

# **CHAPTER 30**

## **THE APPLICATION OF APPROPRIATE TECHNOLOGIES IN WASTE MANAGEMENT IN DEVELOPING COUNTRIES**

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# The Application of Appropriate Technologies in Waste Management in Developing Countries

## Introduction

Waste characterisation data specific to African countries and cities are not generally available, though some regional evaluations have been made. Additionally, the income level of the generators has been shown to be correlated with the generation rate and composition of the *municipal solid waste* (MSW) stream. This correlation has been established in case studies of cities in OECD countries and on the basis of GNP for countries as a whole. Such regional and global-level statistics may be the most reliable bases available for inferences about the characteristics of the MSW stream in Africa. *The limited available data suggest that the MSW stream in the typical African City at point of disposal is high in putrescible organic content. However, it is low in percentage of commercially recyclable components and too low in heating value for energy recovery by incineration* (UNEP International Environmental Technology Centre, 1998).

For the most part in Africa, services are not available for the separate handling of special wastes such as household hazardous waste (HHW); paints, solvents, consumer batteries, etc.), construction and demolition debris (CDD), medical and infectious waste (MIW), tyres, sewage sludge, or chemical and pharmaceutical wastes. The predominant practice is to collect these items along with the rest of the waste stream and co-dispose of them at the same open dumps used for regular MSW.

Until the late 1980s, municipal solid waste management (MSWM) policies and programs in most African cities were formulated and implemented by government agencies without significant public participation. Political and social changes across the continent, including the rise of NGOs, have fostered an increased awareness of environmental issues among the public. Urban populations have become more involved in the issues surrounding MSW. Resistance to MSW incinerators in countries like Cote d'Ivoire, Senegal, and South Africa reflects an emerging involvement of the public in the debate and policy formation process of MSWM.

The key to changing MSWM practice at the consumer level is to make the distinction between public awareness and public education. Public agencies engage in this education primarily through initiatives based in the departments of health and education. Community service organisations, in collaboration with the health department and international health organisations such as the World Health Organisation conduct training seminars on sanitation.

if not properly handled.

## **Safety Aspects**

For any organisation or laboratory institution, the safety obligations start with institutional responsibilities. Maintenance management and safety management are related (Ekosse and Nkoma, 1995a) and Laboratory Waste Management is directly linked to Laboratory Safety Management. There should be a safety policy which must be adopted and implemented. During the short courses conducted in 1994 and 1995 mentioned at the beginning of this paper, participants expressed ignorance of the existence of any institutional safety policies in their laboratories. One of the reasons to account for some of the problems encountered in the execution of an institutional safety policy in most LDCs is having Directors and Managers who are not professionally knowledgeable in Science Laboratory Technology.

The Laboratory Supervisor plays a pivotal role in the implementation of institutional safety policies. He checks all safety equipment and gadgets on a very regular basis to make sure there is no malfunctioning. Individual workers should be informed regarding the hazardous nature of compounds they handle daily at work. Safety drills should be organised by management for workers periodically. Workers must dress to conform to the rules and norms of the profession. It is the corporate responsibility of each laboratory worker to make sure that laboratory safety standards are not compromised, even when it comes to laboratory waste disposal.

## **Educational Aspects**

It is noted that in most LDCs, while Directors and Heads of Departments are academically qualified, most of the laboratory personnel are not fully trained to effectively handle their jobs. In a recent study carried out on the compilation of an inventory of laboratory facilities for the study of environmental resources in Botswana (Ekosse and Khathola, 1997), it was pointed out that most of the laboratory workers either had higher degrees or low technical qualifications. A need was identified to train more laboratory personnel with appropriate technical and specialised qualifications. This is the class of workers able to efficiently handle Laboratory Waste on a daily basis.

Information and research on Laboratory Waste Management has not been encouraging in developing countries. This may apparently be associated to the fact that there are very few training institutions that run programmes in Science Laboratory Technology. there is a crucial demand for regional schools to be set up in Africa in Science Laboratory Technology covering the Environmental

quantity of waste generation. All types and classes of waste are produced in these laboratories. The production of a broad spectrum of laboratory waste is associated with all the environmental, geochemical, health and socio-economic hazards and implications.

Most laboratories separate their waste into different categories but do not dispose of them. It is economical to hire a waste disposal company to dispose of the waste. Because of readily available funds and frequency at which experiments are conducted, National Waste Disposal Companies exist with specialised equipment and trained manpower to handle and dispose of laboratory waste.

### ***Less Developed Countries***

Laboratories in LDCs generate less quality and quantity of waste. Most of the waste generated in these laboratories are disposed off by the laboratory staff. Because of lack of national legislation and regulations in LDCs, it is not certain that the laboratory waste are properly disposed off. Other factors which may affect the disposal of laboratory waste in LDCs are lack of trained and committed personnel, lack of funds and professional negligence.

### **Environmental Aspects**

Conventional methods used for the disposal of waste in general are also applicable to the disposal of laboratory waste. In the past, the disposal of laboratory waste was not a concern because there were few laboratories and society was ignorant of the hazards associated with the waste. Many harmful substances have penetrated into different environments, endangering human health and threatening the ecosystem (Norwebb, 1995). Surface and groundwater have been contaminated, irritating gases have been emitted and vegetation has been discoloured as a result of poor waste management. In most cases, the effects of inappropriate waste disposal are only detected after a long time.

Waste disposal sites located at proximity to urban and residential centres have posed as potential dangers to explosions, fires, and contamination of aquifers. There have been reports that point to the relationship of waste disposal and health effects.

Owing to the environmental and health risks associated with inappropriate waste disposal, there is need for its production to be reduced as much as possible. Laboratory waste could be recycled. Hydrocarbonated waste can be recycled by fractional distillation. Depending on the type of waste, stabilisation, detoxification and neutralisation techniques could be used to reduce its hazard to the environment. Storage in abandoned shafts and salt domes can be harmful

## **Materials Recovery - *Waste Reuse***

*There are few formal systems of materials recovery through public agencies or the private sector in Africa. Instead, **materials recovery**, including source separation and recycling, is largely the domain of the informal sector. The activity is focused on components of economic and/or social value and occurs at several levels.*

At the **household level in low-income peri-urban areas**, *resource recovery begins with the reuse of plastic bags, bottles, paper, cardboard, and cans for domestic purposes.* The rate of reuse in this instance is high, and these materials enter the waste stream only when they are no longer fit for domestic use.

At the **household level in high-income areas**, domestic servants and/or wardens carry out recovery. Rather than reusing the materials directly, they sell their bottles, plastics, cardboard, and paper to middlemen or commercial centres that pay for these materials. Glass bottles are largely returned to their point of sale for direct reuse by the beverage industry. A deposit system has maintained a high return rate continent-wide. In the majority of cities, the glass content of the MSW stream would not be sufficient to support a glass recycling industry. Instead, the bottles not used for beverages are diverted from the waste stream and used as containers in the home. Other glass items are discarded with the rest of the MSW stream.

## **Materials Recovery - *Waste Recycling***

Where there is a market, plastics are recycled by waste pickers, some of whom have modular pelletizers to process the material prior to sale. The material is then sold to local plastic product manufacturers. These plants use granulated or pelletized virgin plastics for the manufacture of packaging material and extrudable utensils and furniture.

Waste pickers with rag-pulling equipment shred, clean, and re-knit this material as all-purpose utility cloths for resale. In South Africa a deposit system is used to encourage the return of bottles and tin and aluminium cans. In addition, specially marked receptacles are placed at greens depots for the drop off of bottles and cans. The country has a sizeable tin mining and processing industry, with a demand for the recycled material. Aluminium is processed for use in beverage containers.

## **Materials Recovery - *Overview***

In summary, the informal recovery and reuse of materials from the waste

stream occurs at several levels in Africa. At the **household level** items are reused before entering the waste stream, thereby extending their useful life. Waste pickers also recover materials for personal and commercial purposes. The extent of **commercial recycling** of paper, metals, glass, and plastic depends on the presence of industrial or other end uses for these materials. While such industries may be found in some primary cities, they are largely absent in secondary cities and in rural areas. Even in those cases where they are found, they do not consistently stimulate recycling in their host cities. With few official statistics on MSW generation and recycling to point to continent-wide, it is not possible to generalise about an overall rate of waste reduction or materials recovery in Africa. As African cities move to upgrade their MSWM systems, obtaining these data will be vital to their design of well integrated systems.

## Administration of MSWM Systems

Administration of MSWM systems takes many different organisational forms across the continent. However, the institutional arrangements are fairly consistent across countries. Generally, administration is relayed through **three layers of responsibility**.

- ❑ At the highest level is the Ministry of Environment or its equivalent. In some countries responsibility for MSWM rests with the Ministry of Health or the Ministry of Planning and Development. The ministry is generally responsible for overseeing MSWM across the country. It controls the allocations for MSW capital investments by city municipal waste authorities. In many cases this ministry is charged with setting standards for MSWM based on laws enacted by the legislature. It is also through this ministry that international co-operation in MSWM is effected.

Often, the central government ministry, such as the Ministry of Environment, is charged with other responsibilities like tourism, wildlife conservation, and land and/or water resources management. These responsibilities generally carry a higher national priority than MSWM, since they often directly generate income. When combined with limited staff and budget constraints, MSWM may not receive due attention or financial allocation from the ministerial level. Besides the ministries, other national environmental agencies share oversight for MSWM. The Environmental Council of Zambia is one such example.

- ❑ Most major cities in Africa have an established **municipal waste collection system**. Collection is carried out by human and animal drawn carts (wheelbarrows, pushcarts), open back trucks, compactor trucks, and trailers. Collection rates across the continent range from 20-80% with a

median range of 40-50% (UNEP International Environmental Technology Centre 1998). In cities across West Africa, vehicle immobilisation rates reach as high as 70%, reducing the rate of collection. Where collection is performed by non-mechanical means, the volume of material to be collected often exceeds the capacity of the collection system. Community groups in some areas not served directly by municipal vehicles carry out pre-collection. For example, in Cotonou, Benin, such a group is authorised to pre-collect the waste and deposit it in communal bins for later removal by the municipality.

In most cities the municipality provides collection. Private operators also provide service on a fee basis to households and commercial establishments. In Cairo, the Zabbaleen is a group that has traditionally specialised in MSW collection and now operates as a co-operative to perform this service with authorisation from the municipal authority. However, though such co-operatives might do much to improve municipal sanitation, they are not common in other African cities. Since the mid-1970s international aid has promoted initiatives to improve the coverage of MSW collection services in Africa. These efforts have focused primarily on vehicular collections in the central city. In some West African cities, such as Dakar and Cotonou, local initiatives have focused on service to formerly neglected peri-urban areas. The lack of reliable collection service undoubtedly takes a toll on the public health and aesthetics of African cities. As the urban share of the population grows on the continent this problem is likely to increase. Collection is a key link in the chain of MSWM from the point of generation to ultimate disposal. In any initiative to upgrade waste management service, sustainable, contextually appropriate collection should be a major focus of attention.

- Various academic departments at universities across Africa provide training in the engineering principles of MSWM. In addition, most countries have sufficient resident personnel to develop and manage effective MSWM systems that are appropriate for local conditions and resources. These can be enhanced as the pool of human and other resources grows with time. However, the evolution of MSWM systems requires an enabling policy and administrative environment to be successful. Thus, in connection with MSWM in Africa, training and human resource development are subordinate issues to institutional and organisational change and to appropriate infrastructure development.

Training and human resource development generally focuses on the training of process and operations personnel. For example, drivers may be trained to operate a new compactor truck or other piece of equipment donated by an international aid agency. However, to be sustainable, such education would need to be supplemented by training of support staff in the maintenance and repair of this equipment. Landfill staff, where available, may be trained in the daily operations of spreading and covering the lifts. However, equipment

failures or the practice of open waste picking may quickly render such training ineffective. NGOs active in MSWM train waste handlers from the informal sector in the safe handling of MSW for pre-collection, sorting for recycling, and composting. The Cape Recycling Network of South Africa is a good example of an NGO involved in MSW training and awareness for members of community organisations. Among the issues addressed by the South Africa Municipal Workers Union (SAMWU) are safety and health issues affecting municipal waste handlers.

The Department of Civil Engineering at the University of Lagos in Nigeria provides training in MSWM to undergraduates. The Biology Department of Bunda College of Agriculture trains students and community groups in the practice of composting. Several other national universities across Africa provide curricular training to undergraduates in MSW-related fields. The Environmental Council of Zambia promotes periodic public information campaigns on the safe handling of MSW. The health department also trains sanitation workers responsible for monitoring sanitary conditions at the landfill. Other health ministries across Africa also provide similar training for municipal health workers on the MSW detail. In addition, the sanitation or public works departments of major municipal governments often provide some period of probationary training for their new workers. This includes MSW collection truck crews as well as manual and supervisory staff at the landfill.

## **Financing Options**

In African countries, the central government generally finances MSWM and other municipal activities through taxes collected by the Treasury. Even municipal property taxes and direct taxes on household refuse collection flow to the coffers of the central government. These funds are then allocated across the different central government ministries and to the municipalities. MSWM is then funded by allocations from the responsible ministry for capital projects and special projects (such as public education) and by municipal allocations for operation and maintenance.

Under this system, MSWM is just one of many ministerial and municipal responsibilities. It does not accommodate the actual budget required for the MSWM program, projects, and operations. User fees are based on a flat rate for collection service to households and commercial establishments. Where this service is provided by the private sector it is likely that the fees yield full cost recovery plus a profit for the service provider. In other cases, where the municipality charges a user fee, full cost recovery may not be realised and the service is subsidised by funds from other sources. Examples where municipal user fees are used include Accra; Conakry, Guinea; and some suburbs of cities in South Africa. The municipalities may retain these revenues specifically for

their MSWM activities, or the funds go into the general municipal pool. Special taxes are also used to raise revenue for MSWM services. In Dakar an MSW collection tax is imposed by the central government and is collected by the Treasury. In Bamako a cleansing tax based on property value is levied and direct user fees are also employed in some areas. Direct user charges also prevail where pre-collection services are provided by community organisations. These revenues cover part or all of the costs for community collections though they may not extend to covering the cost of emptying the communal receptacles and disposing of their contents. These latter costs are borne by the municipality. Direct municipal charges appear to be an emerging instrument for cost recovery in African cities. However the practice is not yet widespread and in general, residents pay via indirect local taxes.

In summary, financing options include taxes, user fees, bank financing (for private service providers), and international aid. The central government is the main mechanism by which these options are exploited. The Treasury generally controls the collection of taxes and the flow of funds to municipalities. Direct user fees collected and retained by municipalities are a relatively new instrument for cost recovery in several African cities. These generally provide partial recovery of the MSWM service costs. Private service providers also apply direct user charges. It is likely that these cover full costs of the service, which primarily involves collection.

## **Municipal Waste Landfills**

The overwhelming majority of landfills in Africa are open dumps. These facilities are generally located at the perimeter of major urban centres in open lots, wetland areas, or next to surface water sources. Though many municipalities have statutory requirements for the construction and maintenance of landfills these are generally not enforced. In most instances the landfills are owned and operated by the same public agency that is charged with enforcing the standards. Often a lack of financial and human resources, coupled with absent enabling policies, limit the extent to which landfills can be built, operated, and maintained at minimum standards for sanitary practice. Thus, landfills are generally sited based on considerations of access to collection vehicles rather than hydrological or public health considerations. This practice ranges from cities in the more arid regions of the North such as Algeria, Libya, and Sudan to those in higher rainfall central countries such as Cameroon and The Democratic Republic of the Congo (formerly Zaire). The environmental and health consequences for water sources at risk are more significant for the latter cities than the former.

At existing landfills management operations are minimal. Most of these facilities are unlined and unfenced. Operating practice generally does not include compaction or the application of daily cover. This may reflect the

absence of appropriate equipment or other resources to carry out these practices. Additionally, large numbers of waste pickers may scour the landfills for materials of economic or personal value. The returns from the sale of these materials go to the waste pickers, and not to the agency operating the facility.

Over the past five years some countries, including Egypt and South Africa, have considered policy changes to promote upgraded landfills for their major cities. These facilities would be classified according to the type of waste they receive, their manner of construction, and their operating procedure. Tunisia has shown leadership in developing a nation-wide sanitary landfill program. New guidelines for the construction and operation of landfills were issued in South Africa in 1995. The Environmental Council of Zambia also considers linking improved landfilling to upgraded MSW collection services in its 1995 solid waste plan, (UNEP International Environmental Technology Centre 1998).

## **Ocean Dumping of Municipal Solid Waste**

Ocean dumping of MSW is banned or restricted by law in most of Africa. This is largely a consequence of restrictions on ocean dumping initially related to hazardous waste under the Lome IV and Bamako Conventions, as well as the London Dumping Convention of 1972. Even though the practice is largely prohibited across Africa, it still occurs to a significant extent in larger coastal cities. Ocean dumping of sewage sludge beyond the 12-mile limit is still practised. However, in most of coastal West Africa as well as in South Africa, policy changes are under way to phase out this practice (UNEP International Environmental Technology Centre 1998).

In summary, landfills in Africa are primarily open dumps without leachate or gas recovery systems. Several are located in ecologically or hydrologically sensitive areas. The landfills are generally operated below the standards of sanitary practice. Waste pickers remove materials of economic value for recycling without a fee to the facility owner and operator.

Operation and maintenance costs are provided from municipal budget allocations and often do not cover the full amount needed. The result is substandard and unsafe facilities, which pose public health risks and aesthetic burdens to the citizens, they are meant to serve. Though the standards of modern sanitary landfills with leachate and gas recovery may be too expensive for most African cities today and for municipalities in OECD countries, sound practice in current operations and in the design and siting of new facilities can reduce the risks posed by existing facilities.

## **Composting of Municipal Solid Waste**

In the suburbs of larger South African cities such as Durban, there are community composting centres. Residents drop off their garden waste and it is composted and resold for household sized gardens. In peri-urban areas throughout Africa, NGOs, community based organisations, and economic interest enterprises also promote composting of MSW. These projects are generally highly labour-intensive with a low capital investment. In Brazzaville (Congo) peri-urban farmers practice small-scale composting, applying the composite to their fields. There are operating composting systems in Benin and Cameroon.

Several NGOs such as the Biomass Users Network (BUN) in Zimbabwe also promote anaerobic digestion and the recovery of methane. However, these systems primarily target rural, agricultural areas and focus on the use of animal wastes rather than MSW. Overall, even though the organic content of the MSW in the typical African city may exceed 70% (wet basis), centralised composting, anaerobic digestion, and gas recovery are not significant components of African MSWM practice. Further investigation of their market potential may prove this to be an overlooked opportunity.

Back-yard Composting is limited. Some NGOs promote the practice in Benin, Cameroon, Egypt, Ghana, Kenya, Nigeria, South Africa, and Zimbabwe but the practice does not have a significant impact on MSWM at the city level. This may be a large forgone opportunity if the typical African waste stream is high in organic material with potentially high yields of compost.

## **Incineration of Municipal Solid Waste**

*Incineration and Waste-to-Energy (WTE) remain little-used options for MSWM in Africa.* One energy recovery plant was recently constructed in Tanzania with foreign assistance. If successful in the long run, this experience would show how safe operations at such a facility can be sustained with local resources. Local capacity to sustain safe and efficient operations at such facilities is a key consideration in weighing the appropriateness of this technology for African cities. These considerations include local technical capacity to maintain and service the facility, the availability of basic spare parts, the scheduled replacement of pollution control equipment, and the effective implementation of a monitoring program to protect public health from plant emissions. The Senegalese have conducted research into refuse derived fuel (RDF). However, implementation of this system faces the same considerations listed above for incinerator technology in general. The high cost of preprocessing RDF poses an additional obstacle to its safe and cost effective implementation in Africa.

High capital and operating costs make incineration and WTE inaccessible

technologies for most African cities. Another limiting factor is the lack of infrastructure to support this technology. This includes human and mechanical resources as well as institutional controls. Furthermore, incineration in Africa would be infeasible if the waste stream is indeed 70% (wet basis) putrescible organic content. Under these conditions, incineration is likely to be an energy-consuming rather than energy-producing option. Characterisation of the ~MSW stream would first be necessary to establish the feasibility of incineration and WTE from MSW in Africa. To date, such city-specific information is largely unavailable for African cities.

In summary, incineration and WTE presently do not play significant roles in MSWM in Africa. High costs relative to other MSWM options, a limited infrastructure of human, mechanical and institutional resources, and the composition of the waste stream itself, suggest that incineration is an inappropriate technology for Africa now and for the foreseeable future.

## **Technologies in Waste Management – The RIIC Experience**

Rural Industries Innovation Centre (RIIC), based in Kanye in Botswana, is involved in several technologies for *waste collection and management*. These are:

- Ventilated Pit Latrine Technology;
- Animal Proof Bin Technology;
- Can Crusher Technology;
- Incinerator Technology; and
- Constructed Wetland Technology.

In this paper, only three technologies are discussed. These are the Incinerator, the Medium Can Crusher, and the Constructed Wetlands.

### **The Incinerator**

The RIIC designed Incinerator has evolved as a result of environmental risks caused by problematic disposal of medical waste in Botswana. The small scale - incinerator is basically a furnace designed to destroy metallic and other medical refuse for safe disposal.

The main objective of the test was to assess the performance of the small scale Incinerator as a means to destroy the waste material (mostly toxic medical waste) to aid in their safe disposal.

**Table 30.1:** Paraphernaliae in the RIIC Incinerator (Equipment, Fuel and Refuse)

<b>Apparatus</b>	<b>Fuel</b>	<b>Refuse</b>
Airflow Meter	Coal	Sharp Contents including:
Electronic Balance		Needles
Tachometer		Surgical Knives
Stopwatch		Drug Containers
Single Phase Motor		Cotton Wool
Termocouple		
Small Scale Incinerator		

The volume of the incinerator provided a limitation on the amount of refuse added per charge. The incinerator was shut to allow the contents to bum out with continuous blowing of air.

A single phase motor powered from an AC mains supply was used to drive the blower-attained air supply in the incinerator. The speeds of the motor and the blower were recorded. Also measured were the output airflow in metres per second from the blower and the airflow into the incinerator through each of the four inlet holes. The airflow as measured above was then converted to the required parameter of airflow rate in cubic metres per minute by multiplying by the cross sectional areas of the ducts.

Temperatures were measured using a thermocouple at 5 different points of the incinerator after burning for a period of 1.5 hours:

- Inside top of the incinerator;
- Inside centre of the incinerator;
- Inside bottom of the incinerator;
- Inside chimney; and
- A zone of 0.05 m around the incinerator

Results indicated the following findings:

- Motor speed - 2878 rpm.
- Blower speed - 2921 rpm.
- Blower Output Flow rate - 16.55 cubic metres per minute.

(*Note:* This is the output flow from the blower when it is not connected to the air line system into the incinerator).

**Table 30.2:** Flow rate through each of the Inlet Holes into the Incinerator. [Source: Rural Industries Innovation Centre (RIIC), 1998]

<b>Hole Number</b>	<b>Air flow rate</b> (metres cubed per min)
1	0.064
2	0.067
3	0.061
4	0.058

The results above indicate that the air flow rate into the incinerator was far much less than the output rate of the blower when it is not connected to the airline, that is, when blowing air into the atmosphere.

This is attributed probably to the airline layout that includes very sharp pipe bends where the air has to make sudden changes in direction. This creates high back pressure against the flow and thus result in very low airflow along the air supply line into the incinerator.

Although the airflow into the incinerator was deemed adequate for its desired purposes, the high back pressure against the airflow along the duct indicate that the efficiency of the air supply system is very poor and thus need to be addressed.

The need for continuous blowing to maintain the incinerator temperatures at the required level for refuse destroyal was evident since at any point the blower was turned off the temperatures dropped drastically, especially at the incinerator Bottom.

**Table 30.3:** Maximum Temperatures Recorded

<b>Incinerator point</b>	<b>Temperature (deC)</b>
Bottom of Incinerator.	1318
Centre Of Incinerator.	1201
Top Of Incinerator.	107
A zone 0.05m around incinerator.	107
At chimney (inside).	989

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Total weight of refuse destroyed per charge - 3.54 kg

Time taken to completely destroy the refuse - 1.5 hrs

Thus refuse destruction - 2.36 kg/hr

Amount of coal used per charge - 36 kg

The calorific value of the coal used - 25 mJ/kg

The design objectives of the small scale incinerator are very viable as indicated by the satisfaction expressed by the nursing community. The test results have indicated that the incinerator is capable of destroying the refuse into harmless waste that can easily be disposed off, thus satisfying its prime objective.

## **Constructed Wetlands**

### ***Treatment of Wastewater in Constructed Wetland Systems***

**Constructed wetlands** in Botswana have joined already existing wastewater treatment systems such as septic tanks-soak away, stabilisation ponds and the recently introduced activated sludge. These systems have been adopted to promote recycling of water.

**Wastewater** consists of *soluble and insoluble material*. *Treatment therefore*

*consists of sedimentation and filtration by the soil (filter medium), absorption (uptake by plants, thereby reducing conductivity), and by biodegradation by bacterial (reduction of biochemical oxygen demand - BOD)*

As wastewater percolates through soil, it experiences filtration process resulting into clarity from turbidity. Bacteria (anaerobic, facultative, and aerobic) feed on the waste for their energy, releasing by-products that either escapes as gas or dissolve in the water. The soil media as water flows along filters the insoluble products. The plants take up the soluble substances in the system. Soil media (mainly sand) traps the insoluble substances and the bacteria start acting upon them. Simpler compounds are produced which include nitrates, phosphates, carbon dioxide, hydrogen sulphide and so on, during biodegradation. The plants thrive on carbon dioxide, nitrates, and phosphates. In the process of taking up nutrients, they also take up other dissolved substances which may include pathogens. Plants release oxygen into the wastewater through their root hairs during biomass growth. The released oxygen is eventually utilised by the aerobic and facultative bacteria. Ultimately, wastewater is purified to a great extent.

### ***Use of Constructed Wetland Systems***

The methodology of constructed wetlands, based on constructed basins planted with wetland species, was pioneered by Dr. K. Seidel in the 1950's [Rossiter and Crawford, 1984) as reported by Gearheart, 1992][1]. These systems can either be Surface Flow (SF) or Subsurface Flow (SSF). The SF system entails growth of rooted emergent plants such as reeds and bulrushes in a shallow basin with the passage of wastewater across the surface of the wetland. The SSF system on the other hand involves growth of rooted emergent plants such as reeds and bulrushes in gravel as a growing medium and wastewater flows through the medium below the surface.

Constructed wetlands are cost effective methods for wastewater treatment and have been and continue to be used in several countries. In California for example, the city of Arcata have been involved in the constructed wetlands for 10 years (Gearheart, 1992)[1]. Gearheart further reported that the in the first five years (1980 -1986), the Arcata city worked on an experimental system of size 6 x 66 metre system. This was followed by a full scale system of 2.8 hectares by 12 hectares successfully in the next five years. The United states have used constructed wetland systems for more than 50 years [( Hammer and Kadlec, 1983) as reported by Gearheart, 1992][1], United Kingdom have used the system for over 100 years (Cooper and Boon, 1985)[2]. Canada [(Nichols, 1983) as reported by Gearheart, 1992][1], the Netherlands (De Jong and Koridon, 1985)[3], South Africa (Haas and Borain, 1995)[4] to mention but a few are active in the constructed wetlands systems.

## ***Purification Efficiency of Constructed Wetlands***

Efficiency of constructed wetlands or reed beds as they are called sometimes is normally referred to the Biological Chemical Demand (BOD), Chemical Oxygen demand (COD) and the elimination of the nutrients as represented by total nitrogen (N<sub>tot</sub>) and total phosphorous (P<sub>tot</sub>). The removal efficiency of the above mentioned parameters can fall within 72% and 99% with respect to BOD, and between 61 to 99% with respect to COD (Netter, 1992)[5]. N<sub>tot</sub> and P<sub>tot</sub> on the other hand vary between 5 and almost 100%. Faecal Coliform (FC) removal mechanism is by adsorption, ingestion, temperature, flocculation, sedimentation and denaturing (Gearheart, 1992)[1]. Removal of FC is normally in the range of 99% or more.

### ***The Botswana Experience***

The constructed wetland for Kanye Prisons in Kanye is taken as a case study. Construction of this 10 metre wide by 60 metre long project started in February, 1997 and was completed in August, 1997. Some modifications were carried out in the period September to November, 1997.

The Kanye constructed wetland was closely monitored for its performance and efficiency. Detailed monitoring began early January, 1998. Physical monitoring included observing the effect of heavy rainfall on the operation of the reed bed and rate of clogging of the pre-filter section as this would determine the frequency of maintenance.

### ***Results and Analyses***

All the analyses were done at the Rural Industries Innovation Centre (RIIC) laboratory. Other laboratories such as Wellfields in Gaborone, and the Department of Water Affairs Laboratory were requested to participate in the analysis of some parameters like BOD which RIIC had insufficient capacity to carry out. The other reason for approaching these laboratories was purely for result comparisons.

### ***Physical Monitoring***

This physical monitoring aspect included observations of the *rate of clogging of the pre-filter system*. Constructed wetlands have the advantage of almost no maintenance. This applies to a wetland that does not incorporate a pump, which would be the only prime mover. In the Kanye constructed wetland case study, it was observed that it took six months after the system began operating before the pre-filter clogged up. Maintenance therefore entailed removal of

**Table 30.4: Chemical Performance Data (1998) of the Kanye Prisons Constructed Wetland**

\* Indicates that no measurements were taken.

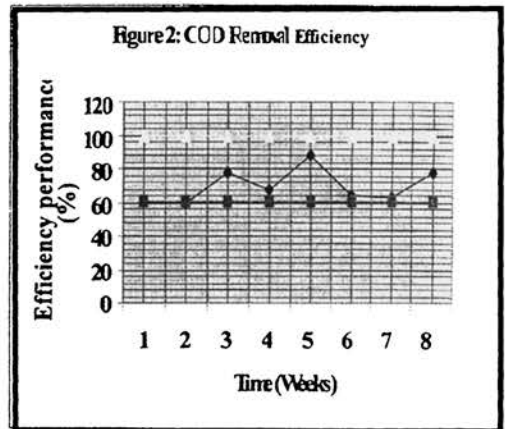
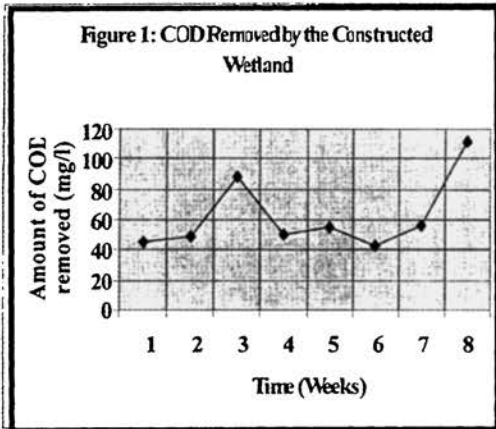


FIGURE 1 shows the COD amounts removed by the system. FIGURE 2 shows the efficiency of the system. It is obvious from the FIGURE 2 that the range of the system efficiency lies between

60% -88%. The straight lines at 61% and at 99% refers to efficiency of systems to remove COD as reported by Netter (1992)[5]. It is worth noting that the influent COD changes from time to time.

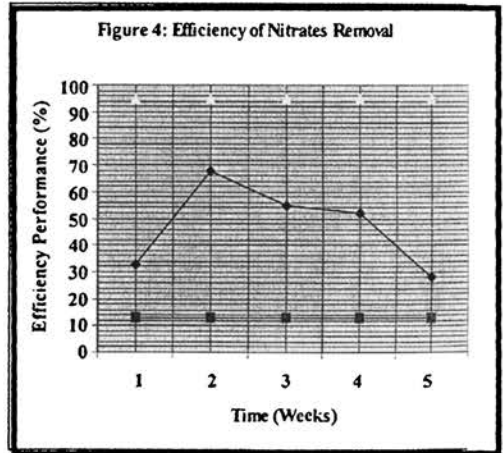
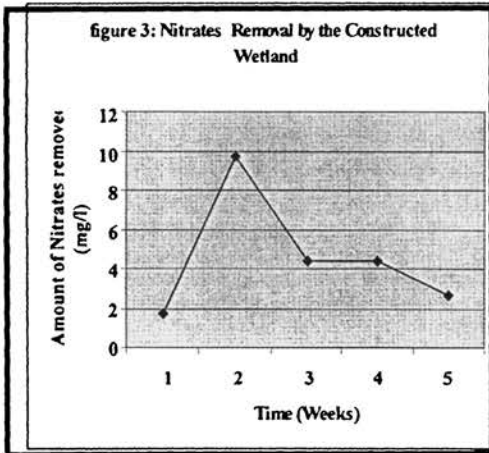
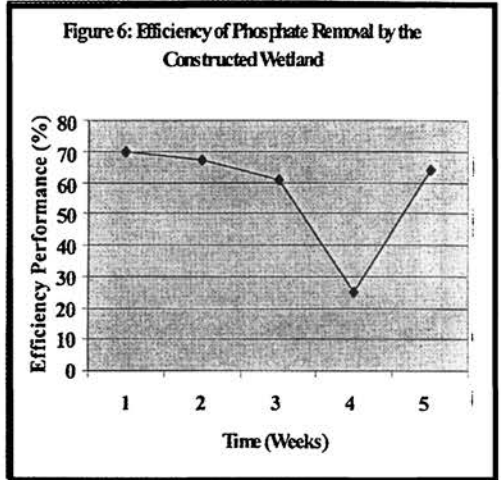
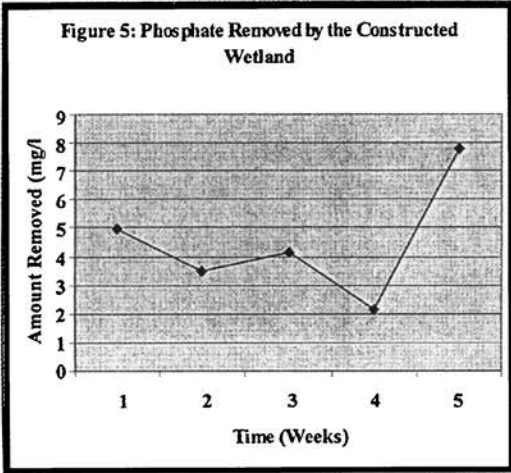


FIGURE 3 and Figure 4 show how much nitrates the system is able to remove and the efficiency respectively. The system was able to remove nitrates between 20 % - 70 %. R. A. Gearheart

(1992)[1] reports a range of 13 % - 95 % removal.



The phosphorous and nitrogen in wastewater are of water quality significance in relation to potential enrichment of receiving waters in terms of nutrients. From the FIGURE 6, it can be seen that constructed wetlands can remove a substantial amount of phosphorous, ranging between 60% - 70 %.

**Metals**

From TABLE 4 above, it can be noted that the reed bed played a role in the reduction of metals like iron, copper, nickel, and sodium. It was surprising however that instead of reducing, the manganese actually increased. No explanation can be offered at this stage.

**pH**

pH of the system remained within the range of 7.0 - 7.9. The treated wastewater passing through the constructed wetland is so clear that there is not much difference with domestic tap water. The turbidity values in TABLE 4 speak for themselves.

**Pathogenic bacterial removal**

Wetlands have been shown to effectively remove faecal coliform to 99% levels (Gearheart et al., 1985; Gersberg et al., 1984). TABLE 5 below show that the Kanye constructed wetland was able to remove faecal coliform to same levels of 99%, faecal streptococci 98%, and total cloakrooms from 90% upwards.

gravel stones and washing them before returning them. Noteworthy is the fact that the prisons were not desludging the septic tanks and consequently most sludge found its way into the pre-filter system.

## ***Discussion***

Results presented above indicate that the Kanye Prisons Constructed Wetland is presently working efficiently. Efficiency refers to the degree of removal of COD, BOD, pathogens, nitrogen and phosphorous. This was satisfactorily achieved.

A point worth stressing is the fact that emphasis was placed on a low impact engineering approach, meaning that unnecessary expenses were avoided as much as possible. Natural processes like gravity flow were taken advantage of thereby excluding pumps in the system. The design concept was such that the reed bed fit naturally into the landscape following the topography.

## ***Conclusion***

Comparison of the data collected from the analyses show that the Kanye Prisons Constructed Wetland have achieved the guidelines of water for irrigation purposes as laid down by the Department of Water Affairs of Botswana. The guidelines state that water for irrigation which originates from domestic wastewater should have faecal coliform content of 1000 CFU/100ml for cooked vegetables, and the BOD should be 35mg/l. Values obtained through the reed bed were faecal coliform 125 CFU/100ml and BOD 24mg/l.

## **The Benefits of Wastewater Treatment**

The benefits of wastewater treatment include the following:

- Protection of public health from waterborne disease;
- Protection of the natural environment and the wildlife that depend;
- Protection of water resources; and
- Removal of toxic and hazardous materials that might accumulate in the environment.

Treated wastewater could be used for a variety of purposes, including recreation. Small hydroelectric power generation can be interesting to investigate especially looking at the vast amounts of wastewater generated.

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