter reviewed scholarly articles from the revered journals and published texts on waste water treatment. The methods for determining the efficiency through the percentage removal pollutants were outlined. SI 6 2007 on effluent standards will be the benchmark against the sewage load from the Masvingo city council. Characterisation of waste water parameters was interrogated at length.

CHAPTER 3:METHODS AND MATERIALS

3. Methods and materials

3.1 Description of the study area

Masvingo is located 292 km south of Harare, the capital city of Zimbabwe (Fig. 3.1). It is divided into high, middle and low-density suburbs. Domestic sewage is pumped to Masvingo Sewage Treatment Works (MSTW) for treatment and safe. The MSTW consists of a conventional trickling filter (capacity: 7.5 ML/d), and an Activated Sludge Treatment (AST) unit with a design capacity of 13.5 ML/d to give a combined capacity of 21 ML per day The sewage works cater for the whole urban community, which includes: domestic, industrial, commercial and institutional land-uses(Garcia *et al.*, 2013).They are located in the northeast of the city, not far from the Mutare highway and comprise two separate but complementary entities namely: the conventional trickling bio-filter and the biological nutrient removal (BNR) plants. The trickling plant was commissioned in 1976 with a capacity to treat 7.5 mega-litres of wastewater per day(Sen *et al.*, 2014).

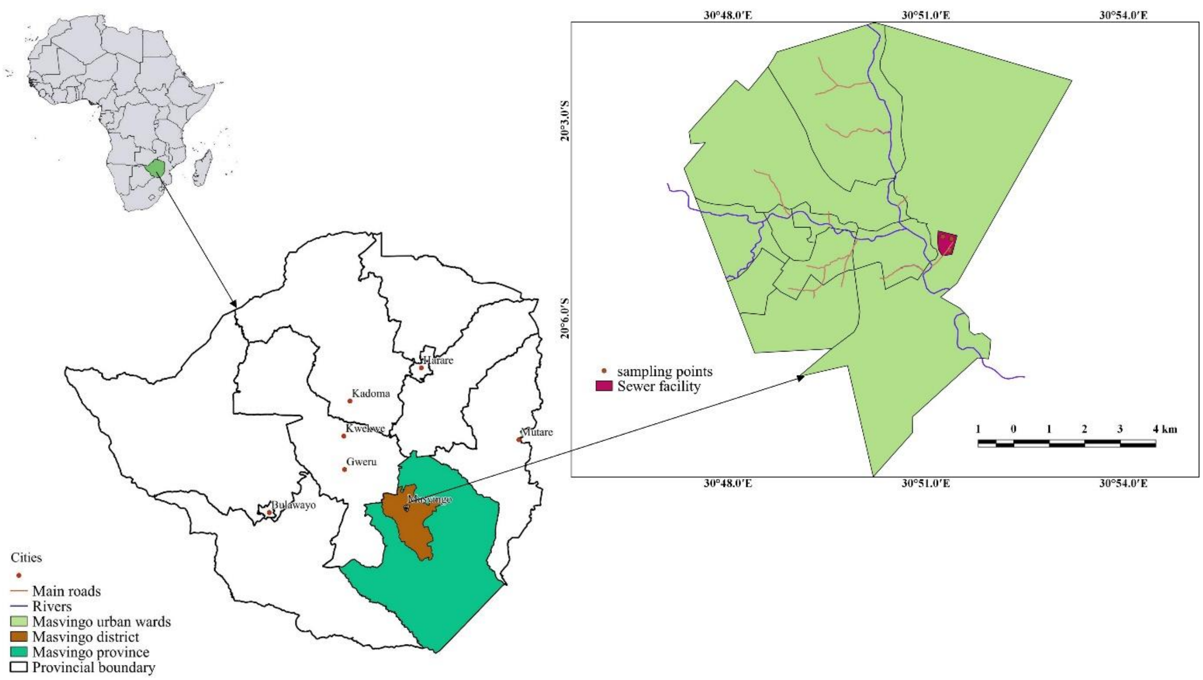

Fig. 3.1. Map showing the location of Masvingo town and the WWTP

3.2 Research design

According to Mary (2009), experimental research designs are the primary approach used to investigate causal (cause/effect) relationships and to study the relationship between one variable and another. For example, if a cardiology student conducts experimental research on the effect of eating junk food on cholesterol and conclude that most hear patient have diabetes then there are aspects (causes) which can cause heart attack (effect).Garcia et al.,(2013) outline that research design is a blueprint utilised in fulfilling the research questions and objectives of a study being undertaken. In addition Chinyama etal (, 2016) explained that a research design is a tool that is used to describe the arrangement of the parameters for collection and analysis of data. The quantitative experimental research design was very suitable for this research since this allowed the researcher to have quantitative evidence of the impacts urban expansion had on the WWTP particularly focusing on the present wastewater parameter reducing capacity of the plant against its historical performance. It was very logical to take this direction of analysis especially given the scope of this study. The design was appropriate for this study for the reason that it provided a thorough and comprehensive inquiry on the subject under study.

3.3 Sampling details

3.3.1 Selection of wastewater quality parameters for measurement

This research study investigated the implications of urban expansion on restructuring on domestic wastewater treatment particularly paying attention to all the key components in wastewater treatment according EMA standards derived from the S.I 6 of 2007.A total of eight wastewater quality parameters were selected for this study as they are key parameters in wastewater treatment. Selected parameters include temperature, pH, settleable solids, turbidity, ammonia, nitrates, phosphates and biochemical oxygen demand. Each of these parameters was selected because they are key in establishing the efficiency of operation of the plant. Selection of parameters information on influent and effluent is useful for supporting influent wastewater characteristic fractions and for determining influent inorganic solids which impact on sludge production (Beagles *et al.*, 2016)

3.3.2 Establishment of sampling points on the WWTP

The Masvingo WWTP has ten unit operation inclusive of both the conventional and AST plant. These unit operations are as follows:

- Feed inlet
- Grit Channel
- Biological Nutrient Removal Unit
- Clarifiers
- Sludge Thickeners
- Cascade (flow to river)
- Primary setting tanks
- Bio-Digesters
- Bio-Filters
- Holding Ponds

Based on the requirement of this study, outlets of the plant thus cascade and holding pond and the inlet to the plant were selected as sampling points for this study as they gave an overview of the treatment efficiency of the plant. Sampling was done at the inlets to these sampling points in order to obtain a fresh sample of the treatment so as to obtain a true representation of the treatment at the plant.

3.3.3 Sample collection, preparation and preservation

The samples were collected, between 29 May and 4 June, 2022 from the Masvingo WWTP established sampling points following procedures of water and wastewater treatment (APHA 2005) Plastic bottles were utilised for sampling after being thoroughly washed with soap and rinsed. The Composite sampling method was selected as the best form of sampling because wastewater treatment is a continuous process hence in order to obtain a representative sample, a number of samples had to be collected at each sampling point in intervals (add source). A sample was taken after every 1 hour, collecting a litre of water each time. Sampling was done at the feeding inlet, holding pond and the Cascade. A 1 litre bottle was used to collect sample after collecting water at these points, the 5 samples for each point were mixed to make up a composite sample of 5 litres for each point. The samples were closed by not closed tightly to allow for air movement so as to preserve microbes in the sample. The samples were then refrigerated to slow down reactions in the samples.

3.3.4 Sample measurement

The samples were measured according the according to APHA (2005). The samples were removed from the refrigerator to allow them to reach room temperature before testing was started. The following parameters were tested for in each sample see appendix 1. Standard Methods of analysis for water and wastewater testing according to APHA/AWWA (2005) were used in the laboratory to determine the physiochemical concentrations of the selected parameters from the collected waste water samples (Table 3.1) were used to determine the mean concentration values of the parameters at each sampling point.

Table 3.1 Analytical techniques used for wastewater sample analysis (APHA, 2005)

Wastewater quality parameter	**Analytical method used**	**Equipment/Apparatus**	**Reference**
Turbidity	Turbidimetry	Turbidity meter – AWSX 35 model, Sedjc, USA	APHA 2005 Method 1020B
Ammonia	Ammonia test Titrimetric Method	Hydro test Ht 1000	(APHA).2005 4500-NH3
Nitrates	Nitrate Test	Spectrophotometer	4500-NO3 – ALPHA (2005)
Temperature	Depth Temperature Measurements	thermophone,	ALPHA 2005 2550
Settable Solids	Volumetric analysis	Imhoff cone.	ALPHA 2540 F
TDS	Gravimetric determination	Filtration apparatus	ALPHA 2005 2540 C
BOD_5	BOD Test	Incubation bottles:	ALPHA 2005 5210 C.
Ph	pH value	Ph meter	APHA (1998) section 4500-H+

3.5 Quality control procedures

Laboratory duplicates or matrix spike duplicates (MSDs) were be used to assess precision and were be analysed. A laboratory duplicate is an aliquot of the same sample, while an MSD is a second MS of the same sample (Add source). For ammonia, nitrate and phosphates, a serial dilution was performed to assess the accuracy of the analyte measurement. A serial dilution for analytes with concentrations that approach the upper limit of the linear range. The serial dilution was on the same sample as the MS analysis. This will enable the assessment of the accuracy of the analysis when spike concentration is insufficient for the analysis due to the high analyte concentration in the sample. Describe what was done as quality control procedures and explain or justify why it was done.

3.6 Statistical analysis

The analysis of variance (ANOVA) was used to determine the variation of wastewater quality parameters and Tukey post hoc was used to separate treatment means. All data were tested for normality using a Kolmogorov-Smirnov test and were found to be normally distributed thus a parametric ANOVA test was used. Mean values across the different sites were tested for deviance from the WHO standards using a one-sample t-test. All data were analysed in R version 4.1.1 and agricolae (version 1.0-2 at 5% level of significance in all cases.

CHAPTER 4: RESULTS

Table 4.1 Variation of wastewater quality across sampling sites at Masvingo WWTP, 2022 (one-way ANOVA and Tukey post hoc)

Parameter	Holding Pond (mean ± SD)	Inlet (mean ± SD)	Cascade (mean ± SD)	$F_{2,6}$	P value
Temperature (°C)	22.17±3.01[a]	22.67±2.52[a]	22.17±2.36[a]	0.04	0.965
pH (pH units)	7.02±0.19[a]	6.92±0.10[a]	7.13±0.10[a]	1.68	0.263
TDS (mg/l)	1279.33±141.31[a]	2029.33±410.70[b]	463.33±136.57[c]	26.63	0.001
Ammonia (mg/l)	113.63±26.84[a]	266.90±52.37[b]	15.10±3.12[c]	41.73	<0.0001
Phosphates (mg/l)	382.33±6.03[a]	140.00±10.44[b]	1.07±0.24[c]	2304.1	<0.0001
Turbidity (NTU)	171.33±37.53[a]	701.33±155.69[b]	20.60±5.77[c]	44.8	<0.0001
Nitrates (mg/l)	145.93±209.84[a]	14.17±8.52[b]	25.73±8.52[b]	11.08	0.019
Settleable solids (ml/l)	1.00±0.92[a]	4.77±1.70[b]	ND	15.23	0.004

[a,b] Means with different superscripts in the same row are significantly different at 5% level of confidence (Tukey post hoc). ND-Not detected

Table 1 indicate that There was a significant difference (P<0.05) in the concentration of all parameters except for temperature and pH. The following parameters had significantly higher concentration at the inlet than the other sites: TDS (2029.33±410.70 mg/l), Ammonia (266.90±52.37 mg/l), turbidity (701.33±155.69 NTU) and settleable solids (4.77±1.70 ml/l). Phosphates (382.33±6.03 mg/l) and nitrates (145.93±209.84 mg/l) were significantly higher at the holding pond than the other two sites. Settleable solids were not detectable at the cascade (Table 1) , see also appendix 1

4.2 Comparison of treated effluent for disposal with national (EMA, 2007) discharge limits

Table 4.2 Comparison of treated effluent for disposal with national (EMA, 2007) discharge limits (one- sample student t- test)

Parameter	**Effluent quality (mean ± SD)**	**$F_{2,6}$**	**P value**	**EMA standards**
Temperature (°C)	22.17±2.36[a]	0.04	0.965	<25
pH (pH units)	7.13±0.10[a]	1.68	0.263	0-4
TDS (mg/l)	463.33±136.57[c]	26.63	0.001	≤5-6
Phosphates (mg/l)	15.10±3.12[c]	41.73	0.0001	≤0.15
Turbidity (NTU)	1.07±0.24[c]	2304.1	0.0001	≤5
Nitrates (mg/l)	20.60±5.77[c]	44.8	0.0001	<10
Settleable solids (ml/l)	25.73±8.52[b]	11.08	0.019	<3
Ammonia	ND	15.23	0.004	≤2.0
BOD_5	47	21.6	0.001	≤30

Bold means are significantly different from the EMA standard (one sample t-test, 5% level of confidence]

Tables 2 indicate that there was no significant (P>0.05) difference between temperature, Ph, Settleable solids and EMA standards. The mean effluent quality of Temperature 22.1, TDS

463.33 (mg/l) and Settleable solids 25.73 (ml/l) were within the recommended limits of the S.I 6 of 2007. Hence there was a significant difference (P>0.05) between Ammonia, Nitrates, Turbidity (NTU), BOD_5 and Phosphates (mg/l) and the EMA effluent standards, hence they were outside the recommended range.

Table 4.3 Wastewater treatment efficiency of Masvingo WWTP during the study period (27 to 4 June –, 2022)

Wastewater quality parameter	Concentration of wastewater quality parameter (mg/l)			
	Raw (inlet)	**Treated effluent**	**Difference**	**% Treatment efficiency**
BOD	319	47	272	85.2
settable solids	4.7	0	4.7	100
Nitrates	14.1	25.7	-11.6	-81.6
Phosphates	140	1	139	99.2
Ammonia	266.9	15.1	251.8	94.3
Temperature	22.6	22.1	0.05,	2.2
TDS	2029.	463.3,	1626	77.1
Ph	6.9	7.13	1.8	2.9
Turbudity	701.3	20.6	680.7	97

Table 3 shows inlet values shows a variation, and a reduction at the cascade. Settable solids are completely reduced by 100% eliminated within the plant, Ph has a efficiency removal of -

2.98507 %, phosphates with 99.2 %, Nitrates with -81%, BOD_5 with 85.2 %, TDS with 77.1 %, Ammonia 94% and Temperature with 2.2 %. Denitrification is a biological process and is therefore dependent on the wastewater temperature.

4.Population equivalent

According to the estimated population of Masvingo city for 2022, the population is approximately 110 000 people. Therefore, since research conducted on wastewater by Germany scientists, average BOD for 1 person was found to be 54g BOD/day. According to historic data from the WWTP, the plant receives an average of 21 Ml/day of water hence the theoretical BOD is calculated as shown below:

54gBOD/day = 54 000mg/day

21Ml/day = 21 000 000l/day

$$BOD\ Average = \frac{\frac{\frac{BOD}{Person}}{day} \times no\ of\ people}{quantity\ of\ wastewater}$$

$$= \frac{54\ 000 \times 110000}{21000000}$$

$$= 282.86mgBOD/l$$

The above value of theoretical BOD deviates from the experimental average value by 11.3%.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter focuses on the discussion of results of experiment conducted on wastewater at Masvingo WWTP and explanation for the results is outlined and conclusion on the study is given in the chapter.

5.2 Table 4.1 Variation of wastewater quality across sampling sites at Masvingo

The results indicated that, temperature and Ph did not vary significantly in the inlet, holding pond and the cascade. Rabbi *et al.*,(2018) argues that alkalinity is a measure of buffering effect of wastewater against Ph changes. The inlet had a Ph of 7.13±0.10 the holding pond had 6.92±0.10[a] and 7.13±0.10. The effluent during the three sampling periods shows that the wastewater alkalinity was adequate to offset any pH drops. The results suggest that the wastewater had enough buffering capacity to maintain the pH at the desired range for bacterial activity in the holding pond. However, a pH of 7.9 is outside the optimal range for denitrification (Prasse *et al.*, 2015). This is desired since the best pH for nitrification is 7.8 to 8.2, which is higher than most plants are normally (Hernández-Sancho *et al.*, 2015).The results for solids indicate a significant reduction at the Cascade , which reflect a pre-treatment process that remove solids via sedimentation , as well as settling of waste to the surface of the filter. This line with the findings of Shakir, (2017) who observes that removal of the solids in the activated sludge is due use of properly sized filter media and availability of underground facilities that facilitate the removal of solids that pass the filter bed. The results also show the significant reduction in the presence nutrients, throughout the treatment process. One of the key functions of the Waste water treatment facility is to remove organic matter from waste water. Reduction in BOD, nitrates and phosphates at the cascade shows that the trickling filters are efficient in removing microbes in water before they can be discharged into the nearby Mucheke river. Phosphates were significantly higher at the holding pond than the other two sites.These values were expected to be high at the holding pond since the objective of the conventional plant is to enrich wastewater for irrigation purposes. However, the presence of ammonia in large quantities of shows the inefficiency of the trickling biofilters to effectively oxygenate the ammonia to nitrate hence the conventional plant is not very effective in nutrient enrichment (WHO,2012). Levels of BOD of 141mg/l in the holding pond make the enriched water not suitable for irrigation as it promotes denitrification in the soil when used for irrigation .

Comparison of treated effluent for disposal with national (EMA, 2007) discharge limits

Phosphates, Nitrites, BOD and Ammonia were significantly ($p>0.05$) different from the S.I 6 of 2007 guidelines, hence we reject the null hypothesis whilst temperature and Ph were within the permissible range in the green category. These parameters were all not within national guidelines for waste disposal as these parameters are in the yellow band. Scott (2018) argues that the inefficiency of the BNRP plant can be attributed to the waste having inadequate retention time for processing as the amount of load has since increased with increase in population .as such the plant no longer reduces these parameters effectively despite the amount of water at the plant being constant. The increase in the amount of BOD because of urban expansion due to increase in individual contribution to waste being treated at the plant. The higher concentration of nitrates being discharged into the Mucheke river at 20.60 mg/l against <10 mg/l expected standard from EMA pose environmental health risks. The effects of nitrogen discharges from wastewater treatment facilities include ammonia toxicity to aquatic life, adverse public health effects, and decreased suitability for reuse.(Manhokwe *et al.*, 2018).The concentrations of the phosphates at 15.10±3.12 exceed the EMA standards ,<0.15 ,which might have an impact on aquatic environment of the Mucheke river and downstream users. The presence of nitrates and phosphates has a negative on oxygen levels hence agal booms. Oxygen levels take a dive as a result of too much phosphorus.

5.3 **Wastewater treatment efficiency of Masvingo WWTP during the study period (27 to 4 June –, 2022)**

As observed from the results, the efficiency of the plant to reduce nutritional parameters in wastewater is very high with most parameters being reduced to over 88%. However, with high efficiency in parameter reduction in the ASTP, parameters ado not fall under the blue band for effluent disposal hence in overall performance the plant is ineffective in disposing water which meets EMA standard guidelines for disposal in the blue band. The efficiency of the ASTP is 10% with regards to meeting EMA guidelines since parameters such as temperature, pH and settleable solids were within EMA guidelines with all other parameters tested at the cascade. In terms of nutrient enrichment presence of high amounts of ammonia in the holding pond is an indicator of inefficiency and the conventional plant is 87% effective in nutrient enrichment for irrigation. The dwindling efficiency of the plant is accredited to urban expansion since the plant design has to cater for a population size which has doubled since the setup of the plant in 1997 (Mapira, 2011). Due to the increase in population the plant is handling a doubled value of nutritional content as a results the plant performance will continue to reduce in efficiency with the continuous growth of the city (Mapetere, Chigonda, & Charizeni, 2019).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6. Conclusion and recommendations

6.1 CONCLUSION

A single short paragraph. Summarise the results in view of the title, objectives and results. What take-home message can you give from the study? What is novel about the study? Comment on the generalisability of findings. Suggest one area fo further research as informed by your results!

The broad scope of the study was to assess the implications urban expansion had on the efficiency of treatment of wastewater on Masvingo WWTP. Experimental research conducted on the wastewater was documented and analysed in chapter four and five. The results showed that the specific objectives outlined in chapter one were achieved.

In conclusion the study showed that the WWTP was disposing water which did not meet WHO guidelines at the cascade since the ASTP plant is expected to release water which falls under the blue band for waste disposal. However despite the parameters not falling within the blue band and operating in the yellow band, the ASTP was highly efficient in reducing wastewater parameters with most parameters having 88% and above efficiency in parameter reduction.The conventional plant had 87% efficiency in nutrient enrichment but however there was high presence of ammonia and BOD in the holding pond which indicated the gradual failure of trickling biofilters in oxygenation of wastewater for irrigation.

The purpose of this study was to assess the implications of urban expansion on wastewater treatment and it can be concluded that urban expansion has had great impact on the treatability of wastewater which has resulted in the treatment plant being incapable of producing water that meets WHO guidelines for waste disposal.

6.3 RECOMMENDATIONS

ONLY recommend based on the results, not speculations.

Suggest at most 3 recommendations as bullets (not numbered)

Based on the research results of this study the following recommendations will be proposed to reduce the concentration of parameters to W.H.O guidelines.

1. Engineers must find a way to increase retention time of wastewater at the plant in order to give the plant more time to process the wastewater which now has higher concentration than when the plant was commissioned.

2. Engineers must design pretreatment processes which will reduce the treatment load on the wastewater treatment plant to increase its efficiency.

3. Council needs to consider expansion of the plant in order to meet the increased load of organic matter being received at the plant in order to facilitate effective waste treatment.

4. Council should consider building another treatment plant so as to share the burden of treatment between the two plants such that the existing plant starts processing waste that it originally processed upon its commissioning.

5. Council must enforce installation of pretreatment facilities in all industries to reduce treatment burden on the wastewater treatment plant.

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Appendix 1 Test Procedures

Temperature and Total Dissolved Solids

100ml of sample was measured using the 100ml measuring cylinder and poured into the 250ml plastic beaker. The Hydrotest electrode cap was removed and washed with distilled water to remove foreign material from the electrode. The electrode was then inserted into the 250ml beaker. Temperature and TDS reading were taken down when values stabilised.

Figure 1 EC meter model? Company, country?

pH

The pH meter electrode was first washed in distilled water, then calibrated using pH standards 4, 7 and 10 in order to standardise the test. After calibration the samples were tested by dipping in the sample and waiting for the pH value to stabilise.

Figure 2 pH meter

Settleable Solids

Water samples were inverted 6 times before pouring 1 litre to the mark in the Imhoff cone. Once all samples had been poured into the imhoff cones, the stop watch was started and an alarm to ring in 45 mins was set. After 45 mins the imhoff cones were gently stirred at the top to loosen material that would stuck to the war of the imhoff cone. After an hour readings were taken of the settled solids.

Turbidity

After inverting the wastewater a sample of water was pipetted into the turbidmeter cuvette to the mark of the cuvette. By carefully handling the cuvette at the top, the cuvette was wiped clean and inserted into the turbidmeter and the “enter” key was pressed. The reading for turbidity was read and taken down in NTU units.

Ammonia

Test tube was filled with sample to the 10 ml mark. One Ammonia No 1 tablet and one Ammonia No 2 tablet were added, crushed and mix to dissolve. Sample was allowed to stand for 10 minutes to allow for colour development. The ammonia test was selected to give concentration of ammonia in mg/l.

Figure 3 Ammonia test

Nitrates

The Nitratest Tube was filled with sample to the 20 ml mark. One level spoonful of Nitratest Powder and one Nitratest tablet were added to tube without crushing. Screw cap was replaced and tube was shaken well for one minute. Tube was allowed to stand for about one minute then gently inverted three or four times to aid flocculation. Tube was allowed to stand for a further three more minutes to ensure complete settlement. Screw cap was removed and wiped around the top with a clean tissue. The clear solution was carefully decanted into a round test tube, to fill to the 10 ml mark. One Nitricol tablet was added, crushed and mixed to dissolve and allowed to stand for 10 minutes. The appropriate test was selected, blanked and test was done.

Figure 4 Nitrate Test

Phosphates

Test tube was filled with sample to the 10 ml mark. One Phosphate No 1 LR tablet and one Phosphate No 2 LR tablet were added, crushed and mixed to dissolve. Sample was allowed to stand for 10 minutes to allow for colour development. The phosphate test was selected on the photometer to check concentration of the phosphate in the sample in mg/L.

Figure 5 Phosphate Test

Biochemical Oxygen Demand

BOD bottles were labelled (1 and 5) and placed on the desk. 2ml of feed was placed in the appropriate bottle and 10ml of cascade and holding pond water was placed in their appropriate BOD bottles. BOD bottles were filled with dechlorinated dilution water the top. BOD bottles. Bottles labelled BOD 5 were placed in the incubator for 5 days at 20^{o}C.

Dissolved oxygen DO_1 and DO_5 were tested by adding reagents in the following sequence:

1. 0.7ml concentrated sulphuric acid
2. Add 1ml of potassium permanganate (invert for complete mixing and left for 20mins

Figure 6 BOD bottles with potassium permanganate

3. 1ml potassium oxalate
4. 3ml alkali iodide
5. 1m manganous suphate (precipitate will form and is let to stand for 5 mins)

Figure 7 BOD bottle with precipitate forming ????

6. 1.5ml concentrated sulphuric acid.

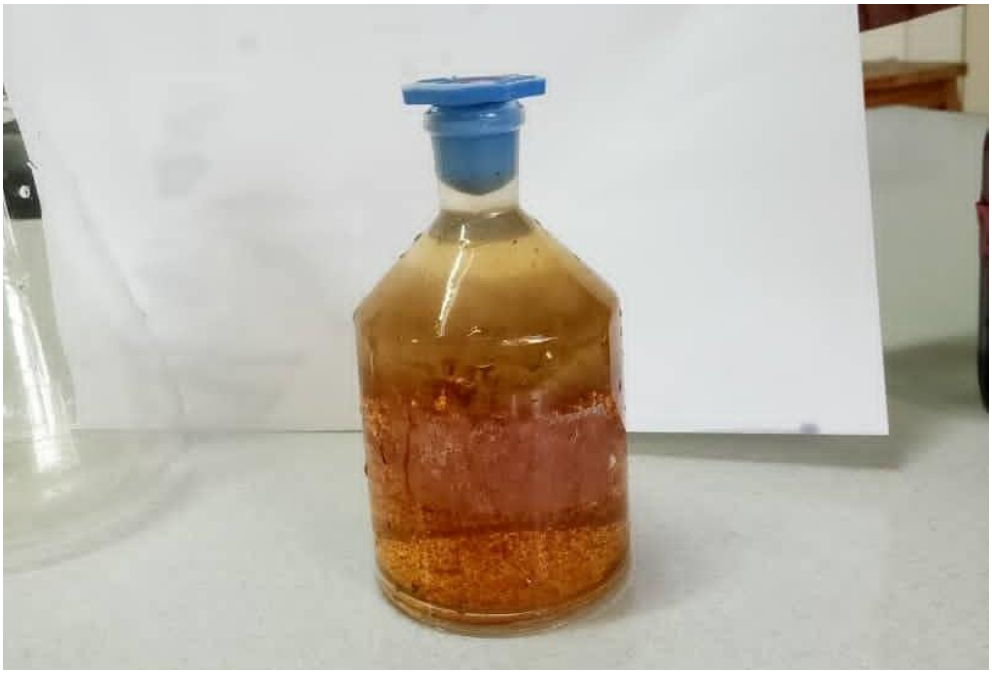

Figure 8 BOD bottle after acid addition   ADD DETAILS!

The solution was then titrated with sodium thiosulphate using starch as an indicator.

Figure 9 Starch being added during titration