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Wastewater treatment strategies of selected Zimbabwean food industries

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This survey aimed at identifying the current practices and experiences of industrial wastewater treatment in Zimbabwe. In this study, questionnaires were used to assess various companies located in Gweru Kwekwe, Bulawayo and Harare. The information collected identified a gap in the treatment of wastewater from food processing industries in Zimbabwe. Current results indicate that about 86% of the food processing industries surveyed have primary treatment facilities. Few companies have proper secondary treatment facilities. Wastewater was characterised for selected effluents. Electrical conductivity (EC) of the wastewater was also recorded to be lower in most of the samples where dairy effluent showed highest EC by a value of 953 µS/cm. Total dissolved solids (TDS) were observed to be higher in dairy effluent as compared with other effluents. Total suspended solids (TSS) of cereal beverage effluent were higher with a value of 90 mg/L. The highest chemical oxygen demand (COD) values were recorded in potato processing effluent (690 mg/L O_2) followed by meat processing effluent (485 mg/L O_2). These values however are above the value recommended in Statutory Instrument (SI) (S.I.) 6 (S.I.6) of 2007 of 60 mg/L. It was noted that more than 80% of the wastewater comes from production processes and a substantial amount (53%) coming from raw material processing. This study indicates that regular inspections are done to enforce the wastewater legislation. Of all the companies studied, 73% of the companies were disposing their industrial effluent directly into the municipal sewer lines. Without the proper treatment facilities, the disposal of polluted effluent into the public sewer poses health and environmental consequences to the community. It can be concluded from the current data that there is a serious need to establish secondary treatment systems to remove organic load from food processing effluent and reduce pollution.

Key words: Wastewater, food processing, pollution, treatment, legislation, disposal.

INTRODUCTION

One of the major consumers of environmental resources and also producers of environmental damaging agents that cause environenemental pollution are the manufacturing industry (Marambanyika and Mutekwa, 2009). The food

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industry is one of the major contributors of wastewater pollution (Kroyer, 1995; Kirby et al., 2003; Blonskaja and Vaalu, 2006). In addition, these food processing industries produce large quantities of wastewater that is difficult and costly to perform biotreatment before discharging to the environment.

Each step in the food industry system, including food production, processing, transportation, storage, distribution and marketing, has some impact on the environment and there is much concern about environmental pollution from such sources. In many developing countries, more than 70% of industrial fluid wastes are dumped untreated into water bodies where they pollute the usable water supply (World Water Assessment Programme, WWAP, 2009). Wastewater management from food and beverage industry constitutes a practical problem for such sources of these polluters (Fillaudeau, 2006). Wastewater generated from food operations has distinctive characteristics that set it apart from common municipal wastewater managed by public or private wastewater treatment plants throughout the world. Food wastewater is characterized by being biodegradable and non-toxic, has high concentration of biological oxygen demand (BOD), suspended solids (SS) and high chemical oxygen demand (COD) (Millard and Ingham, 1993; Mishra et al., 2004; Cristian, 2010).

However, wastewater from food industries varies so greatly in both flow and pollution strength due to variations in operational regimes and nature of raw materials used. The major types of food production processes include yeast, brewery, fruit, vegetable, oils, dairy, meat and fish (Banu et al., 2008; Cristian, 2010; Kosseva, 2013). These industrial wastes vary widely, with associated differences in the specific wastewater contaminants and in-house operations. The characteristics and generation rates of industrial food wastewater are highly variable, depending on specific types of food processing operations, including wastewater from activities of unit operations; mechanical activities and sanitisation procedures. The wastewater can be contaminated with a myriad of different components, including pathogens, organic compounds, synthetic chemicals, nutrients, organic matter and heavy metals (Okoh et al., 2007; Nelson and Sidhu, 2007; Corcoran et al., 2010).

The winery industry generates strong organic wastewater whose quality is highly dependent on the production activities with a typical effluent containing, in addition sugars, ethanol, organic acids, aldehydes, other microbial fermentation products, soaps and detergents (Lassi et al., 2013). Meat processing industry wastewater contains high concentrations of fat, dry waste, sediments and total suspended matter as well as nitrogen and chlorides with high biological and chemical oxygen demand (Sroka et al., 2004). Meat processing and packaging may occur in the same facility or offsite slaughterhouse. In addition to wastewater production, the volume of solid waste by-products generated during processing is significant (Mittal, 2006). Baker`s yeast industry wastewater has high BOD and COD. Gladchenko et al. (2004) reported wastewaters with high strength in the range of 10 to 80 g COD/L, strong nitrogenous ranging from 0.5 to 1.5 g/L total N, sulphate-rich (2 to 10 g/L), phosphorus variable (sometimes P-deficient), recalcitrant for biodegradation and highly coloured. Dairy industry whey wastewater has a typical white colour and a high nutrient level as well as organic matter content (Najafpour et al., 2009). It is usually treated by biological methods such as the activated sludge process and anaerobic filters although aerobic biological processes have high energy requirements whilst anaerobic biological methods require additional treatment (Banu et al., 2008; Kushwaha et al., 2010). The beverage sector products include soft drinks, beer, *Maheu*, flavoured bottled water and juice. Although the products vary, uses of water and wastewater management needs are similar. The main objective in treating the food processing wastewater is to reduce BOD loading. Anaerobic biological treatment systems have been used to reduce COD in Zimbabwean brewery wastewater plants (Parawira et al., 2005).

Environmental legislation has significantly contributed to the introduction of sustainable waste management practices throughout the Zimbabwean food industry (Nhapi and Gijzen, 2002). The environmental protection agencies have imposed more stringent regulatory prohibitions to protect the environment (Mane and Qasim, 2013). The enactment of the Environmental Management Act (Chapter 20:27) in Zimbabwe compelled food organizations to comply with wastewater expected characteristics. There are also changes to the way the environment is managed with the Environmental Management Agency (EMA) stepping up operations. As a result, a growing number of companies are becoming aware that environmental performance can have a significant impact on business success and sustainability. In 2007, Statutory Instrument 6 of 2007 of the Environmental Management Act was gazetted as the Environmental Management (Effluent and Solid Waste Disposal) Regulations, 2007, the main legislation tool guiding wastewater practices. According to EMA regulations, the water and effluent permitting system requires permit holders to do their own self-monitoring and submit reports regularly to confirm adherences. However, in Zimbabwe, industries generally are not fully implementing measures of industrial effluents reduction, which inadvertently encourages environmental pollution (Ikhu-Omoregbe and Masiiwa, 2002).

This survey aimed at identifying the current appropriateness of wastewater treatment methods employed from selected food industries in Zimbabwe through characterisation of wastewater that they produce. The research ascertained the effluent treatment strategies by the food processing in an attempt to provide information

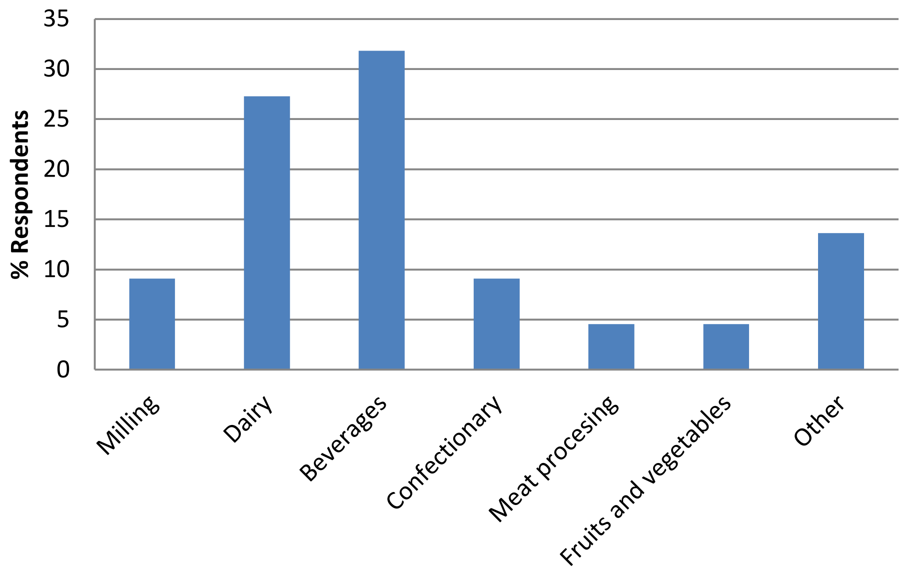

Figure 1. Types of food processing industries assessed in this study.

to encourage management recognition of current and future problems in the pollution area and management action to undertake wastewater treatment.

METHODOLOGY

Survey development

The researchers prepared a questionnaire document which was administered to various food industries of Zimbabwe to ascertain the strategies that they employ in their respective wastewater treatment. The survey questionnaire was divided into sections on general plant and production information and wastewater treatment operations. General plant information included the type of food processing operations conducted at the respective facilities. Production information was based on average daily processing levels and the maximum plant wastewater levels. General questions included disposal techniques employed for effluent and wastewater operation practices. Specific wastewater quality information was investigated on the biological oxygen demand, chemical oxygen demand, total solids, total suspended solids, nitrogen content, disposal means and conductivity characteristics of the wastewater. Questionnaires were distributed to production/quality/environmental contact personnel at the nominated food processing industries of Zimbabwe. A total of 30 questionnaires were distributed to food processing plants and the completed forms were collected and analysed.

Wastewater characterization

The wastewater was collected from selected food processing industries in Harare, Zimbabwe. For the present investigation, all the samples were collected from three different places of pre-discharge, sedimentation tank and final outlet of the wastewater discharge system to make a composite sample. Samples were collected and analysed within 24 h with necessary preservation techniques maintained. Conductivity and pH were measured *in situ*. TSS and phosphates were measured using standard methods (APHA, 1998). COD was determined using (SAZS 574:1997) DR 5000 UV/VIS SPECROPHOTOMETER, HACH (Germany). The metal ion concentration for selected metals was carried out using atomic absorption spectrophotometer (AAS) (Thermo-Fischer iCE 300) as specified by SAZ CF-TM-052. Trace metal ion concentration was determined using Inductively Coupled Plasma (ICP-AES) (ICAP 6000 SERIES), as specified by SAZ test method CFTM-054(ISO 11885).

RESULTS AND DISCUSSION

Distribution of the selected food industries assessed in this study

Although responses were obtained from all sectors, the numbers varied as shown in Figure 1. There are over 102 food manufacturers/processors in this sector in Zimbabwe (Bhonyongwa, 2011). Production is located in the main cities of Harare, Bulawayo, Mutare and Gweru. The concentration of factories is high in Harare (about 63% of total number) and the other cities share the 37% (Bhonyongwa, 2011). A master list of food plants was prepared by considering companies that currently operate at more than 60% production levels that would contribute immensely to the wastewater production. Of the sample size of 30 selected in this study, only 22 responded. Thus, the response rate was 73%, attributed to the sensitivity and security issues of the effluent management in Zimbabwe. EMA has been of late, actively involved in monitoring and most companies were reluctant to submit information on the current state of their waste treatment strategies in case of legal action being evoked against them. Table 1 shows parameters of the wastewater produced by some of the Zimbabwean food processing companies.

Table 1. Summary of the wastewater characteristics in selected food processing plants.

Parameter	Cereal beverage	Dairy juice	Type of processing wastewater						ZWS 558:1999 and S.I. 6:2007 specification requirements
			Potato	Meat	Milk	Soft drink	Beer	Yeast	Maximum permissible limit
pH at 25°C	4.63	6.65	6.68	6.61	11.8	6.68	6.61	6.74	6-9
Phosphates (as P), mg/L	271.2	24.2	11.30	13.1	60.7	116	182	150.6	0.5
Sulphate (as SO_4^{-2}), mg/L	7.09	47.46	19.11	34.4	7.15	56.2	44.1	-	250
TSS, mg/L	90	70	11	24	62	40	26	-	25
TDS, mg/L	760	250	720	501	790	390	250	457.5	500
Chloride (as Cl^-), mg/L	4.42	11.79	30.26	28.1	2.95	30.2	33.0	29.30	250
Grease and oil, mg/L	0.78	10.3	1.44	1.21	0.25	1.32	1.21	4.5	2.5
Conductivity, µS/cm	820	375	778	431	953	489	270	-	1000

In the present investigation, characterization of the effluents showed (Table 1) varying levels of various physicochemical parameters. The pH of a cereal beverage (*Maheu)* effluent was acidic (4.63) while the diary effluent was recorded to be nearly neutral. Electrical conductivity (EC) was also recorded to be lower in most of the samples whereby dairy effluent showed highest EC value of 953 µS/cm. In general, more TDS were observed in dairy effluent as compared with other effluents. Total suspended solids (TSS) of cereal beverage effluent was higher with a value of 90 mg/L compared to 11 mg/L from potato processing wastewater, indicating higher solids and organics. In general, it was also observed that phosphate values were higher in all the effluents with a maximum of 271.2 mg/L in cereal beverage wastewater compared to the permissible 0.5 mg/L, indicating the potential to cause eutrophication (Akan et al., 2008). This could be attributed to the chemicals used for cleaning in place (CIP) or inorganic phosphates from residual pesticides in raw materials removed by wet cleaning methods during cleaning, sorting and grading. Sulphates were below the recommended limit of 250 mg/L. Chlorides were observed higher in beer processing effluent by a value of 33.0 mg/L. This wide variation is attributed to the different scales of operation (Figure 2), from meat processing industry that produces wastewater mainly from CIP to breweries that utilise large quantities for both production and sanitisation.

The food industries did not comply with the National standards for COD of effluent discharge. COD varied significantly which can be attributed to the different oxidizing agents unique to the different industries and those found naturally in the environment. As illustrated in Figure 3, the highest COD values were recorded in potato processing effluent (690 mg/L O_2) followed by meat processing effluent (485 mg/L O_2). These values however, are above the recommended maximum limits (60 mg/L) in local legislation, S.I.6 of 2007.

Table 2 shows metal content of the selected food industrial effluents. The nickel, mercury and cobalt were absent in nearly all industrial effluents with notable mercury levels in yeast processing effluent. Concentration of chromium was observed almost at the same concentration in cereal beverage effluent (0.2 mg/L) and dairy beverage (0.22 mg/L) effluent while it was much less beer manufacturing effluent at 0.009 mg/L. Copper content was highest in beer effluent with a value of 0.44 mg/L and both meat and dairy juice effluents recorded 0.22 mg/L. Dairy juice and beer processing were the only food industries observed to have zinc being above the recommended vale of 0.5 mg/L with recording 0.95 mg/L. A lot of water is used for cleaning of floors during the processing of dairy products and the purity of the water used may be compromised since it is not food grade.

Figure 4 indicates that about 86% of the food processing industries surveyed have primary treatment facilities. This only involves mainly the removal of settled solids. Few companies have proper secondary treatment facilities. It has been noted that most of the wastewater (80%) comes from production processes and a substantial amount (53%) comes from raw material handling. It can be remarked from the current data that there is a serious need to establish secondary treatment systems to remove organic load from food processing effluent and reduce pollution.

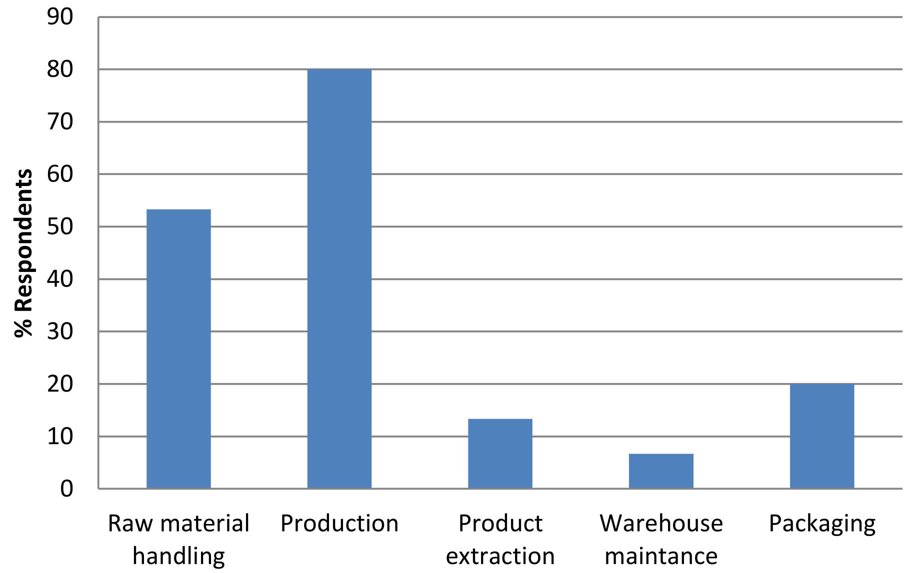

Figure 2. Sources of wastewater in industrial operations.

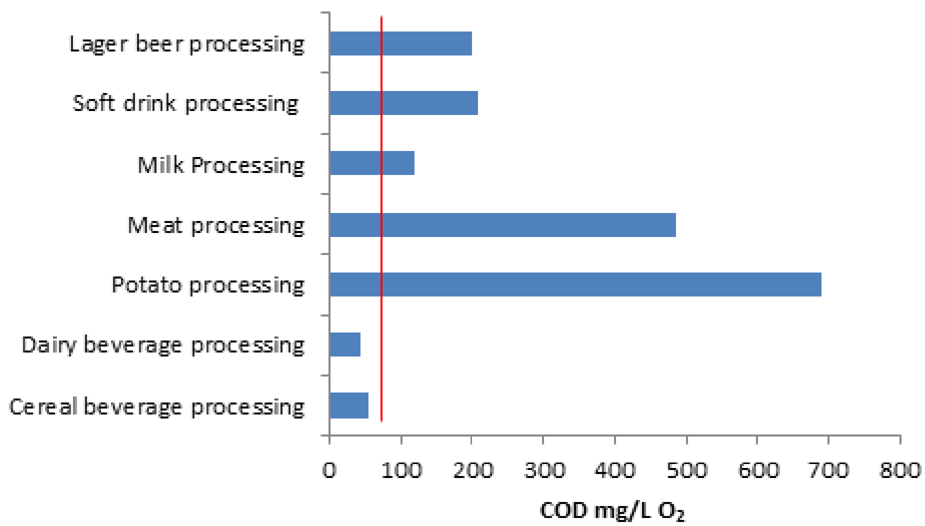

Figure 3. The COD values for selected industrial food effluents.

Legislation compliance and penalties ranges

Wastewater discharge is increasingly gaining attention due to stricter regulations resulting from environmental issues. The overall cost of water usage in the industry is rising at an alarming rate due to the net result of events (Mannapperuma et al., 1993). The food processing industries assessed are also being fined heavily by regulatory authorities with 64% having paid penalties ranging from $1000 to $5 000 per annum on effluent disposal as shown in Figure 5.

Results obtained in this study indicated that inspection services are regular with all the companies indicating a regular check and monitoring with the respective Zimbabwean authorities on the company premises. On the availability of legislative copies of the effluent disposal document such as (Statutory instrument (S.I.) 6 of 2007, water (waste and effluent disposal) Regulations, 2007), 82% had copies at their disposal while the remainder did not have copies of the external document.

Disposal strategies of wastewater and reuse

Results shown in Figure 6 indicate that majority (73%) of the companies are disposing their industrial effluent into the municipal sewer systems. Without the proper treatment facilities, the disposal of polluted effluent into

Table 2. Metal content of the selected food industrial effluents.

Parameter (mg/L)	Cereal beverage	Dairy beverage	Type of wastewater						ZWS 558:1999 and S.I. 6:2007 Specification requirements
			Potato	Meat	Milk	Soft drink	Lager beer	Yeast	Maximum permissible limit
Arsenic (as As)	0.0068	0.071	0.0008	0.003	ND	0.0008	ND	ND	0.05
Cadmium (as Cd)	0.013	0.0014	0.004	0.001	0.002	0.004	0.001	-	0.01
Total chromium (as Cr)	0.20	0.22	0.011	0.005	0.12	0.011	0.009	0.070	1
Calcium (as Ca)	18.67	42.45	23.16	11.42	10.40	23.16	39.11	-	-
Cobalt (as Co)	ND	ND	ND	ND	ND	ND	ND	0.081	-
Copper (as Cu)	0.26	0.22	ND	0.22	0.073	0.36	0.44	0.26	1
Iron (as Fe)	4.18	16.77	21.35	8.77	2.86	6.44	8.95	10.90	1
Lead (as Pb)	0.064	0.64	ND	0.003	0.36	ND	0.003	0.023	0.05
Manganese (as Mn)	0.16	0.76	0.97	0.22	0.063	0.16	0.76	3.68	0.1
Mercury (as Hg)	ND	ND	0.032	ND	ND	ND	ND	1.67	0.01
Magnesium (as Mg)	3.51	16.87	3.51	7.15	1.79	3.51	16.87	-	-
Nickel (as Ni)	0.064	0.12	ND	ND	0.046	ND	ND	0.27	0.3
Selenium (as Se)	0.0006	0.0032	ND	ND	0.005	ND	ND	-	0.05
Sodium (as Na)	273.3	40.07	102	62.19	209.8	102	0.95	-	200
Zinc (as Zn)	0.36	0.95	0.006	0.021	0.17	0.36	0.95	10.04	0.5

ND: Not detected

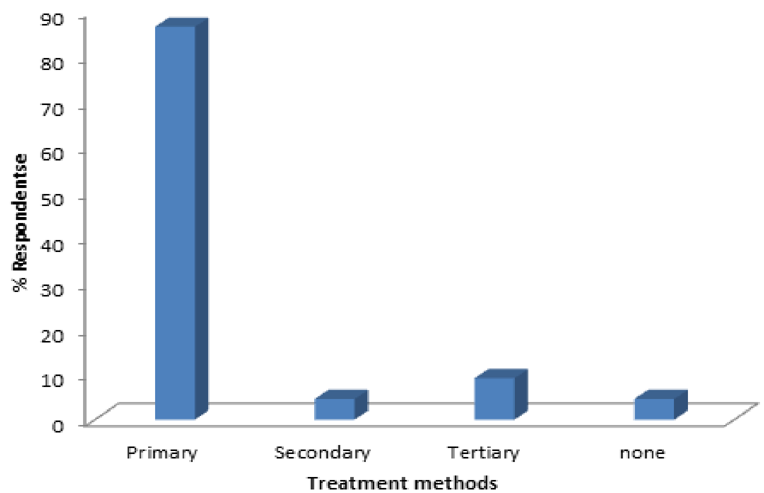

Figure 4. Wastewater treatment methods practised in the food industries.

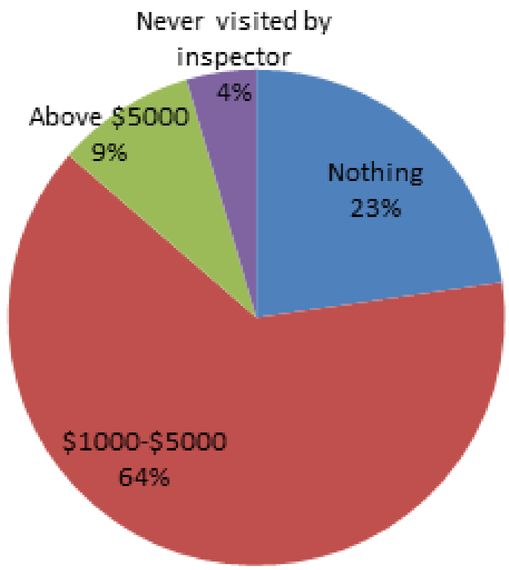

Figure 5. Summary of the annual charges for wastewater handling practice.

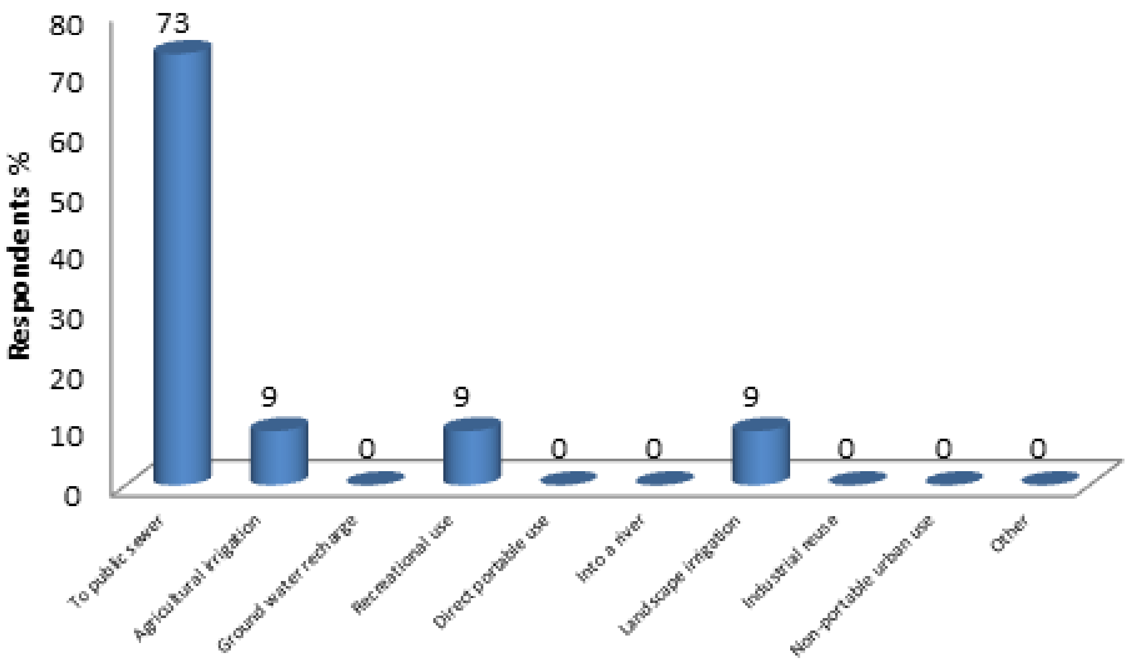

Figure 6. Methods of effluent disposal for the food processing industries.

the municipal sewer poses health and environmental consequences to the community. In a related study, Ikhu-Omoregbe and Hove (2002) indicated that breweries discharged effluent into municipal sewer system for final treatment and some of the effluent was used to irrigate a nearby farmland or discharged into a nearby stream. In another study in Zimbabwe, Ikhu-Omoregbe and Masiiwa (2002) found out that a large number of dairies discharged their effluents into municipal sewers. Majority of smaller dairy operators used their effluents for irrigation, which could impact negatively on the soil and groundwater condition. However, the reuse of treated wastewater has negative ecological impacts (Corcoran et al., 2010). Results from this study differ from related studies carried out in Tunisia. In Tunisia, industries also have to comply with national standards for the discharge of wastewater into sewers, and are given subsidies for pre-treatment processes. An amount (78%) of wastewater collected is treated, mainly to secondary biological standards (FAO, 2010). In addition, the clear water produced from the treated effluent can be utilized for various applications such as flushing, floor washing, plantation, irrigation, etc (Chan, 2013).

Conclusion

It can be concluded from the survey that most food processing industries are not adhering to stipulated wastewater treatment practices. There is an information gap on standard practices with regards to wastewater characterisation as most companies had insufficient data on important parameters. The regulatory authorities are actively involved in monitoring water pollution but the stipulated penalties are not high enough to deter companies from polluting. A paradigm shift is required towards new approaches that include appropriate investments best suited to the industries and communities they serve. Biological treatment processes seem to be a good pollution reduction alternative for food processing industries in Zimbabwe.

Conflict of Interests

The authors have not declared any conflict of interest.

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