# The Effectiveness of Waste Stabilization Ponds in the Treatment of Citrus Processing and Sewage Effluent

## The Case of Mazowe Citrus Estates, Zimbabwe

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## Abstract

This paper discusses the effectiveness of waste stabilization pond systems at Mazoe Citrus Estates in the treatment of citrus processing and sewage effluent. Water samples from the river were collected and analysed for the same parameters as pond water. This was done to establish any changes in river water quality as a result of the discharge or seepage from the pond system. Samples were analysed for electrical conductivity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrogen total and total phosphorus as well as pH tests. The results showed that pH did not comply with the Zimbabwe National Water Authority (ZINWA) standards. COD, nitrogen total and total phosphorus levels were abnormally high, with some reaching 400 mg/L, 30 mg/L and 9mg/L respectively, exceeding the ZINWA red bands limits. This implies that the effluent presented significant risks of water pollution and environmental damage. The results conclusively indicated that waste stabilisation pond systems are not effective in the treatment of citrus processing and sewage effluent.

### Introduction

Waste stabilization ponds are holding tanks used for the secondary treatment of water through decomposition of organic matter by microbiological activity. A waste stabilization pond system consists of anaerobic, facultative and maturation ponds. The number and type of each pond and arrangement of the system is determined by the nature of effluent under treatment and the quality required after treatment.

Waste stabilization ponds are generally regarded as one of the most effective treatment technologies for high organic wastes if designed and maintained properly. According to Ramadan and Pounce (2004a), suitability and reliability of waste stabilization ponds as a treatment system has been recognized since the eighteenth century and have been adopted by many developed and developing countries for effective and efficient treatment of wastewater, especially domestic sewage

At Mazoe Citrus Estates (MCE), a waste stabilization pond system is used for treating the citrus and sewage effluents. Quantity and quality of the citrus effluent varies seasonally due to weather changes and citrus fruit availability. Cyclones, which have resulted in abnormally high rains have resulted in overflows form the ponds into the waste stream which then discharges directly into Mazoe River.

According to an Environmental Audit report dated September 1998, it was found that effluent from the waste stabilization ponds system was polluting Mazoe River and a threat to groundwater zones which have not yet been mapped. Gratwicke (1999) used biomonitoring techniques to assess the water quality of Mazoe River and found out that there was a significant decrease in the aquatic fauna populations after discharge of effluent from the ponds, resulting from discharges from the waste stabilization pond system discharge into the river.

## Statement of the problem

According to Kimball (1999), citrus processing effluents are acidic and require effective treatment to minimize and prevent environmental pollution. Sedimented sewage contains dissolved organics, heavy metals, soaps, detergents and various other chemical which when combined with citrus effluent has the potential of causing severe pollution. This means citrus processing and sewage effluent are problematic to the environment and their treatment using stabilization ponds ought to be investigated.

### Justification

Environmental Management Act (1998), Part (ix), Section 70.1 states that “No person shall discharge or dispose any waste, whether generated within or outside Zimbabwe in such a manner as to cause pollution to the environment or ill health to any person”. Part (ix) of Section 70.6 of the same act also states that “Every person whose activities generate waste shall employ measures essential to minimize waste through treatment, reclamation and recycling”. Likewise, the Water Act [CHAPTER 20:24] (1998) Part (vi)Section 68.1 states that “ …any person who discharges or disposes of any organic matter or inorganic matter including water containing such matter into a public stream or into any other surface or ground water, whether directly or indirectly or though drainage or seepage … shall be guilty of an offence, whether or not he acted intentionally and whether he was negligent or not…” Considering these pieces of legislation and the need to implement an effective ISO 14001 certified environmental management system, it is imperative to conduct a study to establish the effectiveness of the waste stabilization ponds as a wastewater treatment technology.

### Aim

The aim of the study is to investigate the effectiveness of waste stabilization ponds in treating citrus plant processing and sewage effluents at Mazoe Citrus Estates(MCE).

### Objectives

The specific objective was

- To determine the pH, electrical conductivity, BOD, COD, nitrogen total and total phosphorus of pond and river water so as to establish the effectiveness of waste stabilization ponds in treating citrus processing and sewage effluent.

## Research Methodology

The waste stabilization pond system is located about 200m to the west of both the citrus factory and the employee residential village 2. The system consists of nine triangular and rectangular ponds arranged as shown in Figure 1.1. All the dams have almost the same depth even though amongst them some differ slightly in length and width. This therefore makes it difficult to distinguish between the pond types such that almost all the ponds are considered to perform the same functions. The ponds are not lined at the bottom to minimize seepage into groundwater zones. Effluent from all the ponds flows by gravity and seeps into the river . Therefore it is imperative to average the effluent parameters from all the nine ponds since the effluent is considered to mix before seeping into the river. A special type of reed of the phragmite species has been seeded in the ponds to facilitate reduction of nutrients.

### Sampling

Samples were collected using sterilized 750ml polyethylene plastic bottles. Composite samples were obtained from a total of five samples per pond from five different designated points. Each pond was divided into five almost equal sections from which a sample was collected from each section at random, which were then mixed to make a composite sample.

### Sampling Points

Twelve samples were collected from the points shown in figure 1.1 at the investigation site:
one meter before effluent mixture was discharged into the first anaerobic pond. The sample collected from this site is labeled dam 0. Four different points were selected at random and the already designated sampling point in all ponds. The existing designated points are as follows: exit points from dam 1-5, and designated points in dams 6-9. Samples collected from these sites are labeled dam 1 to 9 respectively. The five sub-samples per pond were mixed to come up with two 750ml composite samples, which are then analyzed as duplicate samples. The results are given as an average of the two duplicate samples.

### Sampling Procedures

*Sampling from dam 1 -9*

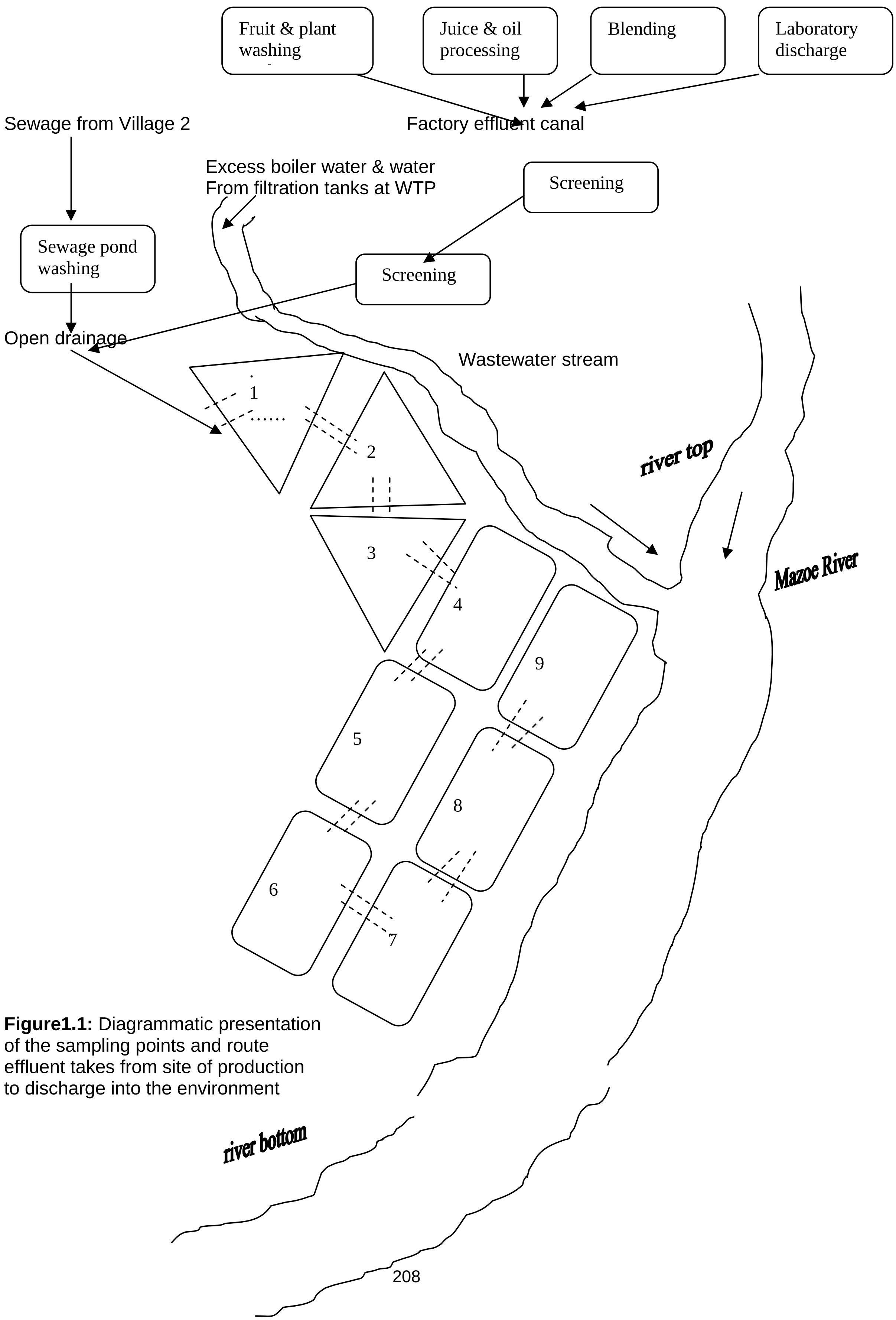


**Figure1.1:** Diagrammatic presentation of the sampling points and route effluent takes from site of production to discharge into the environment

A 750ml bottle was rinsed in the effluent to be sampled. The bottle was totally submerged in the water to a depth of 30-50cm. After 10 seconds, the bottle was tightly closed before it was brought to the surface. Four more samples were collected from the same pond and mixed to obtain two duplicate samples.

*Sampling the raw effluent and river water*

A 750ml bottle was rinsed in the water to be sampled. The bottle was then directed to the direction from which the water was flowing. The bottle was closed soon after filling to the brim.

**Sample Analysis**

As required by Operational Guidelines for the Control of Water Pollution in Zimbabwe, 2000, standard methods for the examination of water samples were used. Samples were analyzed for electrical conductivity BOD, COD, Nitrogen total and total phosphorus.

The pH measurements were conducted shortly after sample collection. The methods used in the analysis s of all the parameters are summarized below :

**pH Measurement**

A glass electrode pH meter (704 Metrohm) was first calibrated using a buffer solution. The probe was dipped into the effluent sample and readings were taken.

**Electrical Conductivity Measurement**

A glass electrode Conductivity meter was first calibrated using a standard buffer solution. The probe was dipped into an effluent sample and the reading was noted.

**Determination Of Biochemical Oxygen Demand (BOD)**

Dissolved Oxygen (DO) was determined 15 minutes after sampling and repeated after 5 days of incubation period at $20^{O}C$ in the dark.

**Determination Of Dissolved Oxygen**

A 0.7ml of concentrated $H_2SO_4$ was added to 300ml of diluted effluent sample. These were mixed and 1ml of 0.025N $KMnO_4$ solution was added until the mixture turned pink. 1.0ml of 0.05N Potassium Oxalate solution was added until the solution turned colourless. 3ml of 0.015N alkaline KI solution and 1.5ml of concentrated $H_2SO_4$ were added to the solution. 1ml starch solution was then added and the solution was titrated with 0.025N $Na_2S_2O_3$ solution to final disappearance of the blue colour. The BOD was then computed according to the equation

$$BOD = \frac{(X - Y - az)(a + 1)}{a + 1} \text{ mg/l}$$

Where $X$ = ml of 0.025M $Na_2S_2O_3$ used before incubation

$Y$ = ml of 0.025M $Na_2S_2O_3$ used after incubation

$a$ = Volume of dilution used to 1ml of the sample

$z$ = $Na_2S_2O_3$ equivalent to $O_2$ consumed in the system

**Determination Of COD**

5ml of sample was pipetted into a 100ml flask (A) and filled to the mark with distilled water. 5ml from A were pipetted from each volumetric flask into separate boiling flasks fitted with condensers for refluxing. 15ml of distilled water were then added to each boiling flask. The first blank solution was prepared by adding 20ml of distilled water to a separate boiling flask. 10ml of dichromate was pipetted to each boiling flask and to another empty flask, which was then filled to the mark with distilled water (second blank). This second blank was used to standardize the FAS solution. 30ml of concentrated sulphuric acid was added to each flask using a graduated cylinder and heated to boiling and reflux for 2hours. The flasks were cooled to room temperature and each solution was titrated with the FAS solution. The solution turned green from the production of the chromic ion and then a blue colour appeared. Just before the end-point the solution turned gray and then a red colour developed which indicated the end-point. The normality of the FAS is determined from titrating the second blank and is calculated as follows:

$$N_{FAS} = \frac{(\text{10ml of dichromate}) \times (\text{0.25N dichromate})}{\text{ml of FAS titrated}}$$

$$\text{i.e. } N_{FAS} = \frac{\text{vol (dichromate)} \times \text{conc.(dichromate)}}{\text{vol (FAS) (in ml)}}$$

The COD was then calculated according to the equation

$$COD = \frac{(N_{FAS})(8000)(\text{ml of } FAS_{1st\ blank} - \text{ml of } Fac_{simile})}{\text{0.5ml of sample}}$$

**Determination Of Nitrogen Total (As N) – Kjedjal Method**

100ml of sample was placed in a 200ml long necked flask and 3g of anhydrous sodium sulphate, 0.3g of nitrogen-free mercuric oxide and a few drops of nitrogen free sulphuric acid were added. The mixture was heated over a small flame until it was colorless. It was boiled gently for a further 2 hours (Note: precautions were taken to prevent the upper part of the flask from overheating). The heated mixture was cooled to room temperature and diluted to 75-85ml with distilled water. A piece of granulated zinc, a solution of 15g of sodium hydroxide and 2g of sodium thiosulphate in 25ml of distilled water were added while shaking the flask and immediately the flask was connected to a distillation apparatus. The liberated ammonia was distilled into 20ml of 4% w/v solution of boric acid. The distillate was then titrated with N/10 sulphuric acid using methyl red as indicator. The operation was repeated using a blank.

Calculations

Ammonia $liberated_{sample}$ = $titre_{sample}$ - $titre_{blank}$

Each ml of N/10 sulphuric acid is equivalent to 0.001401g of nitrogen.

**Determination Of Total Phosphorus (As Phosphorus)**

Standards supplied by authorized suppliers were first run on the U.V. Spectrophotometer before the effluent samples were run. 10ml of raw sample were pipetted into a conical flask and 50ml of deionized water were added. 10ml of the diluted sample was pipetted into a conical flask, and 1ml potassium molybate was added with shaking. 1ml stannous sulphate was added with mixing. The sample was poured into the cell of the U.V. Spectrophotometer and the reading taken.

## Results

Figures 1.2 to 1.13 are graphical presentations of results in which pond water parameters are compared with ZINWA limits.

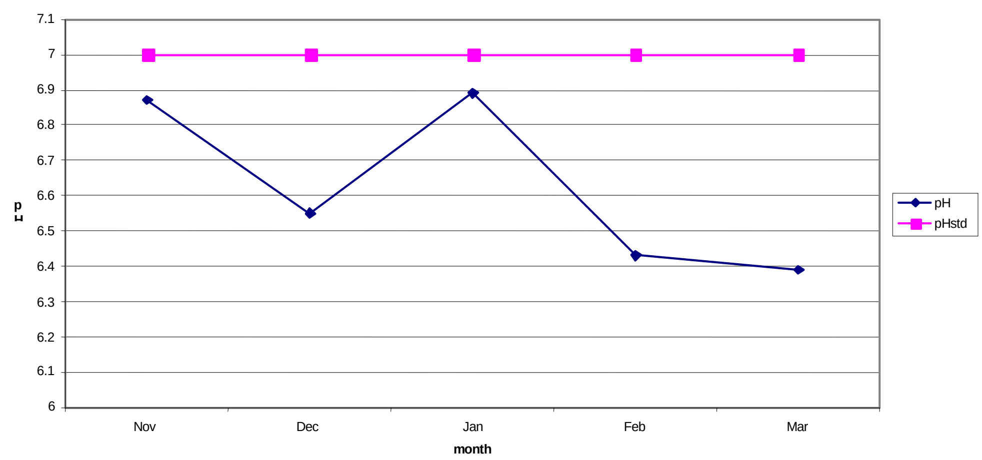


**Figure2:** Variations in pond water pH and comparison with ZINWA standards

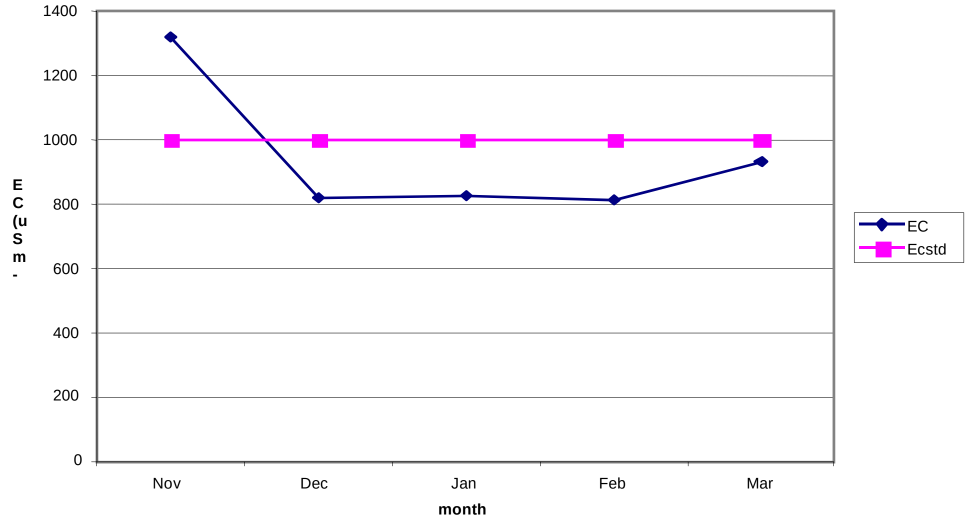


**Figure 3:** Variations in EC from Nov to Mar and comparison with ZINWA standards

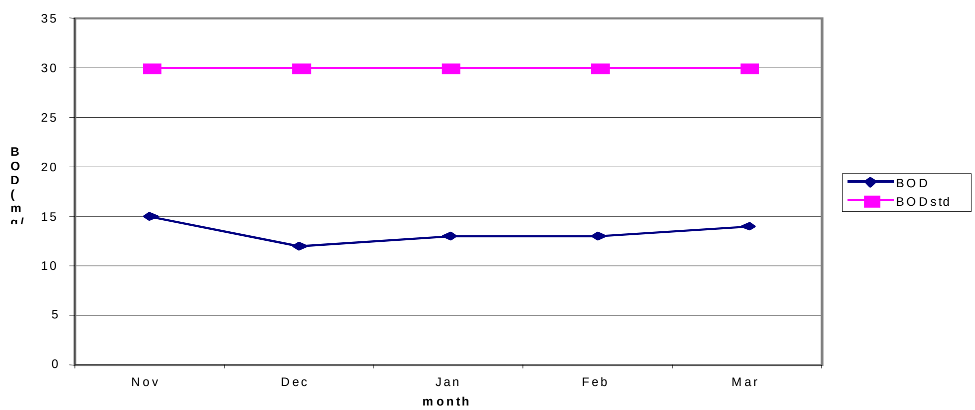


**Figure 4:** Variations in BOD from Nov to Mar and comparison with ZINWA standards

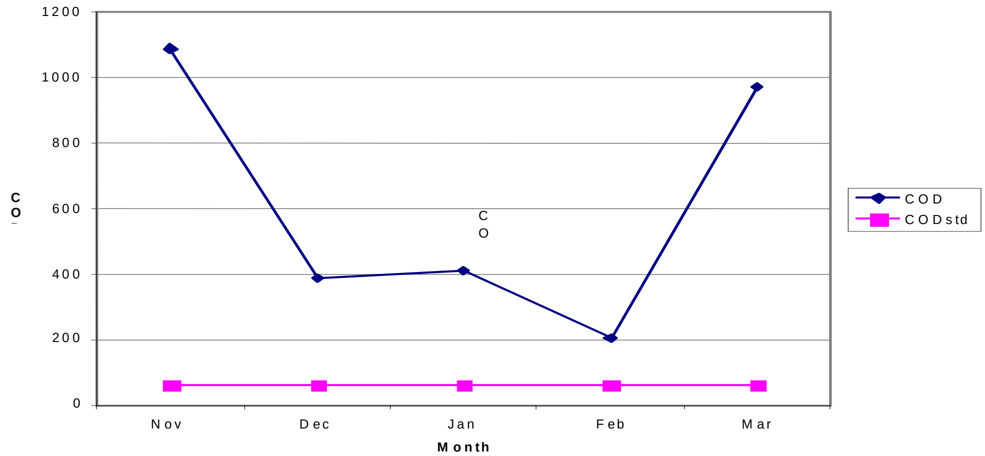


**Figure 5:** Variations in COD from Nov to Mar and comparison with ZINWA standards

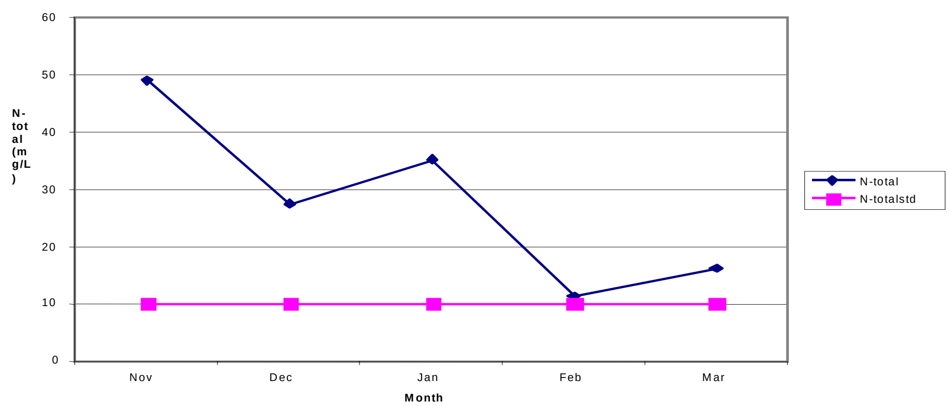


**Figure 6:** Variations in BOD from Nov to Mar and comparison with ZINWA standards

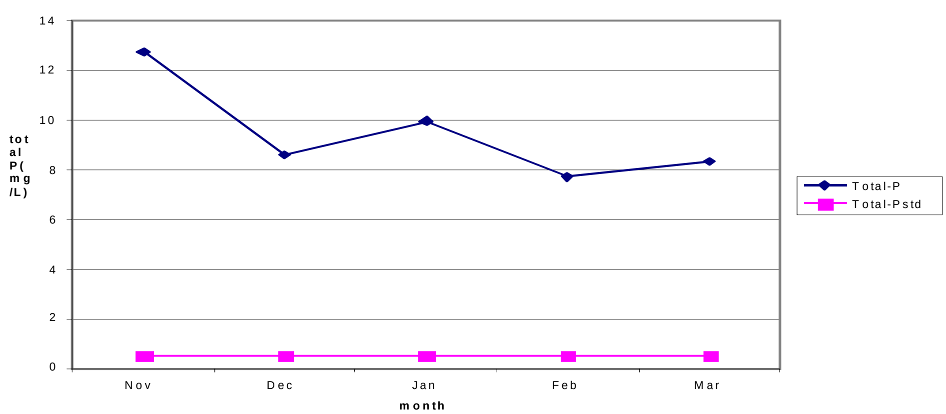


**Figure 7:** Variations in total- P from Nov to Mar and comparison with ZINWA standards

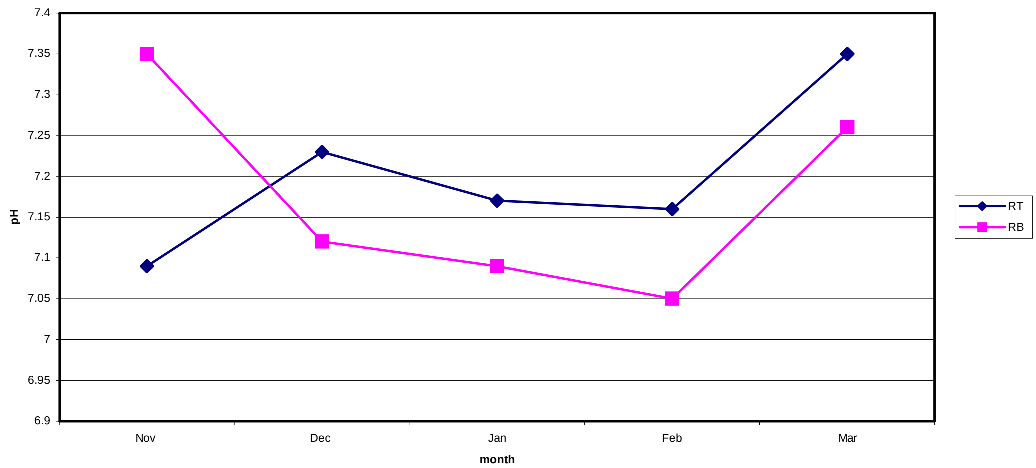


**Figure 8:** Comparison of river top pH with that of river bottom.

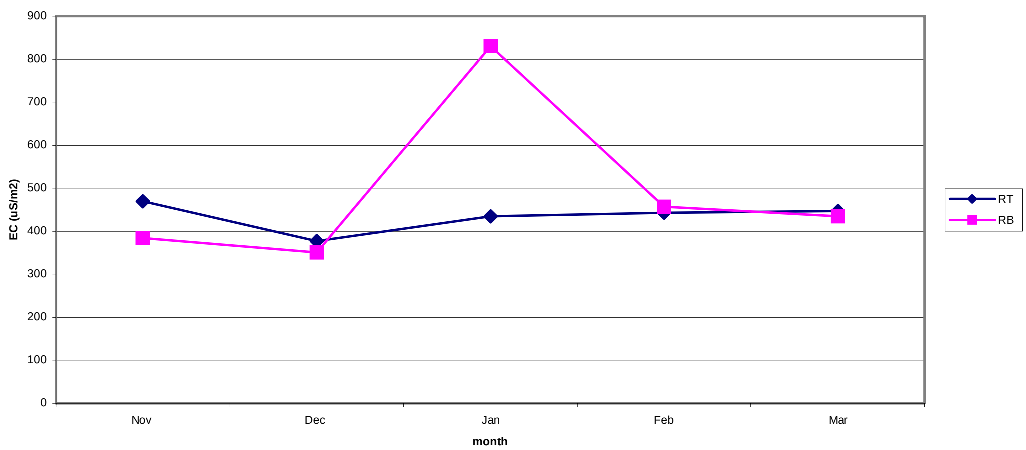


**Figure 9:** Comparison of river top EC with that of river bottom.

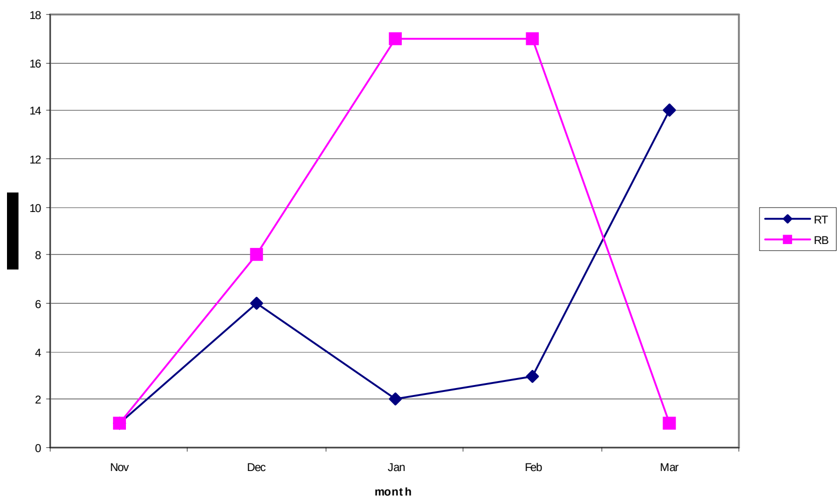


**Figure 10:** Comparison of river top BOD with that of river bottom.

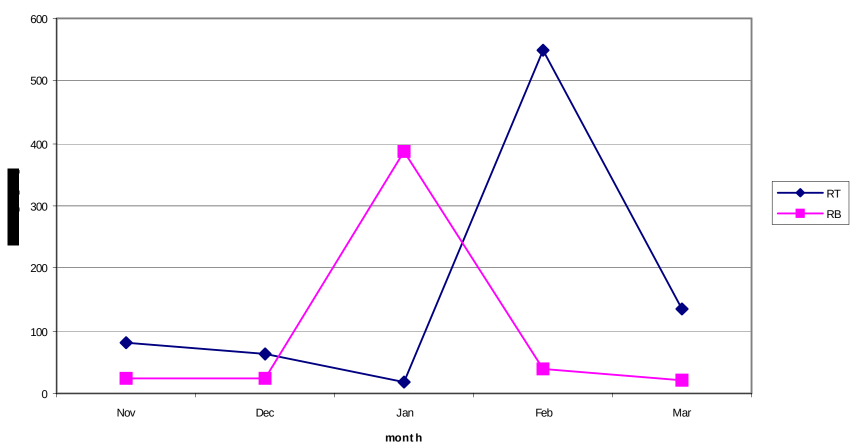


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**Figure 11:** Comparison of river top COD with that of river bottom.

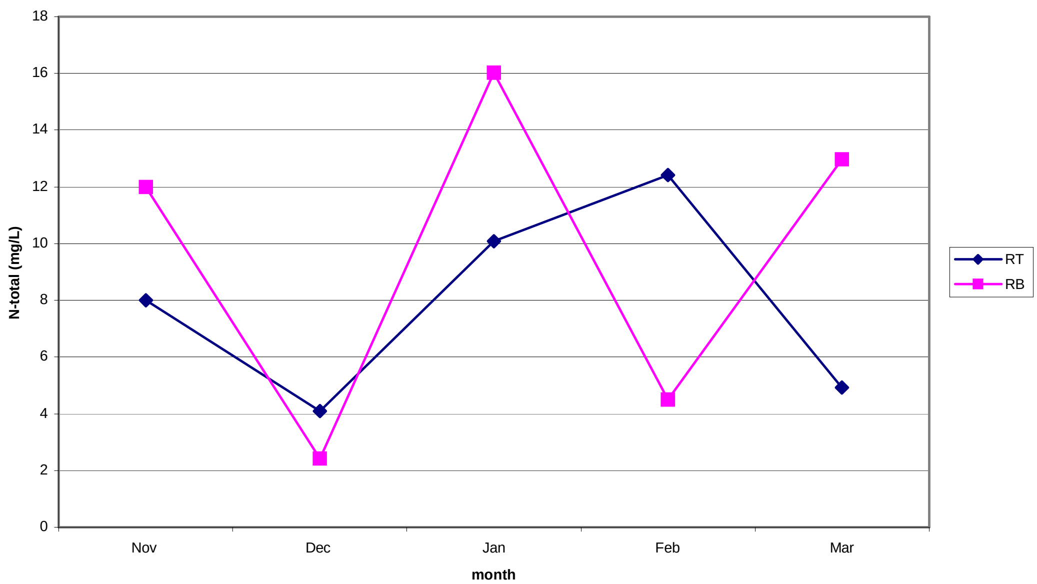


**Figure 12:** Comparison of river top N-total with that of river bottom.

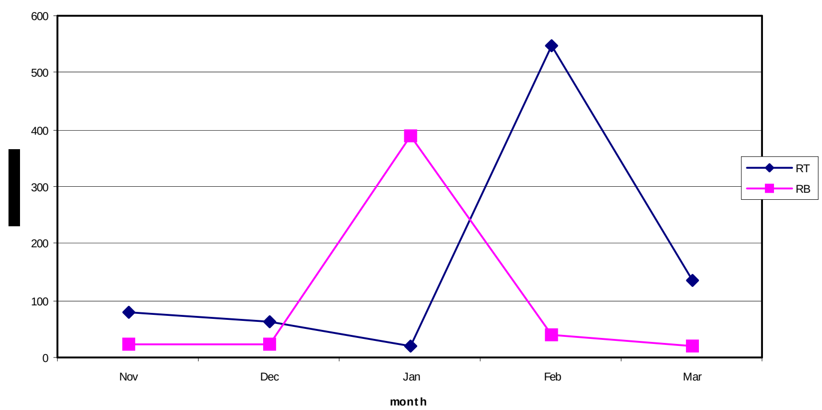


**Figure 13:** Comparison of river top Total - P with that of river bottom**.**

NB: All parameters with a subscript (std) represent the ZINWA limits

## Discussion of results

### pH

Generally, pH values of ponds 1 to 4 were well below the optimum of 6.8 for effective microbial degradation which according to Parawira (2004) could have inhibited microbial degradation in the ponds. Average pond pH was below the optimum for the efficient and effective operation of the ponds to meet the physical and chemical requirements for good quality effluent to 7.0 (Ramadan and Pounce, 2004a). Therefore this implies that activity in the ponds was decreased to significant levels when the pH was outside the optimum range which inhibited further treatment of the wastewater especially removal of COD and nutrients (Ramadan and Pounce, 2004b). The average pH of pond water from November 2004 to march 2005 was well below the ZINWA limits as indicated in Figure 1.2. There was an expected continued pH decrease after March due to less water availability for dilution which can also imply a continued deterioration in river water quality as the effluent is discharged. Significance testing at 5% shows that the treatment is not effective with respect to pH.

Acidic pH mobilise heavy metals (Chapman, 1996) in water and soils resulting in the leaching of these substances into surface water and groundwater sources. Considering the waste stabilization ponds at MCE, it may be true as the wastewater is discharged into Mazoe River as seepage. Seepage discharge from the ponds is suspected to contain high concentrations of heavy metals as evidenced by the prevalence of lantana camara at the discharge zone. These metals are dissolved in the acidic effluent and may to a greater extent leach into Mazoe River resulting in heavy metal contamination of the river water. Even though there is no available evidence of groundwater contamination, it is possible that the acidic condition of the ponds may be catalysing the leaching of contaminants into groundwater sources, which, according to an environmental audit report have been identified but not mapped by MCE.

Observations of aquatic plants growth after discharge of effluent as compared to other upstream areas show that there is a decrease in the richness of plants which, is suspected to have been caused by the acidic waters which seep into the river from the pond. River water samples collected and analysed from November 2004 to March 2005 show that there is a general decrease in the pH of the river water after discharge of the pond water as seepage, even though statistically insignificant (Figure 1.8). It is imperative to state that there is a significant decrease in pH of the river water as the discharge point of excess water from boiler section and overflow from filtration tanks is almost at the same point as the location of the ponds relative to Mazoe River. The backflow from the filtration tanks is that water which has passed through the sedimentation tanks and treated for dissolved solids including reductions in heavy metal concentration. Therefore it means this water had a significant dilution effect on the pond seepage into Mazoe River.

**Electrical Conductivity**

Electrical conductivity of the pond effluent was above the normal limits for ponds 2 up to 9 in November. This may have been due to the unavailability of water for dilution as generally there were some decreases in the parameter in December after the rains. Ponds 2, 3 and 8 had on average electrical conductivities that are above the ZINWA standards . High electrical conductivity in some of the ponds may be due to presence of ionized constituents in the accumulated sludge, which since their construction have never been desludged. There was a general decrease in electrical conductivity from November to February in all ponds which can be accounted for by the dilution effect of rainwater during the period. An increase in conductivity was noted in March, which may be due to absence of rains and increases in rates of evaporation as noted from the high temperatures and dry air.

There was no established trend on the change in electrical conductivity after the discharge of the effluent into Mazoe River (Figure 1.9). However the electrical conductivity in Mazoe River water before and after discharge was within the limits of ZINWA that is 1000uS/$m^{-2}$. There was however a significant increase in electrical conductivity after discharge of effluent by 396 units, which from an environmentalist's perspective was capable of causing some slight ecological shift even though it is within limits.

**Biochemical Oxygen Demand ($BOD_5$)**

Results of BOD indicate that the BOD was within permissible limits in all ponds with regard to Operational Guidelines for the Control of Water Pollution in Zimbabwe. There was however a general increase in BOD of the river water after discharge of effluent as seepage (Figure 1.10). The BOD was expected to be above 100mg/l for the raw effluent as is characteristic of citrus plant processing and sewage effluents. According to Chapman (1996), there is a relation ship between BOD and COD. Comparing the results of BOD and COD, it follows that the relationship between these two parameters is well beyond the proved limits (Chapman, 1996).

**Chemical Oxygen Demand**

COD levels were well above the permissible limits as required by ZINWA standards (Figure 1.5). Standards require that COD should be less than or equal to 60mg/L for effluents which are discharged into surface water (Operational Guidelines for the control of Water Pollution in Zimbabwe, 2000). Ponds 2 to 6 had abnormally high values of COD as compared to ponds 1 and 7 to 9. The pond wastewater had the least average COD of 204mg/L, which is well above the red band limits. This means that the effluent presented significant risk of water pollution and environmental damage (Operational Guidelines for the control of Water Pollution in Zimbabwe, 2000). pH below the optimum pH of 7 could be one of the reasons which resulted in the abnormally high COD of the pond water. Absence of precipitation metals such as the ferrous ions before the effluent is introduced into the ponds, lack of desluging of pond contents (Ramadan & Pounce, 2004) and discharges from the laboratory may have contributed to high COD of pond water due to high composition of mineral ions and other dissolved ion constituents. Significance testing at 5% level using t-test shows that waste stabilization ponds with respect to COD results are not effective. It can therefore be stated that COD is one of the problem parameters for the waste stabilization pond system at Mazoe Citrus Estates.

**Nitrogen-total**

Abnormally high levels of nitrogen total, on average more than 25mg/L were found in dams 2 to 5. ZINWA standards require nitrogen total to be less than or equal to 10mg/L.This could be attributed to the conversion of nitrogen locked up in the organic material to inorganic nitrogen forms. These high values of nitrogen in the wastewater imply that the water presents significant risk of polluting the receiving water and other forms of environmental damage. However there was a general decrease in nitrogen levels from ponds 6 to 9. This may be attributed to the nitrification-denitrification processes in these ponds for nitrogen removal (Ramadan & Pounce, 2004) even though the design of the pond does not specify which are the facultative and maturation ponds. Statistical analysis using the t-test at 5% level of significance indicate that there is a significant difference in nitrogen total levels of the wastewater as compared to those required by ZINWA standards. There was a general increase in the nitrogen total levels of the river water (Figure 1.12)even though statistically insignificant as shown by results using the t-test at 5% level of significance.

**Total-Phosphorus**

Total phosphorus was abnormally high in all ponds (figure 1.7)This is a good justification to state that phosphorus removal from the wastewater in the ponds is ineffective. Ponds 2 to 6 had the most abnormal values for phosphate which on average were greater than 10mg/L. ZINWA standards require the water to have a phosphorus content equal to or less than 0.5mg/L (Operational Guidelines for the control of Water Pollution in Zimbabwe, 2000).This therefore means that the effluent, basing on results of phosphorus content which is the limiting factor to eutrophication has highly significant adverse effects on the receiving water.

There were decreases in phosphorus in ponds 7 to 9 which may be due to nutrient removal mechanisms in the ponds. High phosphorus in the ponds could also be due to accumulation of organic phosphates in the pond sludge (Ramadan & Pounce, 2004a), as the ponds have not been desludged since their construction in the late seventies. The general decrease in nitrogen and phosphorus levels from December could be due to the dilution effect of the rainwater (Gratwicke, 1999) and the bloom of aquatic fauna in the ponds (Ramadan & Pounce, 2004a), which therefore used up most of the nutrient for their nutrition. Statistical analysis using the t-test at 5% level of significance indicate that there is a significant difference in phosphorus levels of the wastewater as compared to those required by ZINWA standards.

pH, BOD, COD, EC, nitrogen total and total phosphorus values of river bottom as compared to those of river top (Figures 1.8 – 1.13 ) indicate that there are slight changes in river water quality even though statistically insignificant. Provided there was no dilution effect of the excess boiler water and backflow from the filtration tanks at the water treatment plant, there could have been a statistically significant decrease in pH and a significant increase in COD, nitrogen total and total phosphorus.

## Conclusion

The waste stabilization pond systems at Mazoe Citrus Estates are not effective in treating citrus and sewage processing effluents. This is evidenced by the abnormally high values of COD, nitrogen total and total phosphorus of the pond water which in some ponds were more than five times the ZINWA limits which are stated in the Operational Guidelines for the control of Water Pollution in Zimbabwe( 2000). pH was on average acidic and to a greater extent inhibited other biological treatment mechanisms such as the removal of nutrients. High values of COD, nitrogen total and total phosphorus and the acidic pH means that the effluent presents significant risks of pollution to the receiving water and environmental damage. BOD and EC were generally within the required ZINWA limits. Statistical analysis using the t-test at 5% level of significance indicate that there are significant non-compliances of the effluent with respect to pH, COD, nitrogen total and total phosphorus

## Recommendations

- pH control of factory effluent before it flows to the waste water treatment plant can be achieved by liming the effluent after screening of suspended solids. This implies that improvements must be done on the drainage system (engineering) of the effluent to enable liming after screening. Liming after screening will also save the amount of lime used as it is applied to effluent directed to the ponds.
- Effective screening must be done to reduce amount of solids, resulting in decrease in BOD, N- total and total P.
- Desludging of pond contents: A raft mounted sludge pump can be used. The sludge can be discharged to landfills, lagoons or any other environmentally acceptable means of disposal.

Modification of design to produce good quality effluent suitable for disposal into the environment : Instead of using nine ponds, a system of appropriately designed five or six cells of anaerobic and secondary facultative ponds in series are economical for a water treatment system with effective performance and meeting the requirements for discharge of the treated effluent in a surface waterway such as Mazoe River. For example, after desludging, pond 1 and 2 can be combined and modified to suit a design for an anaerobic pond

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