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CLIMATE CHANGE AND WASTE MANAGEMENT: A BALANCED ASSESSMENT

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ABSTRACT

This paper examined the two-way interaction between climate change and waste management. It showed that while solid waste management can have exacerbating effects on the climate especially due to the emission of greenhouse gasses, climate change will have some positive impacts on wastewater management facilities such as waste stabilization pond and septic tanks. It was also shown that rising temperatures will lead to exponential increase of bacteria activity in wastewater treatment facilities, hence resulting in increased efficiency. The effects of other climate change indicators such as increased rainfall, flooding and drought on some waste management facilities have also been highlighted. The work indicates that while high temperatures may be good for these units, increased rainfall will have a net negative effect leading to inundation and consequent overland flow of wastewater from treatment facilities. Furthermore, interaction between popular solid waste management options namely: composting, landfill, incineration and anaerobic digestion was succinctly illustrated. Waste management strategies for reduction of greenhouse gas emission in developing countries were proposed.

Keywords: climate change, waste management, global warming potential, biogas, fossil fuel, environment

INTRODUCTION

Climate change is thought to be the culprit responsible for some of the recent environmental problems the world over, most prominent of which are severe flooding in parts of Asia and America, droughts in parts of Africa and the global food crises which gave rise to civil unrests in many parts of the world. Even though the current global economic recession has been blamed on unscrupulous economic practices (Obama, 2009), proper scrutiny may reveal that climate change has a hand in it. According to Holdern (1992), climate change is the most important and dangerous, and certainly the most complex global environmental issue to date. Apart from direct threat to lives and the environment, climate change is a serious setback to sustainable development.

PRIMARY CAUSES OF CLIMATE CHANGE

A review of the factors purported to be responsible for climate change will reveal that climate change is inevitable. The primary cause of climate change is the variation of the solar radiation retained by the earth's surface (Pidwirny, 2006). Routinely, variation in the quantity of solar radiation reaching the earth is controlled by three cycles known as the Milankovitch cycles. They are the *eccentricity* which has a 100,000 years cycle and has to do with the shape (elliptical or circular) of the earth at any time; *precision of the equinoxes* which has a cycle of 26,000 years and has to do with earth's rotation; and *obliquity* which has a 41,000 years cycle and has to do with the inclination or tilt of the earth (Pidwirny, 2006). Other occasional factors which may lead to short-lived climatic variations include: volcanic eruptions, variation in solar outputs, variation in orbital characteristics and variation in atmospheric CO_2 (Pidwirny, 2006).

Apart from variation in atmospheric CO_2 on which man has a substantial influence, the other factors, to a large extent, are independent of anthropogenic factors. So much sensitization has been going on about the role of burning of fossil fuel in climate change, however it must be noted that burning of fossil fuel does not initiate climate change, rather it only amplifies it (Pidwirny, 2006). This is to say that without burning fossil fuel, climate change would still have taken place but what remains to be ascertained is by how much the burning of fossil fuel has *hastened* and *aggravated* climate change.

Research efforts have shown that deforestation and burning fossil fuel have increased atmospheric CO_2 from 280ppm to 380ppm between early 1700's and 2005. This represents 35.7 % increase in about 300 years and all things being equal, 100% increase in the next 530 years. The greenhouse gases that are making the largest contribution to global warming besides carbon dioxide (CO_2) are methane (CH_4) and nitrous oxide (N_2O) both of which are produced during the management and disposal of wastes. There is no universal consensus on the quantity of greenhouse gases emitted over the years, but it is obvious that the emission assumes an increasing trend (see Figure 1). The figure (using the data obtained from Monni, Pipatti, Lehtilla, Savolainen & Syri, 2006) shows that by 2030, the concentration of greenhouse gases in the atmosphere will be equivalent to 1500 mega tones of CO_2. This implies that, if the current trend is not checked, a time will come when climate change will no longer be a recurring phenomenon that takes hundreds of thousands of years but a sustained event. Countries have to reduce their dependence on fossil fuel in order to check the rate of climate change, but there is no readily available replacement for fossil fuel.

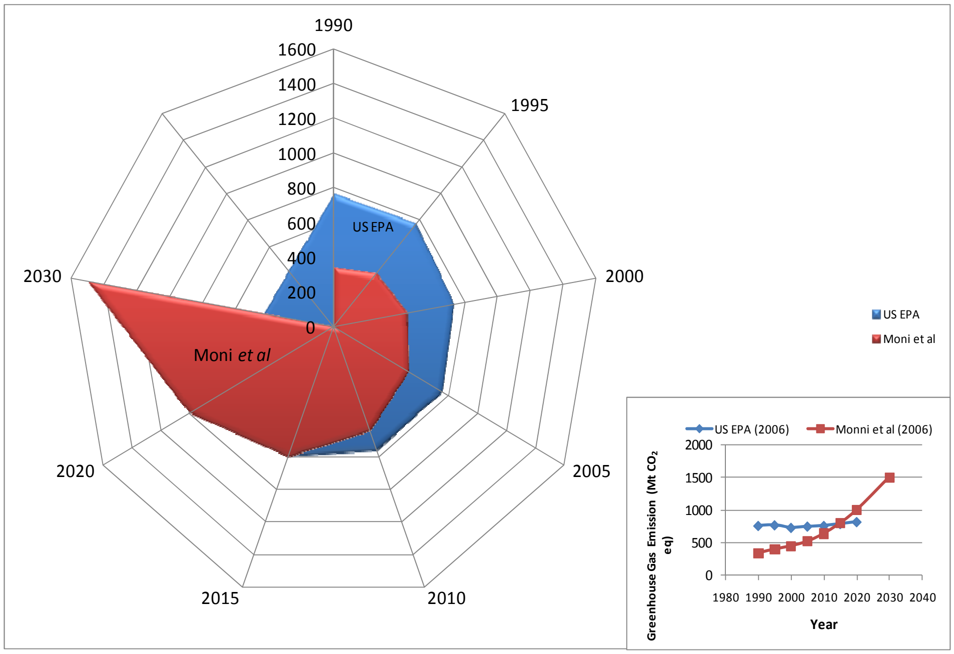

Figure 1: Greenhouse Gas Emission in MtCO$_2$eq. (Data Sources: United States Environmental Protection Agency [USEPA], 2006 & Monni et al, 2006)

CLIMATE CHANGE AND ENVIRONMENTAL HEALTH

Climate change has a lot of implications for the environment and consequently public health. While it has been estimated that for 1m rise in sea level, 3.7 million people will be displaced from the coastal regions of Nigeria (Awosika, French, Nicholls, & Ibe, 1992), droughts in the hinterlands will lead to unhealthy sanitary conditions. Additional application of fertilizer may be needed to take advantage of the potential for enhanced crop growth that can result from increased atmospheric CO_2. This can pose a risk, for additional use of chemicals may impact water quality with consequent health, ecological, and economic costs (Rosenzweig, Iglesias, Yang, Epstein & Chivian, 2002). The two most important climatic elements determining the occurrence and localization of pests and diseases appear to be moisture and temperature. In general, pests and disease vectors do better when the temperature is high under conditions of optimum water supply. Global warming is therefore likely to extend the range of distribution of certain pests and diseases of crops polewards (Adejuwon, 2004). In general climate change is associated with (i) variability and changes in rainfall patterns; (ii) changes in water levels in lakes, rivers, seas, ponds, streams and groundwater; (iii) frequency of storms and droughts; (iv) increased desert encroachment, and (v) excessive heat. Almost all of these have serious implications for the environment and public health.

SOLID WASTE MANAGEMENT AND ENVIRONMENT

Nature exists in a balance. The most difficult challenge facing man is not exploiting nature, but maintaining this critical balance while doing so. Massive exploitation of the earth crust has provided man with endless natural resources which are constantly being transformed into products that are discarded as waste after serving their purpose. Unfortunately, man cannot return these waste products to their crude state in the earth crust; hence the easiest route of escape is to release these materials to the atmosphere in gaseous forms. The accumulation of these gases in the atmosphere over many years has upset a critical balance of nature. The issue of global warming and climate change will continue to be a threat until man learns to return used or waste products to their crude states. Obviously, this is impossible and the closet that man can ever come to that is recycling and reuse. The most popular contributor to global warming via gaseous emission into the atmosphere is the burning of fossil fuel. Recently, concerted efforts are being made, especially in developed nations, to reduce dependence on fossil fuel as a means to reduce global warming. However, a silent but massive contributor to greenhouse gases is waste management. A recent report by the United States Environmental Protection Agency estimates that 42% of total greenhouse gas emissions in the US are associated with the management of waste materials (USEPA 2009). Figure 2 shows the contributions of these gases to global warming and a simple analysis reveals that activities associated with waste and waste management contribute a total of 57% of CH_4 emission compared with 26% contributed by energy production. It would seem that CO_2 is the most critical greenhouse gas by looking at the figure but a large portion of CO_2 emission comes from treating food waste and is of no consequence to global warming because it is biogenic meaning that it was atmospheric CO_2 before it was fixed by plants.

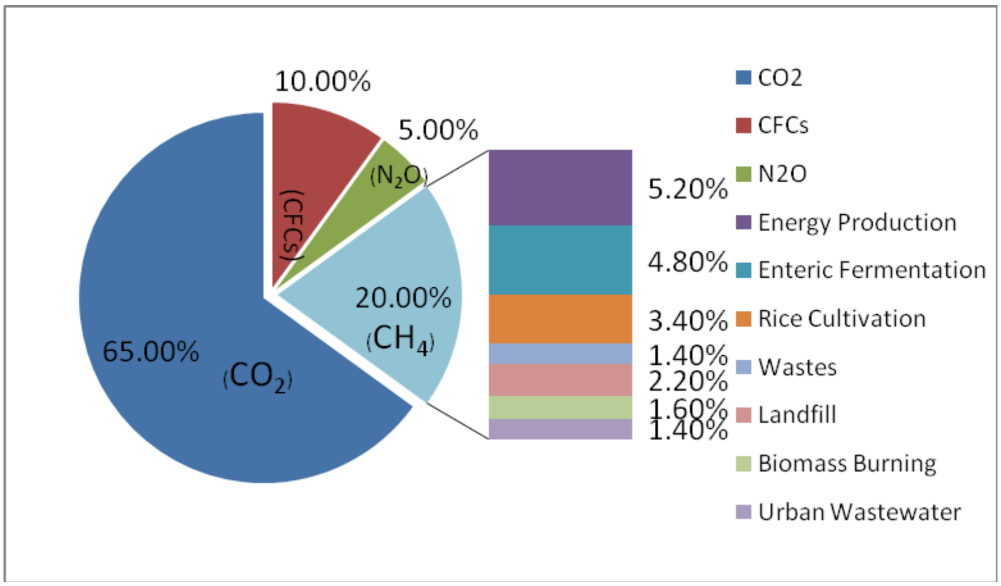

Figure 2: Contribution of Different Gases to Global Warming (Illustrated with data from Intergovernmental Panel on Climate Change as cited by Baldasano and Soriano, 1999)

Waste management options such as landfill, composting, incineration / mass burns and anaerobic digestion / biogas plants collectively emit substantial amount of greenhouse gases. Composting makes use of micro-organisms to oxidize biodegradable wastes (especially food and garden waste) to CO_2 and water vapour, using oxygen in the air as the oxidizing agent. Anaerobic decomposition converts biodegradable carbon to biogas, which consists of about 65% CH_4 and 34% CO_2 with traces of other gases. In landfills, microbes gradually decompose organic matter over time producing roughly 50% of CH_4 and 50% of CO_2 and trace amount of other gaseous compounds. Methane emissions from landfill represent the largest source of greenhouse gas emissions from the waste sector, contributing around 700 Mt CO_2-e for 2009 followed by incineration, estimated to contribute around 40 Mt CO_2-e (UNEP, 2009).

Global warming potential of waste management can be reduced by a combination of sorting, biogasification, incineration and landfilling (see Figure 3). Global warming potential (GWP) is a factor that allows the concentrations of greenhouse gases to be expressed in terms of the amount of CO_2 that would have the same global warming impact (Smith, Brown, Ogilvie, Rushton & Bates, 2001). GWP is expressed as carbon dioxide equivalent (CO_2e) over a specific time horizon, say 21 years, 100 years or 500 years. Methane (CH_4) is estimated to have a GWP of 25, whereas carbon dioxide (CO_2) and nitrous oxide (N_2O) have GWPs of 1 and 310 respectively (see Table 1). GWP is estimated using Equation 1.

$$GWP_i = \frac{\int_0^{TH} a_i x_i(t)dt}{\int_0^{TH} a_{CO_2} x_{CO_2}(t)dt} \qquad (1)$$

Where a_i and a_{CO2} represent the radiative forcing of the chemical specie in question and CO_2 respectively; x_i represents the time-dependent concentration of the chemical specie in the atmosphere after the time of release; x_{CO2} represents the time-dependent concentration of CO_2 in the atmosphere after the time of release; and *TH* is the time horizon over which GWP is desired. The radiative forcing is the amount of energy absorbed by the chemical specia as infrared energy attempts to leave the earth.

Incineration has a lower global warming potential because, the heat generated can be diverted as a source of energy in the place of fossil fuel. Even though the global warming potential of landfill can be reduced by trapping the methane and using it as a source of energy, some of the gas will still escape and, of course, the accompanying CO_2 has no energy potential (see Figure 4). There is also additional capture of carbonaceous materials by the soil (sequestration). Use of compost may also have beneficial effects on greenhouse gas fluxes by replacing other products like fertilizer and peat; and may also lead to increased storage of carbon in the soil. Furthermore, the major greenhouse gas from incineration is CO_2 while the major greenhouse gases in landfill are CH_4 and CO_2. CH_4 has a global warming potential which is twenty one times higher than that of CO_2, hence the higher emission factor of landfill. Figure 3 shows vividly that the global warming potential of both incineration and landfill can be reduced by employing a wholesome waste management strategy involving sorting. Sorting ensures that waste materials are segregated into generic forms for ease of recycling, treatment and subsequent disposal. In the case of incineration, sorting helps ensure that recyclable combustible materials such as plastic, tyre and paper are excluded from the incinerator, hence lowering global warming potential. It can be clearly seen from Table 1 that the CO_2 from incineration and decomposition of organic matter in landfills and composting plants is short cycle and has no global warming potential as opposed to the CO_2 from burning of fossil fuel.

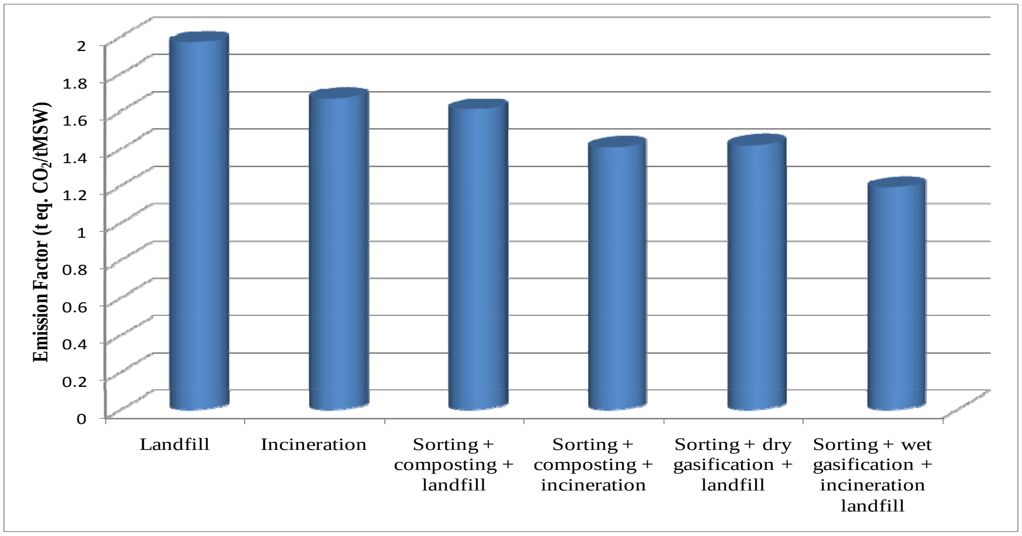

Figure 3: Reduction of Emission Factor of Landfill and Incinerators (Data for this chart was sourced from Baldasano & Soriano, 1999)

Table 1: Global Warming Potential of Greenhouse Gases from Waste Management (Smith et al, 2001)

Emission	**Origin**	**Trend in Atmospheric Concentration**	**Effective Global Warming Potential (100 Years)**	
			Emission	**Carbon Sequestration**
CO_2 (fossil C)	Combustion of plastics	Increasing	1	0
CO_2 (Short-cycle)	Combustion and respiration of biomass	Stable	0	-1
CH_4 (Short-cycle)	Methane-forming decomposition under anaerobic conditions	Increasing	21	(not applicable)
N_2O	Combustion process, nitrogen metabolism in the soils, fertilizer manufacture	Increasing	310	(not applicable)
CFC-12	Refrigerant/insulation foam	Increasing	8100	(not applicable)
CFC-11	Refrigerant/insulation foam	Increasing	3800	(not applicable)
HFC-134a	Refrigerant/insulation foam	Increasing	1300	(not applicable)
HFC-141b	Refrigerant/insulation foam	Increasing	600	(not applicable)
CF_4	Primary aluminum smelting	Increasing	6500	(not applicable)

Figure 4 shows the interaction between selected waste management options and global warming. Positive sign implies contribution to global warming while negative sign indicates a counteracting effect on global warming. It should be noted that CO_2 emission is common to all four options viz: landfill, composting, incineration and anaerobic digestion. However, the

CO_2 generated by composting, anaerobic digestion and landfills is biogenic and hence has no global warming potential. Landfill and composting offer an exceptional advantage of carbon sequestration. Carbon sequestration is a viable means of replenishing carbon composition of the earth crust as well as reducing greenhouse gas emission. The global warming potential associated with landfills depends on whether biogas is captured or not. Biogas which is a combination of methane and carbon IV oxide is a replacement for fossil fuel. Methane from landfills is of organic origin and therefore has low global warming potential compared to other greenhouse gases. It is obvious that composting has no global warming potential because the CO_2 released during decomposition is of organic origin and is therefore biogenic. In many developing countries compost is sold to farmers for soil amendment. Incineration provides energy in the form of heat thereby reducing requirement for fossil fuel, but it has the disadvantage of releasing greenhouse gases of high global warming potentials into the atmosphere.

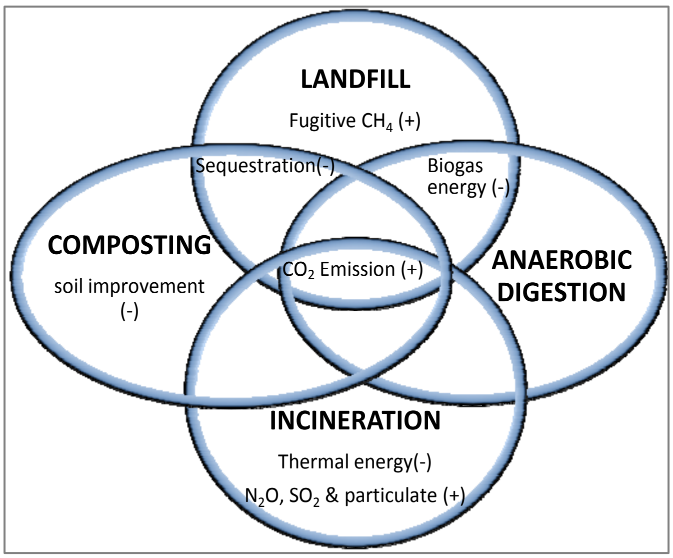

Figure 4: Interactive Contribution of Waste Management Options to Global Warming

EFFECT OF CLIMATE CHANGE ON WASTEWATER TREATMENT FACILITIES

Waste treatment facilities are designed to effect removal or reduction of organic matter, harmful chemical compounds, useless solid and pathogenic organisms from waste products before discharging them into the environment. Most often waste products are discharged into water bodies which serve as water supply for most communities in Nigeria. If these wastes are not properly treated before discharge, it could lead to outbreak of epidemics, fish kills, eutrophication of water bodies (Agunwamba, 2001), and accumulation of lethal heavy metals in the body. Water contaminated by human, chemical or industrial wastes can cause a number of diseases through ingestion or physical contact. Water-related diseases include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis and yellow fever. Consequently, no other type of intervention has greater impact upon a country's development and public health than the condition of clean drinking water and the appropriate disposal of human waste (Swedish International Development Agency , 2000). Climate change will definitely affect the performance of many waste treatment facilities as the efficiencies of these plants depend to a large extent on environmental factors.

Waste Stabilization Ponds

A waste stabilization pond (WSP) is a basin dug in the earth which removes organic and pathogenic organisms one thousand times better than the conventional treatment plants (Mara, Pearson & Silva, 1983). This waste treatment facility is very suitable for African communities because it uses no advanced technology and is therefore easy to construct and maintain. Its efficiency depends on abundance of sunlight and high ambient temperatures (Agunwamba, 2001). Hence it is obvious that rising temperatures will favour the performance of the waste stabilization pond. Results obtained by Polprasert, Dissanayake and Thank (1983); Arthur (1983); Saqqar and Pescod (1992); Agunwamba (1997) showed that bacterial activity in ponds is a function of temperature. In fact, results obtained from a more recent study in Northern Brazil suggest that maximum design volumetric loadings may increase to 350 g BOD_5/m^3d at 25°C rather that restricting it to 300 g BOD_5/m^3d at 20°C (Pearson, Mara, Orugai, Cawley & Silva, 1996). The effect of temperature on the performance of waste stabilization pond can be easily visualized in Figure 5.

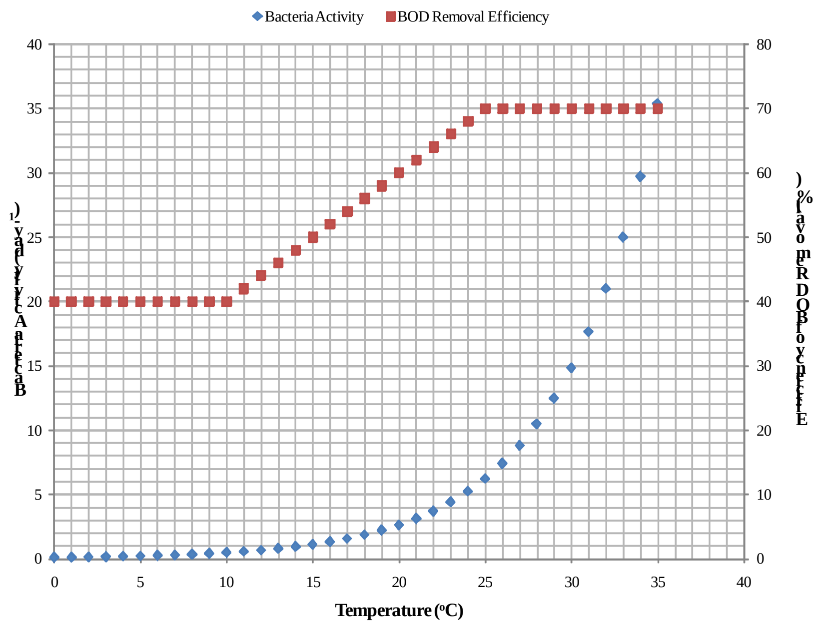

Figure 5: Effect of Temperature on Microbial Activities.

In Nigeria, a new technology evolved as a result of the incorporation of solar reflectors in the conventional waste stabilization pond for the purpose of increasing the efficiency and reducing the land area requirement of waste stabilization ponds (Agunwamba, Utsev & Okonkwo, 2009). This involves fitting model waste stabilization ponds with solar reflectors to enhance bacterial activity and pathogen removal (Figure 6). Utsev (2011) modelled the solar enhanced WSP and established a new equation for the design of solar enhanced WSP as shown in Equation 2.

$$\frac{N_2}{N_1} = \frac{\left[\exp\left\{\frac{ux}{2D}\left\{1-\left(1+\frac{4K_1ID}{u^2}\right)^{1/2}\right\}\right\}+N_p\right]}{1+K_o\theta} \quad (2)$$

Where x is the characteristic length, which is the average distance travelled by the wastewater while under direct exposure to sunlight; N_p represents the density associated with the particles, which shield the bacteria from being affected by irradiated light; D denotes the dispersion coefficient which accounts for deviation of hydraulic behavior from that of perfect plug flow; U is the flow velocity of the fluid; N_1 and N_2 are the bacteria concentrations before and after irradiation, respectively; I represents the density of irradiation while K_1 stands for the inactivation rate constant; K_o represents the bacteria die-off rate coefficient without solar radiation enhancement and θ is the detention time. Equation 2 indicates enhanced performance of waste stabilization pond due to increased solar radiation.

Figure 6: Solar Enhanced Waste Stabilization pond

Since climate change is associated with elevated CO_2 levels, the multiplication of algal population in the pond is highly catalyzed. Through photosynthesis, algae releases oxygen for respiration and subsequent biodegradation of organic matter by the bacterial population in the pond. Algae also produces the physicochemical conditions for pathogen die off (Agunwamba, 2001). Light intensity also favours algal reproduction as Oswald and Gotaas (1957) reported that for ponds receiving influent with BOD concentrations greater than 300mg/l, light intensity becomes the limiting factor for algae growth. Obviously, climate change greatly improves the performance of waste stabilization ponds. However, flooding which is engendered by climate change could pose a problem for waste stabilization ponds. Flooding can cause overloading of ponds thereby causing them to fail temporarily. Flooding can also cause ponds to overflow causing *overland* flow of wastewater and consequent pollution of the environment and contamination of groundwater (see Figure 7). Overland flow of wastewater can lead to the deposition of pathogens on crops, flow of wastewater in water wells, overloading of other treatment facilities which have cracked walls and eutrophication of lakes and streams.

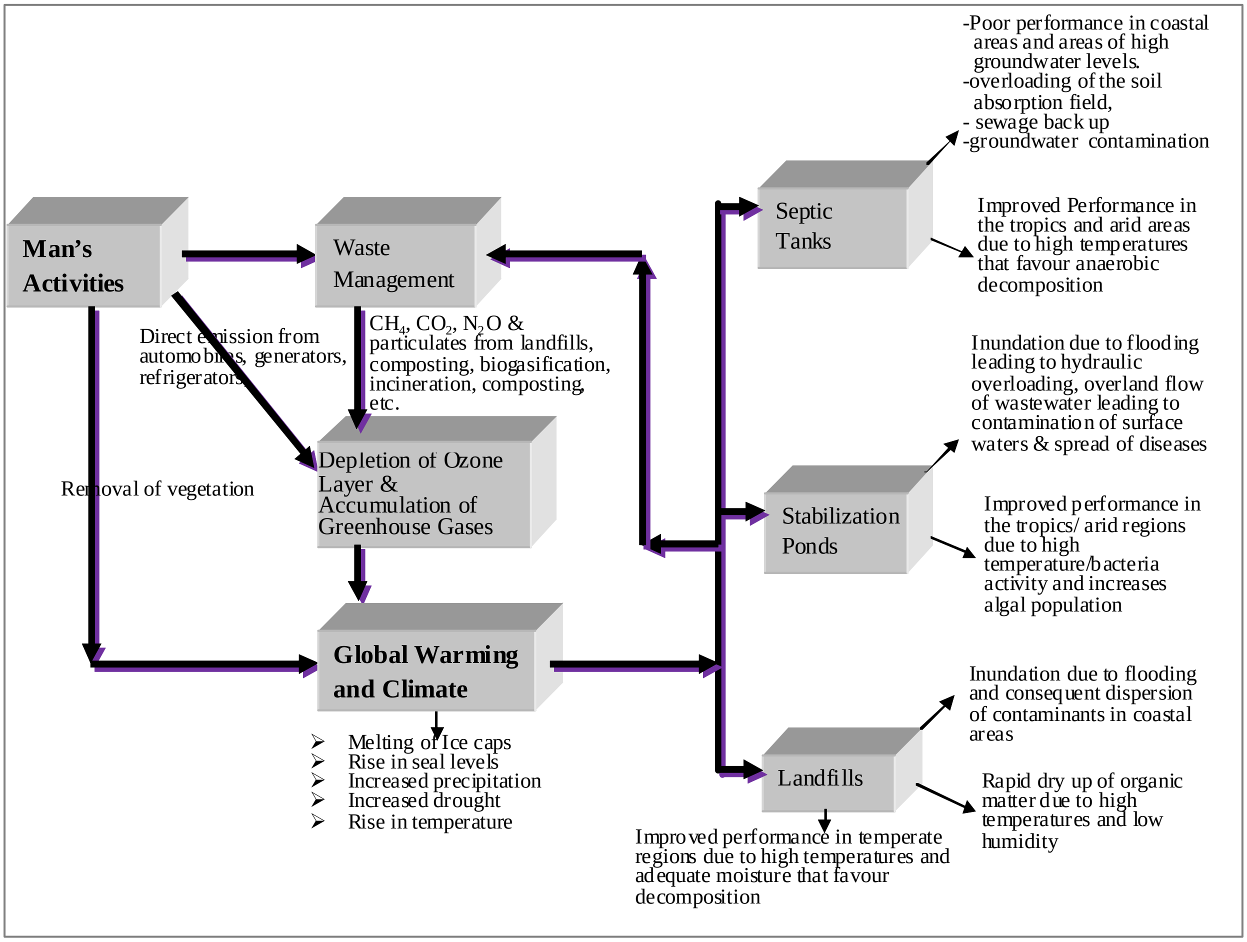

Figure 7: Interaction between Selected Waste Treatment Options and Climate Change

Septic Tank System

The septic tank is an enclosed receptacle designed to collect wastewater, segregate settleable and floatable solids (sludge and scum), accumulate, consolidate and store solids, digest organic matter and discharge treated effluent (Bounds, 1997). The structural requirement of the septic tank is that: the septic tank including all extensions to the surface shall be watertight to prevent leakage into or out of the tank. It shall be structurally sound and made of materials resistant to corrosion from oil and acids produced from septic tank gases (Kansas State Department of Health and Environment, 1997). A cursory inspection of the septic tanks in Nigeria will reveal that most of them do not meet this requirement as contractors use inferior materials in a bid to maximize profit. Even in the United States, Bounds (1997) reported that although most regulatory authorities require watertightness, enforcement is almost non-existent.

Climate change could lead to elevated groundwater levels in some places (Figure 7). This will cause some soils to become unsuitable for the construction of the septic tank. When groundwater levels are elevated, groundwater will find its way into septic tanks through cracks in the walls of the septic tank thereby causing overloading and subsequent failure of the system. If however, water levels do not get to the septic tank, wastewater could leak out of the tank through cracks. If there is not enough separation between the bottom of the tank and the groundwater, the wastewater leaking from the tank will not undergo a substantial degree of treatment before joining groundwater. This will definitely cause pollution as Cogger (1988) reported that contamination of groundwater form onsite waste disposal systems (OSDS) has been implicated in up to 40% of groundwater attributed outbreaks. However, if the structural integrity of the septic tank is guaranteed such that leakages do not occur, then rising temperatures resulting from climate change will enhance the performance of the septic tank. According to Seifert (1999), digestion of wastes is a temperature dependent process, and colder temperatures may hinder effective breakdown of wastes in septic tanks. The implication of that statement is that septic tanks perform better under higher conditions of temperature. Also Viraraghavan, (1976) observed that generally, periods of higher air and soil temperatures showed better efficiencies of the septic tank system.

Soil Absorption System

The septic tank is more or less a primary treatment facility whose effluent is usually discharged into a soil absorption field, a constructed wetland, a waste stabilization pond, baffled anaerobic filter, a mound system, rock-plant filter, peat filter, synthetic filters or pressure distribution system, for further treatment before reuse or disposal. In Nigeria, the soil absorption field or soak away is the most commonly used treatment system for septic tank effluent because of its low cost and ease of construction compared to the other systems. In 1980, a study found septic tank/soil absorption systems to offer the lowest cost and the highest level of performance among six on-site treatment techniques tested (USEPA, 1980). Researchers have shown, however, that certain conditions must be met for optimal performance. The bottom of the soil absorption field should be far from the water table or an impermeable bed rock. USEPA (1999) recommends that since the soil absorption area must remain unsaturated for proper system functioning, it may not be feasible to install septic systems in regions prone to frequent heavy rains and flooding or in topographical depressions where surface waters accumulate. Cogger, Hajjar, Moe and Sobsey (1988) found that the depth of unsaturated soil beneath the system was determined to be a more decisive factor in system performance than hydraulic loading. This is because when flooding occurs, water table rises and the soil absorption system is inundated leading to an anaerobic condition which drastically reduces efficiency since the soil absorption system is an aerobic system. In addition, flooding reduces the travel path of wastewater leading to short circuiting which causes wastewater to join groundwater without proper treatment. The consequence is that the contaminated groundwater flows into wells and boreholes which causes the spread of diseases if the water is ingested by man.

Landfill

A landfill is usually a depressed portion of the earth where decomposable refuse is dumped and allowed to decompose. In advanced countries landfills incorporate systems for gas collection and for sorting of reusable and recyclable materials. Sorting of reusable and recyclable materials help to minimize the quantity of waste dumped on the site and provide raw materials for industries. In Nigeria, however, landfills take the form of poorly maintained open dumps overflowing with all sorts of refuse – putrescible and non putrescible. No sorting or gas collection is done. This waste management facility is used to achieve two principal aims viz: elevation of depressed areas and disposal of waste. Its operation relies on the interaction between putrescible matter, moisture and temperature. It gives rise to methane (CH_4), carbon IV oxide (CO_2), trace compounds, leachate and residual matter. Rise in temperature will alter decomposition rates and thus affect the landfill gases generated, length of active gassing phase, site settlement; closure and completion (see Figure 7). However, since decomposition processes are complex, higher temperatures will not necessarily imply higher decomposition rates – where higher temperatures and high moisture content will accelerate decomposition, higher temperatures combined with low moisture content will hamper decomposition (Beb & Kersey, 2003). According to Beb and Kersey (2003), higher temperature will also lead to higher evaporation losses which will lead to the production of less but stronger leachates. In addition increased precipitation and rise in sea levels could lead to the inundation of landfill sites leading to the dispersion of untreated waste to the surrounding.

REDUCING EMISSION THROUGH HOLISTIC WASTE MANAGEMENT

In many Nigerian cities and communities, solid waste is usually sent to open dumps scattered all over the city. There is no systematic approach to solid waste management. Wastes arriving at the open dumps are usually unsorted. However, recyclable materials such as plastics, bottles, metal scraps, cans rubber and leather are retrieved from the dumps by scavengers who earn a living by selling recovered materials (Figure 8). Some of the waste items such as plastic cans and bottles are sold to families while the rest are sold to the industry as raw materials for new products. Unfortunately, these scavengers are largely uneducated and sometimes constitute a nuisance to the society. A study conducted in three states of Nigeria (Lagos, Akwa Ibom and Borno) revealed that about 44% of scavengers did not go beyond primary school and none had a tertiary education (Okudo, 2010). Cases of thefts by scavengers are common. The ultimate goal of these scavengers is to earn a living rather than promote environmental sanitation or public health; hence their role in solid waste management is still primitive.

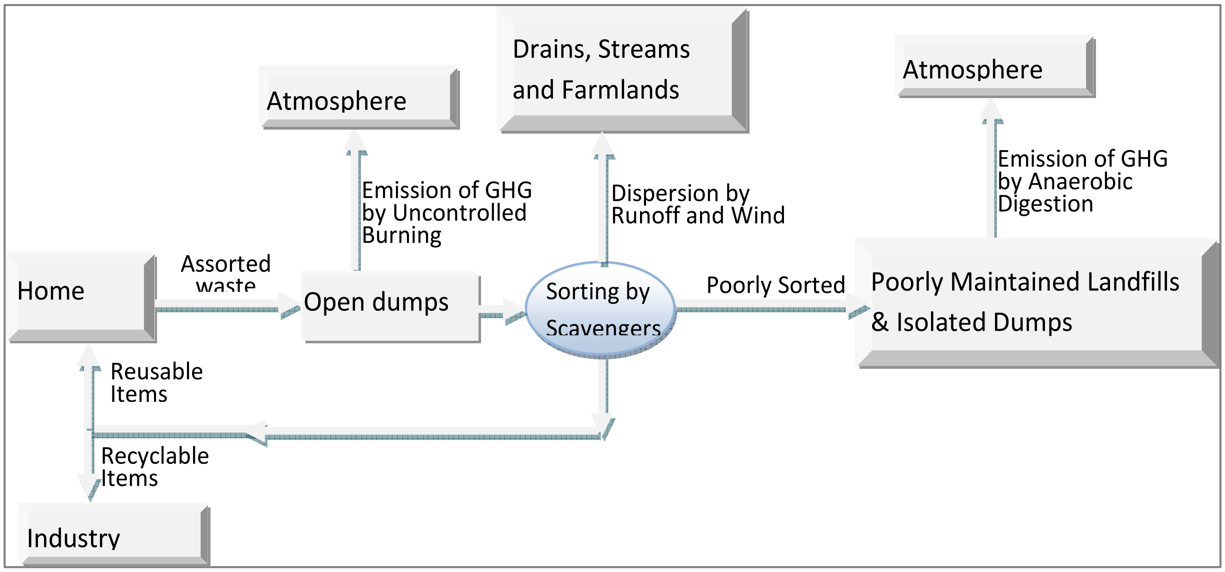

Figure 8: Prevailing Solid Waste Footprint in Nigeria

The municipal waste management authorities are saddled with the responsibility of evacuating residual waste from the open dumps. Waste remaining at dump sites after the activities of scavengers are collected and finally disposed at landfills which are usually poorly maintained with no provisions for compaction, gas collection and leachate control. Most municipal waste management authorities are understaffed and ill equipped, and therefore cannot keep pace with the rate of waste generation. It is not uncommon in Nigeria to see open dumps overflowing with waste to the extent that drains are blocked and traffic is obstructed. This situation often prompts people to set the dumps ablaze, in an attempt to create space for more waste, leading to massive release of greenhouse gases (Figure 9). Most times these dumps are set ablaze before all reusable and recyclable materials are recovered by scavengers, resulting in huge loss of potential raw materials for industry. The dumpsites can also be set ablaze by some scavengers who specialize in picking metals in order to reduce the rigour of going through heaps of waste.

Figure 9: Picture of a Waste Dump Set Ablaze by Scavengers

In order to promote environmental health and sanitation as well as reduce greenhouse gas emission in a developing country like Nigeria, a waste management flow chart (Figure 9) has been proposed. The flow chart is aimed at engendering sustainable development through environmental sanitation, maximum resource and energy recovery, and reduction of greenhouse gas emission. Given the level of development in Africa, it is not easy to eliminate open dumps. However, existing open dumps can be converted to transfer stations operated and maintained by municipal authorities. These transfer stations should have walls and gates to check unauthorized access and provide a boundary for waste materials. This will further reduce dislodging of waste materials by runoff and wind as well as prevent uncontrolled burning and obstruction of traffic. Scavengers could be formally employed for sorting of waste in the absence of mechanized options. In the proposed waste management strategy, sorting has been given a cardinal and indispensable role. It has been shown earlier (Figure 3) that the emission factors associated with incineration and landfill can be reduced by sorting. Sorting provides enormous resources for the industry; and renders waste amenable to easy handling, treatment and disposal. After sorting, recyclable items such as paper, metals, glass and plastics are sent to the industry. A cursory survey revealed that some items such as paper, bottles and plastic cans are reused by low income earners. Waste papers are used for wrapping food items in local markets; or they can be used in the place of tissue papers. In addition, waste tyres are used for making shoe polish and soles for footwears; waste papers are used for the production of toilet tissues; plastic and nylon materials are converted into pellets and then used for production of car bumpers, car mirror holders, rubber slippers and shoes, plastic buckets, plates and cups; metal scraps are converted into cutlasses, hoes, spades, metal plates and steel rods (Okudo, 2010). Figure 10 suggests that sorting should be done at the transfer station but a better option is sorting at source (SAS). Families could also be mandated to deliver their wastes in sorted forms. This will require that families have different waste bins for different categories of waste such as: (i) recyclable and non-recyclable, (ii) biodegradable and non-biodegradable, (iii) compostable and non-compostable, (iv) combustible and non-combustible, etc. A more elaborate but less practicable option is to sort them into generic forms such as food waste, plastic, glass, paper, nylon, textile, metals, etc. This is more difficult because it requires that each family will have about seven waste bins for different categories of waste.

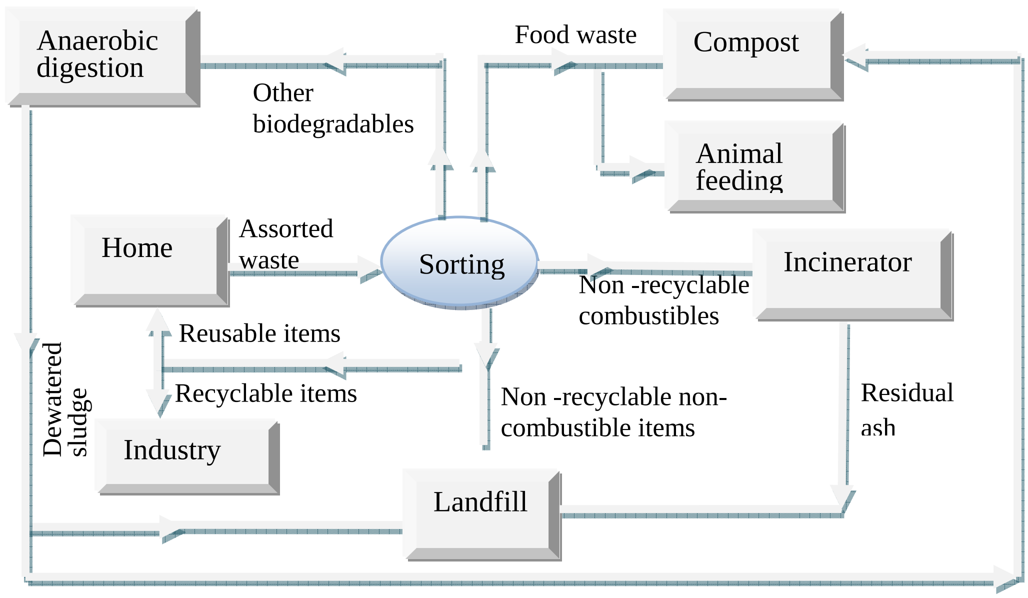

Figure 10: Best Waste Management Practice Flow Charts for Minimization of Greenhouse Gases and Maximum Resource Recovery

In developing countries, organic waste constitute over 70% of waste generated which can be composted to provide manure for increased agricultural productivity. Composting is a natural process that requires no artificial raw material. The CO_2 released during the process is biogenic and therefore has no net climatic impact. With a bit of advanced technology, organic waste can also be digested anaerobically to generate biogas. The replacement of fossil fuel with biogas is a positive step in curbing climate change. Food waste can also be fed to domestic or farm animals as illustrated in Figure 10.

CONCLUSION

Climate change is an undesirable phenomenon whose negative impacts outweigh the positive impacts. The interaction between climate change and waste management is complex one that is difficult to predict with precision. The emission of greenhouse gases through solid waste management practices such as waste collection (transportation), incineration, landfill, anaerobic digestion and composting contribute to global warming and attendant climatic variations. The major greenhouse gases released in the course of solid waste management include CO_2, CH_4 and NO_2. Though climate change has partly been aided by the emissions from solid waste management, there is evidence to show that climate change can have positive effects on some waste treatment facilities. Climate change may have a net benefit for waste treatment facilities such as the waste stabilization pond assuming that the site is not prone to flooding. But the septic tank and the soil absorption field will most likely receive a net negative effect as the water table will rise in most places since according to USEPA (1999), flooding and rise in water table are critical for these systems. This will lead to a massive pollution of the groundwater during the raining season when the water table is high. Hence we may likely witness a higher incidence of water-related diseases. The net effect of climate change on landfills cannot be asserted with certainty in this paper; however, landfills will likely perform better in early raining season and worse at the peak of the dry season. This is because there will be high moisture content, less flooding and high temperature in early raining season. However, at the peak of the dry season, there will be very high temperatures and very low moisture content: a situation that may lead to drying up of some organic matter and inactivation of micro organisms. Drainage systems will be hit very hard with the consequence that erosion cases will rise drastically.

The role of solid waste management in climate change is significant. Hence greenhouse gas emission can be reduced through a thoroughly formulated and holistic waste management strategy. Though individual waste management options are preferred depending on individual needs of municipalities, emission of greenhouse gases can be drastically reduced by a combination of sorting, anaerobic digestion (biogassification), composting, incineration and landfilling. Anaerobic digestion offers the added advantage of biogas production, composting offers the advantage of carbon sequestration, soil improvement and emission of biogenic (zero GWP) CO_2, incineration offers the benefit of energy recovery while landfilling yields biogas and captures carbon. All these benefits are accrued by combining these options. Since it has been shown that waste management options generate greenhouse gases which have been implicated in climate change, it is necessary to adopt best management practices in order to sustain the gains of development. Waste management is not the sole responsibility of municipal authorities as many people assume, it is a collective responsibility. The role of the individual does not end at waste generation. People are so eager to get the waste out of their homes, but they do not care where these waste materials end up so long as it is not in their backyard. However, no one is relieved of the burden of waste they generate until the waste is responsibly and safely disposed. In the best waste management practice proposed in this paper, sorting has been assigned a central role in order to promote resource and energy recovery, and to engender ease of waste handling, treatment and disposal. Other key components of the proposed strategy are recycling, reuse, animal feeding, composting, anaerobic digestion (biogasification), incineration and landfill. This strategy will fare better if individuals are advised to deliver their waste in sorted forms.

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