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A WATER QUALITY ASSESSMENT PRIOR TO THE DISPOSAL OF DOMESTIC SEWAGE AND INDUSTRIAL EFFLUENTS AT A KWEKWE BASED EFFLUENT TREATMENT PLANT, ZIMBABWE.

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ABSTRACT

This study focuses on curbing point source anthropogenic water pollution arising from the disposal of domestic sewage and industrial effluents. A water quality assessment (WQA) was performed at a Kwekwe based Effluent Treatment Plant (KETP) vis-á-vis the Zimbabwean government's effort of achieving the Millenium Development Goal (MDG) of ensuring environmental sustainability by availing safe water for its growing population. Particular emphasis was laid on determination of the physico – chemical properties of water quality namely, acidity, dissolved oxygen (DO), temperature and suspended solids (SS) before effluent discharge into Kwekwe River. The study reveals the effluent quality data at KETP with respect to the Standards Association of Zimbabwe`s (SAZ`s) regulating standards for effluent discharge. It was observed that, implementation of vibrant WQA programs reinforce compliance with the minimum requirements for effluent discharge. A chi-squared (χ^2) significance test for association at 5% level established that there is an association between WQA and aquatic pollution reduction.

Keywords: anthropogenic water pollution, effluent, eutrophication, physico – chemical properties, water quality assessment.

INTRODUCTION

In the earth – atmosphere system, water is considered to be the most prevalent substance and one of the most vital resources to the well being of life. Water has three main uses: agriculture, industry and domestic consumption (Elizondo and Lofthouse, 2010). The principal domestic uses of water include drinking, washing and bathing (Kuruk, 2005). Shortages of fresh water for domestic consumption, as well as suitable for industry and agriculture have been a critical problem in most parts of the world (Arrandale, 1995). The costs of correcting degraded water and dealing with unforeseen conflicts over water shortages may be very high for future generations to come (Chinhanga, 2010). Water is also the most widely used resource for hydroelectricity generation, transport, recreation and waste disposal. To this extent, the aquatic environment is more vulnerable to pollution emanating from various anthropogenic activities which have undesirable and devastating impacts on water quality. However, this water pollution can be reduced by targeting to achieve the MDG of ensuring environmental sustainability by 2015 through regular WQAs.

Water pollution refers to the presence in water of harmful objectionable material obtained from sewers, industrial wastes and rainwater run – off in sufficient concentrations to measurably degrade water quality (United Nations, 1997). *Anthropogenic water pollution* is the introduction into fresh waters of physical, chemical or biological components (as a result of human activities) giving rise to their occurrence in concentrations high enough to degrade *water quality* as well as affecting aquatic habitats, people, animals, plants and infrastructures (Meybeck,1993).

There has been concern in Zimbabwe about the health of Kwekwe river due to effluents being discharged into the river by a Kwekwe-based iron and steel company (Chinhanga, 2010). *Effluents* are liquid waste materials that are by – products of human activities such as liquid industrial discharge or sewage (ISO 14001, 2000).

The major anthropogenic point sources of pollution to fresh water, (shown in Table 1), emanate from the collection and discharge of domestic waters and industrial wastes (Peters, Meybeck and Chapman, 2005).

Table 1: Point sources of pollutants in the aquatic environment as a result of human activities.

Point source	*Oils and Greases*	*Organic micro-pollutants*	*Bacteria*	*Trace Elements*
Sewage		S^3	S^3	S^3
Industrial effluents	S^2	S^3G		S^3G

Key:

S^2 Local/regional - moderately significant

S^3 Local/regional - more significant
S^3G Global – more significant

Untreated waste – water from sewage and industrial effluents is proving to be one of the most pervasive and devastating anthropogenic point – source of pollutants to the aquatic environment due to:

- Increase in organically bound energy such that heterotrophic growth and associated de – oxygenation of the receiving water is unacceptably high (Scott, 1993).
- Prevalence of *eutrophication* in the receiving water owing to the discharge of effluent that is extraordinarily rich in Nitrogen (N) and Phosphorus (P). N and P from the untreated waste water run off into the surface water, causing increased aquatic plant growth and biological oxygen demand, decreased levels of DO and decreased fish populations (Chasi, 2008). Eutrophication is a natural, slow-aging process for a water body, but human activity greatly speeds up the process (Art, 1993).
- Rampant increase in the transmission of water borne communicable diseases such as cholera, bilharzia, parasitic worms and other diarrhoea diseases (Bredenhann, 1998).

To this end, many urban towns are currently being challenged by impairment of drinking water quality due to the diffusion of leachate from untreated effluent streams into leaking domestic supply lines as well as ground water pollution in nearby rivers which is a hindrance to aquatic activities including fishing and swimming. Moreso, underground water around mines and industries is liable to pollution due to seepage from the untreated waste water.

(Chasi, 2008) also suggested that the soil around mines and industries and also along the immediate vicinity of receiving rivers' down stream can be contaminated due to the excessive accumulation of nitrates, phosphates, pathogens or organic micro-pollutants, hence destruction of the local soil morphology (soil texture, structure, consistency, colour, permeability and temperature) and ultimately, impoverished local vegetation within the contaminated zones. Other problems associated with polluted water bodies are intestinal infections with parasitic worms, cholera, bilharzia and various diarrhoea diseases culminating from the illegal harnessing of untreated waste – water or polluted water for gardening, bathing, drinking, fishing and other domestic chores.

Consequently, this study seeks to improve the quality of effluent discharged into rivers and streams so as to pose no harm to human beings who rely on the water for domestic chores, together with aquatic plants and creatures. It also endeavours to facilitate the achievement of the environmental sustainability MDG of halving, by 2015, the proportion of the population without sustainable access to safe drinking water (United Nations, 2000).

This study therefore, exposes to all Effluent Treatment Plants' (ETPs') technical communities that WQA is a fundamental tool for inhibiting pollutant flows and loads from the ETPs in accordance with the regulating standards for effluent discharge into the receiving rivers and streams. It is data obtained from WQAs that lead to water standards and, ultimately, legislations and regulations (Chapman, 1996). *WQA* is the overall process of evaluation of the physical, chemical and biological nature of water in relation to its natural quality, human effects and intended uses which may affect human health and the health of the aquatic system itself (Chapman, 1996). The actual collection of information at set locations, at regular intervals, inorder to provide the data which may be used to define current conditions and establish trends in water quality is referred to as *water quality monitoring* (Bartram and Balance, 1996).

Similar studies show that pollutant flows and loads into receiving streams can be reduced by adopting the cradle – to – grave effluent control technique which involves a regular WQA from the creation (cradle) of the effluent to its final disposal (grave) (Bredenhann, 1998). The relevant physico – chemical properties of water quality that can be assessed are given in Table 2 according to (Ward and Robinson, 1990).

Table 2: The major physico – chemical properties of water quality.

Property	**Importance to user**
Acidity	Forestry
Dissolved Oxygen	Fishery
Temperature	Fishery, power supplies
Suspended Solids	Dam maintenance.

MATERIALS AND METHODS

Study area

The study was carried out at KETP in the Midlands province of Zimbabwe (Figure 1). Kwekwe town lies 18°92'S, 29°81'E and 1.2 km above sea level. It receives mean annual precipitation of between 600 and 699 mm (Chenje, 2000).

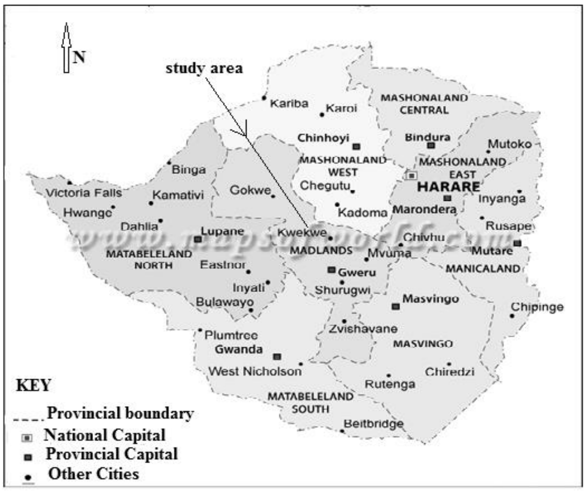

Figure 1: Map of Zimbabwe

Experimental design

The researchers performed random sampling of KETP`s raw sewage, industrial effluent and clarified effluent, in polyethylene bottles on a weekly basis for six months between September 2008 and February 2009. This was coupled by laboratory sample analysis of the temperature, pH, DO and SS.

Precaution: Before withdrawing the test portion for analysis, the effluent storage bottles were well shaken so as to homogenize their contents.

The data was analysed using Microsoft Excel to draw Figures 2 up to 5. The researchers also performed a 5 % level χ^2 significance test for association between WQA and aquatic pollution reduction. The nature of correlation between WQA and aquatic pollution reduction was determined using Correlation and Regression analysis.

The observed effluent analysis results were compared with the SAZ`s minimum requirements for effluent discharge into nearby rivers and streams (Table 3).

Table 3: The SAZ`s recommended limits for effluent discharge into receiving water bodies.

	SS / ± 0.1 mgL^{-1}	Temperature / ± 0.1 ^0C	pH / ± 0.01	DO/ ± 0.01 mgL^{-1}
Sewage	< 250.0	< 35.0	6.00 – 9.00	> 0.60
Industrial Effluent	< 25.0	< 35.0	6.00 – 9.00	> 0.60
Clarified Effluent	< 10.0	< 30.0	6.00 – 9.00	> 0.60

Determination of Temperature in waste water

A digital thermometer (TPM) – 10`s electrode was placed gently into the domestic sewage, industrial effluent and clarified effluent samples, respectively. The respective temperature readings were taken together with their uncertainties and plotted in Figure 3.

Determination of pH in waste water

A Hanna pH meter HI 98128's electrode was placed gently into the domestic sewage, industrial effluent and clarified effluent samples, respectively and the pH meter's digital display readings were taken and plotted in Figure 4.

Determination of DO in waste –water

The DO meter, 4002 – DRS' electrode was placed gently into the domestic sewage, industrial effluent and clarified effluent samples, respectively. The DO meter's digital display readings were taken together with their uncertainties and plotted in Figure 5.

Determination of SS in waste water

The filter paper was marked and dried in an oven at 103 degrees Celsius for a time interval of 15 minutes, cooled in air for 1.0 minute and then weighed on Mettler Toledo's analytical balance. The paper was later clipped into a Buchner funnel, Hartley type and then moistened with distilled water. A quantity of effluent sample containing at most 20mg of solids was then filtered. When filtration was completed the paper was then washed twice with a few millilitres of distilled water. The papers were then dried for 30 minutes in an oven at 103 degrees Celsius, cooled in air for 5 minutes and then weighed. Results were expressed in mg/L together with their uncertainties as shown in Figure 2.

RESULTS AND DISCUSSIONS

For each of the three effluent types, namely the raw sewage, industrial effluent and the clarified effluent samples, line graphs were drawn illustrating the levels of SS, Temperature, pH ,and DO against time in an endeavour to determine the nature of the relation between WQA and reduction in pollutant loads and flows into Kwekwe river.

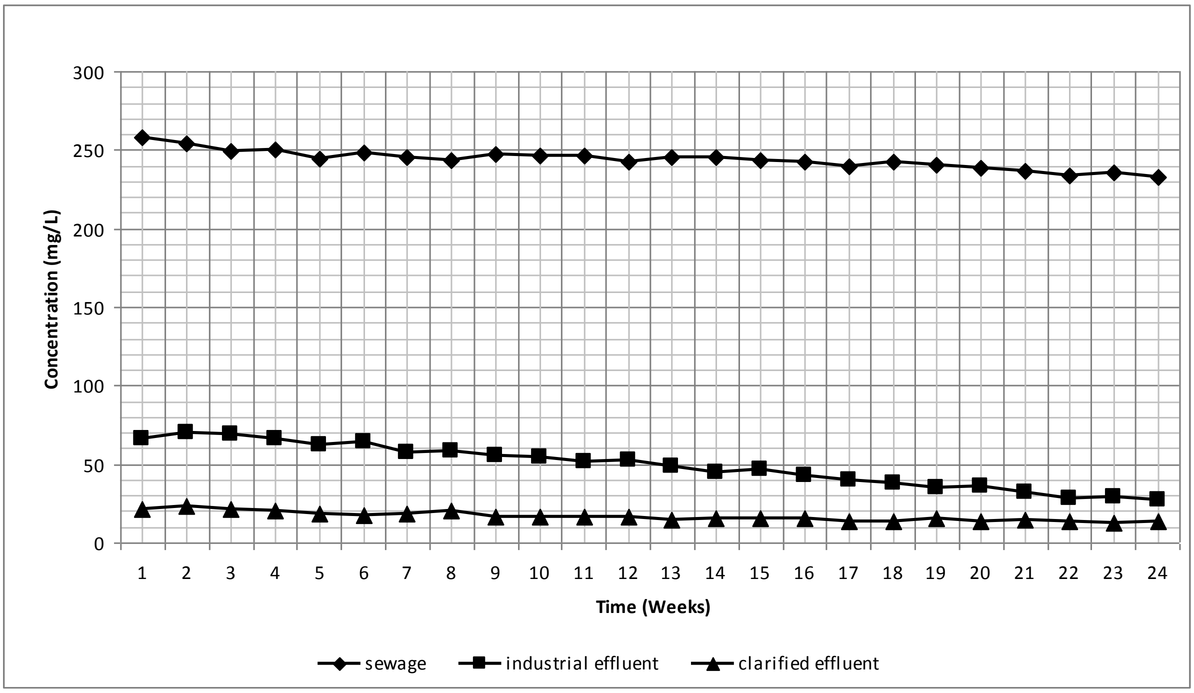

Figure 2: Weekly SS Analysis for 6 months.

Figure 2 indicates that the SS concentrations for the three effluent types gradually decreased with time due to the WQA program`s control measures. The SS concentration in raw sewage was found to be within the recommended range. However, the illustrated concentrations of SS in both the industrial and clarified effluents were above the standard limits. This implies that higher concentrations of SS were being discharged from KETP into Kwekwe river thus making it susceptible to siltation and other aesthetic nuisances.

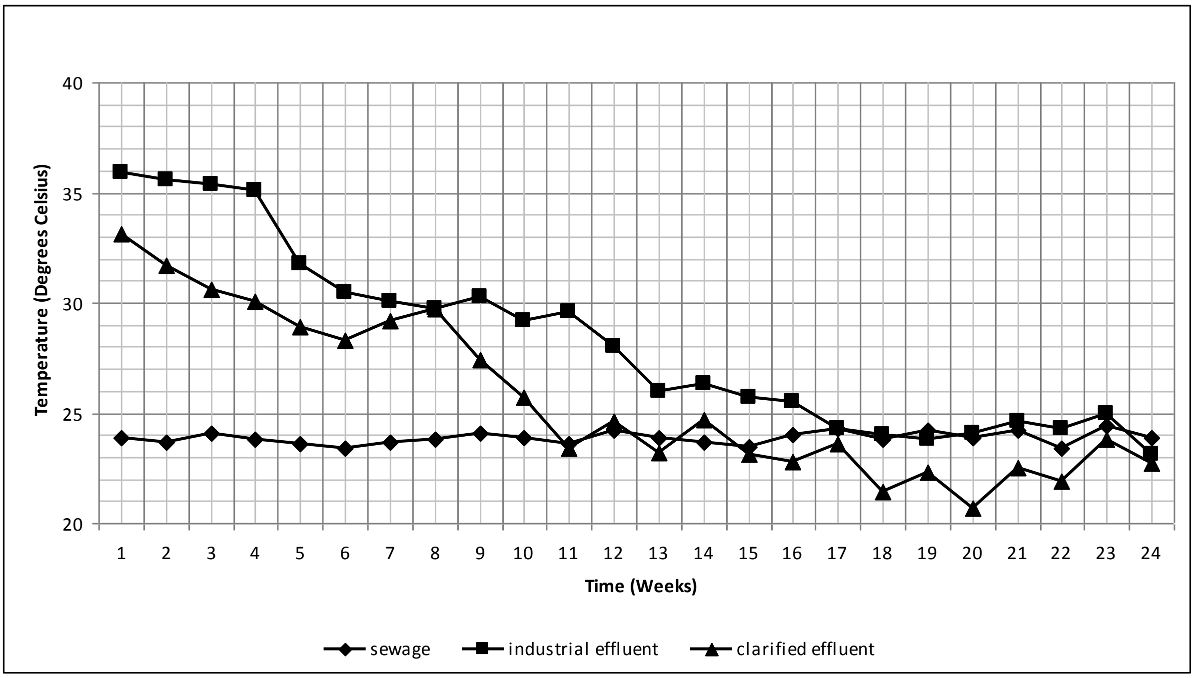

Figure 3: Weekly Temperature Analysis for 6 months.

Figure 3 illustrates a gradual decrease in the trend of the temperature readings of the three effluent types due to the implementation of control measures provided by the WQA program. It was also interesting to note that all the observed temperatures were reasonably within the expected range. This implies that KETP was discharging effluents at temperatures favourable to receiving water bodies thus facilitating a conducive environment for bio-chemical reactions as well as the life of fish and other aquatic biota.

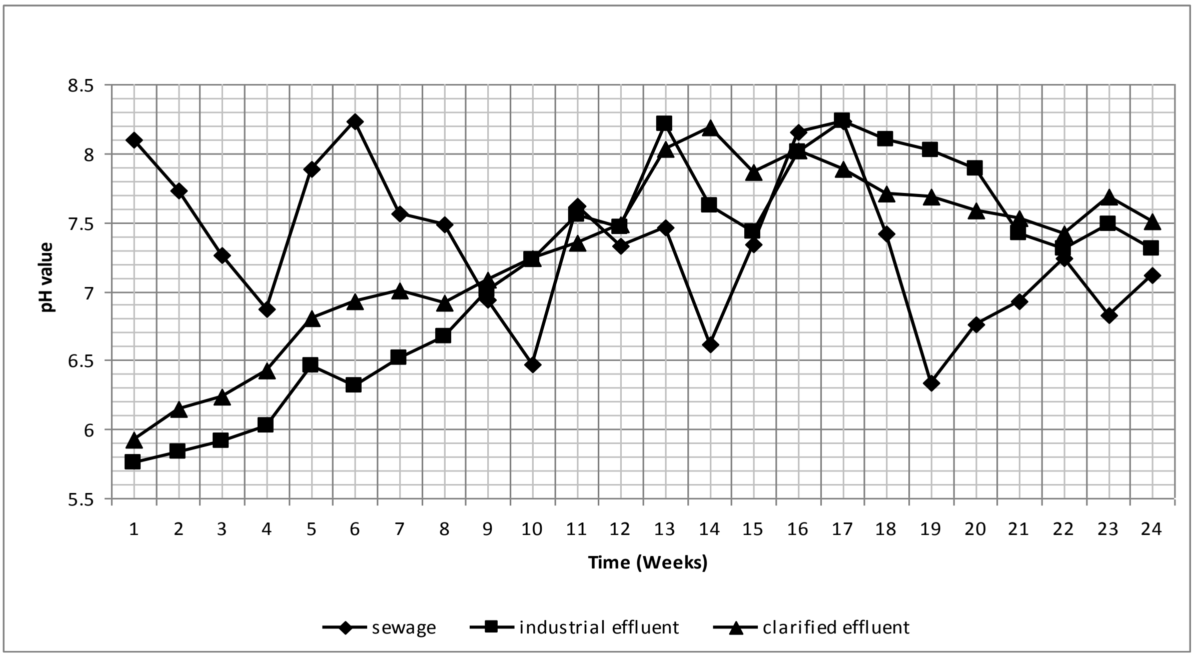

Figure 4: Weekly pH Analysis for 6 months.

Figure 4 shows a continuous fluctuation in the pH levels for the three effluent types between the 6.00 – 9.00 range. All the pH values were observed to be within the recommended range implying that effluents with accepted pH levels were being discharged from KETP into the Kwekwe river thus making the river water suitable for aquatic life, domestic consumption, agricultural irrigation etc.

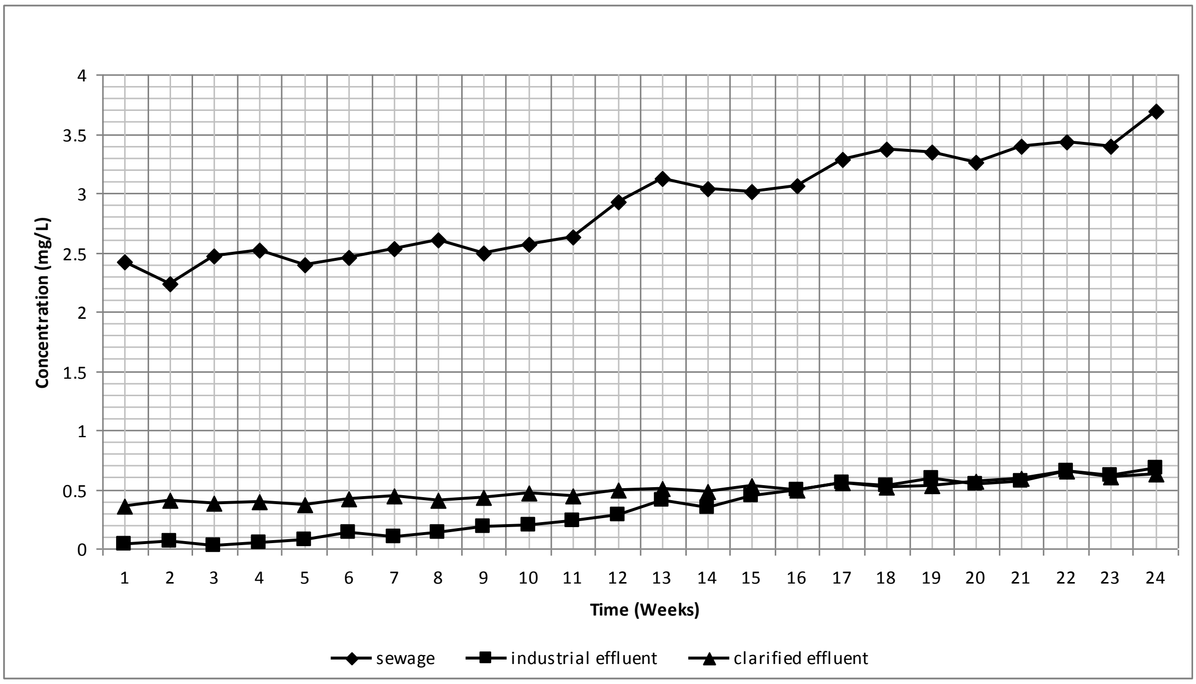

Figure 5: Weekly DO Analysis for 6 months.

Figure 5 illustrates a gradual increase in the trend of the DO concentration for the three effluent types due to improved safety measures facilitated by the WQA program. The DO concentration in raw sewage was found to be within the recommended range i.e > 0.60 mg/L. However, the concentration of DO in both industrial and clarified effluents was below the standard limit. This implies that lower concentrations of DO were being discharged from the KETP into the Kwekwe river, thus, affecting aquatic creatures such as fish which may die of suffocation and also making organic matter to decompose anaerobically. Anaerobical decomposition causes water to have a very unpleasant taste, smell and colour.

All in all, Figures 2 and 3 indicate that both SS concentrations and Temperature levels exhibit a very negative linear correlation with time in weeks, yielding product moment correlation coefficient values, r, between – 0.6 and – 0.95 and values of the coefficient of determination R between 0.36 and 0.90. Figure 4 shows that there is some positive linear correlation between pH values and time in weeks, with product moment correlation coefficient values, $r \approx 0.5$ and a coefficient of determination , $R \approx 0.25.$ Figure 5 indicates that there is a strong positive linear correlation between the concentration (mg/L) of DO with time (weeks), yielding product moment correlation values in the interval $0.70 \leq r \leq 0.95$ and coefficient of determination values in the range $0.49 \leq R \leq 0.90$. This implies that, the more we perform WQA, the more we reduce water pollution. Figures 2 to 5 show that there was a remarkable declination in the levels of flows and pollutant loads into the receiving waters of Kwekwe river during the six months research period.

χ^2 significance test for association between WQA and aquatic pollution reduction.

H_0: There is no association between WQA and aquatic pollution reduction.

Testing at 5 % significant level yields $\chi^2_{5\%}(4) = 9.488$.

Rejection criteria: H_0 is rejected if $\chi^2_{\text{calculated}} > 9.488$.

Table 4: A Contingency table obtained after combining cells with Expected frequencies less than 5.

	SS / ± 0.1 mgL^{-1}	Temperature / ± 0.1 ^0C	pH / ± 0.01 and DO/ ± 0.01 mgL^{-1}	Total
Sewage	244.0 (208.6)	23.9 (52.4)	10.23 (17.15)	278.13
Industrial Effluent	49.1 (50.3)	28.2 (26.0)	7.48 (8.51)	84.85
Clarified Effluent	16.7 (29.8)	25.7 (15.4)	7.77 (5.03)	50.23
Total	150.7	77.9	21.76	413.1

Table 5: Determination of the test statistic $\chi^2_{\text{calculated}}$.

O	E	$\frac{(O-E)^2}{E}$
244.0	208.6	6.01
23.9	52.4	15.50
10.23	17.15	2.79
49.1	50.3	0.03
28.2	26.0	0.20
7.48	8.51	0.12
16.7	29.8	5.76
25.7	15.4	6.89
7.77	5.03	1.49
		$\chi^2_{calculated} = \sum \frac{(O-E)^2}{E} = 24.54$

Conclusion: Since $\chi^2_{\text{calculated}} > 9.488$, we reject H_0 and conclude that there is significant evidence at 5 % level to suggest that there is an association between WQA and aquatic pollution reduction.

CONCLUSION

The χ^2 significance test for association at 5 % level established that there is an association between WQA and aquatic pollution reduction, since $\chi^2_{calculated} = 21.44$ was found to be greater than the critical value, $\chi^2_{5\%}(4) = 9.488$. This suggests that there is urgent need for all Effluent Treatment Plants to implement vibrant WQA programs so as to curb point-source anthropogenic water pollution that may arise from the disposal of domestic sewage and industrial effluents, hence, ensuring environmental sustainability.

RECOMMENDATIONS

Town councils should enforce by – laws which ensure that all organizations within their jurisdiction, which emit pollutants into the environment must have viable departments which cater for effluent sample monitoring and assessment programs. Assessment of water quality after the disposal of effluents and assessment of domestic supply waters should also be considered for further study on water quality so as to justify the need for employing regular WQAs particularly in Zimbabwe and the world at large so as to facilitate the achievement of the MDG of providing safe drinking water by 2015.

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REFERENCES

Arrandale, T. (1995). *A Guide to Clean Water*. pp 57 – 60. Retrieved from http://www.answers.com/topic/water on 12/11/10.

Art, H.W. (1993). *A dictionary of ecology and environmental science* (1st ed). Henry Holt and Company, New York. pp 196.

Bartram, J. and Balance, R. [Eds]. (1996). *Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes*. Chapman and Hall, London, pp 21 – 129.

Bredenhann, L. (1998). *Waste Management and the Minimum requirements*. Department of Water Affairs and Forestry, Pretoria, Republic of South Africa. pp 6 – 27.

Chapman, D. (1996). *Water Quality Assessments. A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*, second edition. Chapman and Hall, London, UK. pp. 38 – 146.

Chasi, M.D. (2008). *Local Environmental Action Planning Manual*. EMA, Harare, Zimbabwe. pp 3 – 52.

Chenje, M. (Ed.) (2000). *State of the Environment in the Zambezi Basin*. A report by Southern African Development Community (SADC), The World Conservation Union (IUCN), Zambezi River Authority (ZRA) and Southern African Research and Documentation Center (SARDC). Maseru/Lusaka/Harare.

Chinhanga, R.J. (2010). *Impacts of industrial effluents from an iron and steel company on the physico-chemical quality of Kwekwe River water in Zimbabwe*. International journal of Engineering, Science and Technology Vol. 2, No. 7, 2010, pp. 129 – 140.

Elizondo, G. M. and Lofthouse, V. (2010). *Towards A Sustainable Use of Water at Home: Understanding How Much, Where and Why?* Retrieved from http://www.kadinst.hku.hk/sdconf10/Papers_PDF/p184.pdf on 07/12/10.

Kuruk, P. (2005). *Customary Water Laws and Practices*: Nigeria. Retrieved from http://www.fao.org/Legal/advserv/FAOIUCNcs/Nigeria.pdf on 06/05/09.

ISO 14001. (2000). *Petroleum and Natural Gas industries – offshore production – installations – Guidelines on tools and techniques for hazards identification and risk assessment*. International Organization for Standardisation, Geneva. pp 11 – 24.

Meybeck, M. (1993). *The Assessment of the Quality of the Aquatic Environment*. pp 187 – 199. Retrieved from http://www.de.scientificcommons.org/m-meybeck on 23/01/11.

Peters, N.E., Meybeck, M. and Chapman, D. (2005). *The Effects of Human Activities on Water Quality*. Chapman and Hall, London, UK. pp 79 – 152.

Scott, S. (1993). *Effluent Collection, Treatment and Re-use Handbook*. Mc Graw Hill, London, UK. pp 1 – 69.

United Nations, (1997). *Glossary of Environmental Statistics in Methods*, Series F, NO.67, Cambridge University Press, New York.

United Nations, (2000). Millenium Development Goals. Retrieved from http://en.wikipedia.org/wiki/Millenium_Development_Goals on 18/03/11.

Ward, R.C. and Robinson, M. (1990). *Principles of Hydrology*. Mc Graw Hill, London, UK. Chapter 8.

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