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CHARACTERIZATION OF THE WASTE SLUDGE FROM PAINT BOOTH OF AUTOMOTIVE PARTS

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ABSTRACT

The waste sludge from paint booth of the automotive industry is a significant environmental liability due to its environmental impacts caused in the course of productionand the solid waste generated during the application process. The present study seeks an adequate way to reuse waste paint sludge, based on the physical, chemical, morphological, and mineralogical characterization of three samples subjected to high temperatures: waste paint sludge composed by base and varnish (WPS), deactivated waste paint sludge (DWPS), and deactivated waste varnish sludge (DWVS). First, the samples were burned in an electric muffle furnace with staggered firing temperatures in order to verify loss of mass during the firing process. The physical, morphological, chemical, and mineralogical characterizations of the samples were performed using particle size analysis by Laser Diffraction, Scanning Electron Microscopy, Energy Dispersive Spectroscopy, and X-Ray Diffraction. The firing process demonstrated a mass loss of over 90.0% of the samples, showing that there is no significant mass change over 600ºC. The experimental characterization showed occurrence of particles with diameters ranging from 1.156 – 837.1 µm, and heterogeneous agglomerates with irregular shape and sizes ranging from 2 – 300 µm. The elementary chemical composition of the samples demonstrated basically, the amounts of titanium, aluminium, silicon, and sodium; founded under cristaline phases of rutile, aluminium oxide, and quartz. The findings of this paper can be used in future studies aiming at the reuse of this waste for example into ceramic materials.

Keywords: Environmental liability; Solid waste characterization; Paint sludge

INTRODUCTION

Solid waste is one of the major causes of environmental degradation, mainly due to the large volume produced. In this context, the waste sludge from paint booth of the automotive industry serves as an important environmental liability, due to its environmental impacts caused during production and residue generated in its application process, usually via manual or mechanized spray process, in which paint that was not adhered to the surface of the material (overspray) is collected in an aqueous or slurry form.

Solvent-based paint is produced, in general, by mixing chemicals (primarily resins, dry pigment, and pigment extenders). In the course of the mixing, solvents and drying oils are also added. After mixing, additional grinding and mixing may occur. Next, tints, thinner (regularly a volatile naphtha or blend of solvents), and the remaining resin are added and mixed to the paint base or concentrate. The paint is filtered in order to remove non-dispersed pigment, to reach the proper consistency (Dursun and Sengul, 2006). The paint presents a volatile portion comprising water or organic solvents and a solid portion which forms a film adhered to the surface of the material. On the whole, all types of paint basically consist of solvents, resins, pigments, and additives (CETESB, 2008). According to Almesfer *et al.,* (2012), the primary constituents expected to occur in high volume of waste paint are: polymers, surfactants, foam controllers, titanium dioxide, and thickeners.

According to the Brazilian Coatings Manufacturers Association (ABRAFATI, 2014), Brazil is one of the five biggest paint market worldwide. In 2013, 1,426 million liters were produced in the country, wherein the segment of automotive industry was responsible for 4% of this total, which means 51 million liters of paint. These exposed values show the potential generation of waste paint sludge by the automotive sector, resulting in serious environmental issues. The paint production segment of the automotive industry has an estimated average annual growth rate of 5%, considering the period from 2000 to 2013, as shown in Figure 1.

The contribution by sectors in the total volume of paint produced in 2013 is shown in Figure 2, which notes that automotive industry presents 51 million liters production (ABRAFATI, 2014). Although house paint is the major paint sector in Brazil, it should be highlighted that overspray of automotive paint is much bigger than house paint, with larger potential of waste sludge generation.

The evaporation of the organic solvents in the coatings creates air emissions from surface coating operations, which consist mainly of volatile organic compounds (VOCs). VOC destruction or VOC recovery are the possible actions aiming to limit VOCs emissions. VOC destruction occurs from the oxidation of VOCs to produce carbon dioxide and water and this can be accomplished by means of heat from incineration (Pierucci *et al*., 2005) or catalytic oxidation (Datta and Philip, 2014). Incineration is a rapid exothermic oxidation process that destroys organic material in the off-gas (Pierucci *et al*., 2005). VOC recovery consists of adsorption or scrubbing (Datta and Philip, 2014). The authors (*op. cit.*) evaluated the performance of a rotating biological contactor (RBC) when treating complex mixtures of VOCs frequently found in surface coating manufacturing and application facilities.

The Typical Contaminants Composition (TOC) of the components contaminating the air are: Acetone (31 mg/Nm^3), Methyl ethyl ketone (683 mg/Nm^3), Ethyl acetate (29 mg/Nm^3), Toluene (523 mg/Nm^3), Butyl acetate (492 mg/Nm^3), and Xylenes (802 mg/Nm^3). TOC can usually range from 1,200 to 2,500 mg/Nm^3 in the air flow, which is maintained practically at the controlled flowrate of 14,000 Nm^3/h; however, in special conditions it may reach values up to 3500 mg/Nm3(Pierucci *et al*., 2005). Viguri *et al.,* (2005) related the characterization of a solvent-based paint waste, with a high level of VOC content (toluene + xylene: 7–18% wt) leading to high flammability (Flash point: 25 °C) and high TOC content (2,160 mg/L).

The waste paint sludge from automotive industry is generated during painting process of paint booth. In this process, overspray is collected in an aqueous or slurry form, called waste paint sludge (Praxedes, 2013), into automated paint booth. The painting process comprises three steps: *primer* application, *base* application (paint), and varnish application (*clear*).

Volatile organic compounds (VOCs) and heavy metals are the main factors responsible for the high toxicity of the waste sludge from paint booth. The VOCs are conferred to paints and varnishes due to the presence of solvents, which can easily penetrate into the body via inhalation; while heavy metals come from pigments, with high potential to

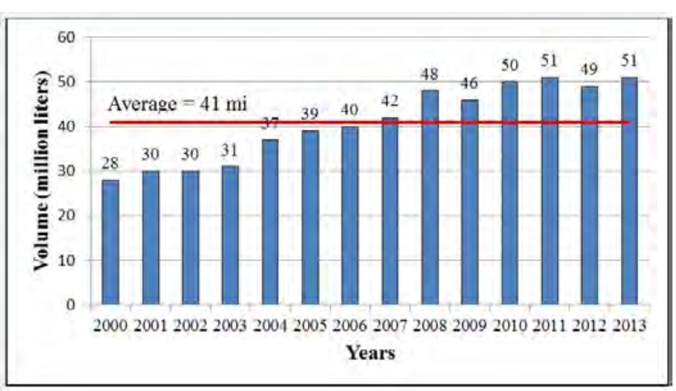


FIGURE 1
Volume produced by automotive paint sector in Brazil (million liters). Source: ABRAFATI (2014)

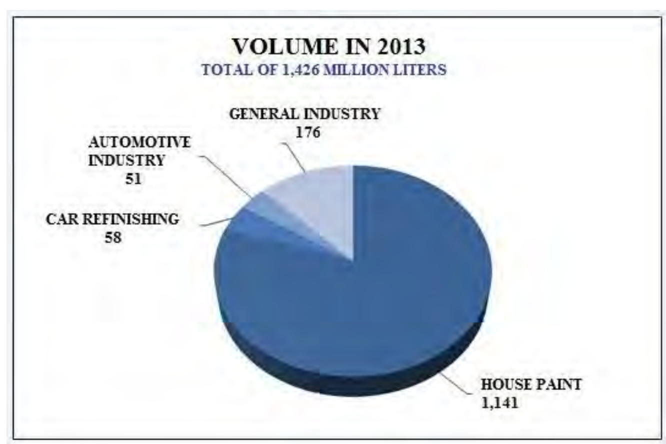


FIGURE 2
Contribution by sectors in the total volume of paint produced in Brazil in 2013 (million liters). Source: ABRAFATI (2014)

contaminate soil and groundwater (Praxedes, 2013).

Paint sludge contains uncured polymer resins, pigments, curing agents, flotation agents and other minor formulation ingredients. Furthermore, paint sludge, which is a very complex material, contains water and a variety of organic solvents. The presence of uncured paint resins, which cure and form a film upon heating, makes the sludge very sticky and hard to handle (Salihoglu and Salihoglu, 2016). The chemical compositions of different water-based used at automobile manufacturing plants is given in Table 1, Table 2 shows the paint waste contents, and Table 3 gives the chemical composition of a flocculent and detackifiers used by the automotive industry.

The paint sludge is classified with EU waste code of 080113* implying hazardous characteristics (Salihoglu and Salihoglu, 2016). According to the Annex A of the NBR 10.004 technical standard from the Brazilian Technical Standards Association (ABNT, 2004), the waste sludge from paint booth is classified as a dangerous waste from no specific source (Identification Code F017 – Waste and sludges of paint from industrial painting), with its grave characteristic consisting its toxicity. Thus, this solid waste is classified as a Class I waste, and is considered hazardous due to its potential risks to public health and/or to envi-

TABLE 1

Chemical composition of a solvent-based paint used in automotive industry. Source: Salihoglu and Salihoglu (2016)

Material	*Level (%)*[a]	*Level (%)*[b]	*Level (%)*[c]
n-buthyl acetate	35	3	
xylene	5	18	41.64
butan-1-ol	3	14	
1,3,5-triazine-2,4,6-triamine, polymer with formaldehyde	20		
butylated ethylbenzene	1	1	
naphtha (petroleum), hydrotreated light	1	3	
2-(2-butoxyethoxy) ethanol	1		
heptane	1		
naphtha (petroleum) light alkylate	0.25		
solvent naphtha (petroleum) light a.	0.25		
naphtha (petroleum) hydrodesulphurized heavy	0.25		
1,2,4-trimethylbenzene	0.25		
solvent naphtha (petroleum), medium aliphatic	0.2		
methanol		2	
melamine formaldehyde		12	
cumene		1	
3-methacryloxypropy-trimethoxy-silane		5	
polymethylmethacrylate		42	
carbon black			3.15
calcium carbonate			8.97
thickener			2.97
triethylamine			0.32
toluene			19.92
drying agents			1.59
talc			9.98
polycarboxylic acid			0.54
methyl-ethyl-cetoxime			0.16
bonding agent			1

Note:

a) Composition of the paint used by an automotive plant in Turkey (data taken from safety data sheet of the paint of the paint manufactured by PPG).
b) Composition of the paint manufactured by DuPont is reported by Papasavva *et al.* (2001 *apud* Salihoglu and Salihoglu, 2016).
c) Composition of the paint is reported by Arce *et al.* (2010 *apud* Salihoglu and Salihoglu, 2016).

TABLE 2
Paint waste contents (% d.w.). Source: Arce et al. (2010)

BTEX (benzene, toluene, ethylbenzene, xylenes)	14	Cu	0.01	Sb	0.01
As	0.01	Fe	1.58	Se	0.01
Ba	6.24	Hg	0.01	Si	1.43
Ca	6.77	Mg	0.32	Sr	0.97
Cd	0.01	Mo	0.11	Ti	0.52
Co	0.23	Ni	0.54	Zn	0.30
Cr	0.33	Pb	0.10		

TABLE 3
Chemical composition of a flocculent and two detackifiers used by an automotive plant in Turkey (manufactured by PPG). Source: Salihoglu and Salihoglu (2016)

Flocculent		Detackifier for water-based paint sludge		Detackifier for solvent-based paint sludge	
Content	*Level (%)*	*Content*	*Level (%)*	*Content*	*Level (%)*
Detackifier for solvent-based paint sludge	10	Aluminum sulphate	20	Aluminum sulphate	20
Ammonium chloride	3	Ammonium, diallyldimethyl-chloride, polymers	0.25	Amines, polyethylenepoly-, polymers with 1,2-dichloroethane	0.25

ronment. Therefore, it must be treated and disposed properly, in industrial landfills.

The studies of industrial waste reuse are motivated mainly by the need of environmental preservation, depletion of raw materials, as well the need for recycling waste. Thus, studies on recycling and reuse of materials have shown alternatives to attend to the need of developing sustainable practices (Praxedes, 2013). Several studies have been performed aiming at the reuse of different solid waste as glass powder (Costa and Silva *et al*., 2011), red ceramic (Campos *et al*., 2012), construction waste (Lintz *et al*., 2012), foundry sand (Barros *et al*., 2013), paint sludge (Praxedes, 2013), and waste latex paint (Nehdi and Sumner, 2003).

Appropriate ways to reuse waste sludge from paint booth of automotive parts has been soughted for, aiming to promote the reduction of the need to dispose them in industrial landfills; consequently, increasing landfills' life cycle as well as reducing environmental liabilities. Thus, this paper contributes towards studies for the reuse of solid waste.

The present study aims to characterizate the waste sludge from paint booth of the automotive industry, after burning at high temperatures, in order to propose an alternative for reuse such as recycling this solid waste into life cycle of production chain, for example ceramic. Specific goals are determined by the physical, thermal, chemical, morphological, and mineralogical characteristics of the waste sludge from paint booth.

METHODOLOGY

Samples collection

The samples of waste sludge from the paint booth were provided by a manufacturer of automotive parts and accessories, located in the southern state of Minas Gerais - Brazil.

The residues are from the remains of the painting process of the pieces into paint booth. As the waste generated in the process depends on the purpose of painting and of the products used (*primer*, *base,* and varnish), three different samples were collected directly from the discharge point of the booth, before and/or after the chemical treatment process of the sludge, in order to check if there is any difference in their composition. The samples collected are:

- Waste paint sludge composed by *base* and varnish (WPS);

- Deactivated waste paint sludge composed by *primer, base* and varnish (DWPS);
- Deactivated waste varnish sludge (DWVS).

The deactivated waste sludge is the paint sludge after chemical treatment, which involves breaking the chemical chain. The paint must be tacky to adhere to the pieces, whereas the overspray falls in the water and must be disabled in order to lose its initial characteristics. For water treatment of the paint booth, deactivators, agglomerators, defoamers agents, and alkalizing for pH control are used. The samples were properly packed in plastic bottles for further preparation and characterization.

Samples preparation

The samples were prepared by weighing 100g of waste sludge in porcelain crucibles, using an analytical balance Shimadzu AY 220 and placed in an electric muffle furnace Fornitec 1870, with burning capability of 1200°C. To eliminate moisture and organic compounds as VOCs, furnace temperature was placed between 525°C and 750°C for WPS, and 200°C, 600°C and 1000°C for DWPS and DWVS; with a variation of +/- 2°C and for one hour at each stage. The firing temperatures differed in order to determine the difference in mass loss of the samples with respect to temperature increase. At each stage of the firing process, samples were taken to cool in a desiccator and then weighed to verify the loss of mass. At the end of this process, samples were turned into powder form to be evaluated in terms of their particle size distribution and chemical, mineralogical, and morphological composition.

In this case study, the electric furnace used in the burning of the samples had no control gas emission system, due to the small quantities of material analyzed. However, it is emphasized that in the case of preparing large amounts of waste sludge from the paint booth for reuse, there is a need to implement measures to prevent air pollution by VOCs. These are the primary pollutants present in the sample that can turn into particulate matter, a secondary pollutant, through chemical reactions in the air.

Samples characterization

After the manual grinding of WPS samples with a mortar and pestle, using 750°C for DWPS and 1000°C for DWVS, the samples were physically, chemically, morphologically, and mineralogically characterized using particle size analysis by Laser Diffraction (LD), Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), and by X-Ray Diffraction (XRD) respectively. In addition, the thermogravimetric analysis was carried out: the paint sludge *in natura* was inserted in the METTLER equipment, model TG50 using porcelain crucible. The working temperature was from 25 to 1000 ° C (heating rate of 10 °C/min), and oxygen gas with atmosphere at 30 mL/min.

Particle Size Analysis by Laser Diffraction (LD). The analysis was performed using a Microtrac Bluewave S5822 granulometer, which determines materials with particle sizes ranging from 0.0107 to 2000 µm. During the preparation, the samples were manually milled and approximately 1.0g of waste sludge was dispersed in deionized water at ambient temperature and brought to granulometer.

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS). Samples were prepared as previously described in section 2.2 and small portions were placed on stubs. Afterwhich, the materials were vacuum metallized on one Metallizer Quorum ES Q150R, with a micrometer gold film. This was done to transfer electrical conductivity to the samples for the analysis of their chemical and morphological characteristics, using SEM ZEISS equipment model EVO MA15 and EDS BRUKER equipment, model XFlash 6I10.

X-Ray Diffraction (XRD). Samples of waste sludge from the paint booth of automotive parts were placed in a metallic mold for mineralogical analyzis. The X-ray diffractometer employed was PANalytical model X'Pert PRO (10mA and 40W). The angles were swept from 10º to 90º and the analysis time was 0.5 seconds per step, where the step equal to 0.2°.

RESULTS AND DISCUSSION

Thermal analyzes

Figure 3 shows the loss of mass profiles from WPS, and Figures 3 and 4a and 4b present DWPS, and DWVS samples obtained by the variation of mass changes analysis, with an increase in temperature during the burning of the materials in an electric muffle furnace at staggered temperatures.

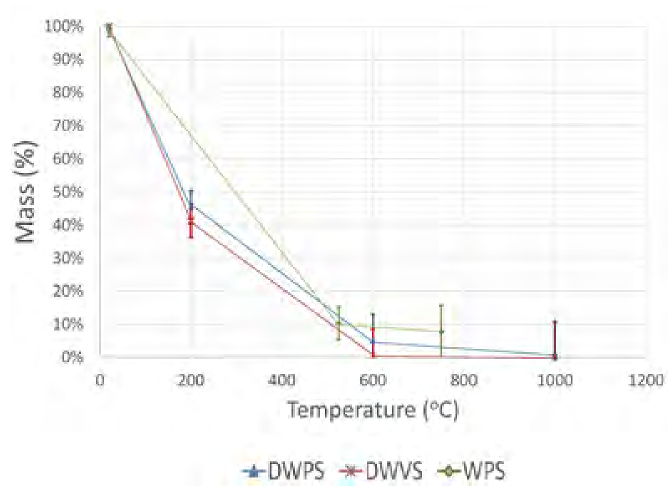


FIGURE 3
Thermal analysis of the WPS, DWPS, and DWVS samples

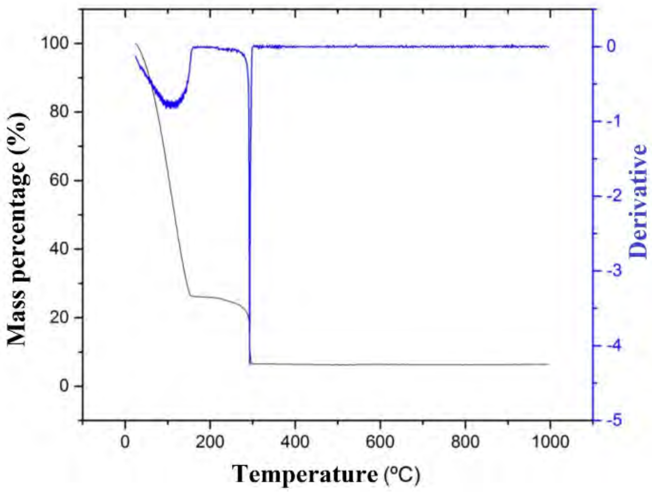


FIGURE 4
Curves of TG/DGT of the waste sample of: a) deactived paint sludge (left); and b) deactived varnish sludge (right)

It is observed that after one hour firing at 525°C, the WPS sample has mass loss of approximately 90% of the initial amount. However, increasing the firing temperature to 750°C, the new loss represents only 2.6% of the initial mass, as shown in Figure 3. From this finding it is inferred that, for the main thermal breakdown/combustion of the paint's sample, the most portion was eliminated at 525ºC. At the end of the burning process in the furnace, it is observed that the mass of the remaining residue is around 8% of the original amount.

Since after the first firing stage at 525 °C almost 90% of the waste was lost by thermal breakdown/combustion of water and organic solvents, it was decided to reduce the staggered temperatures of burning in the other samples (DWPS and DWVS); so as to better assess the variation mass relative to the temperature increase. The new firing temperatures became 200º, 600º and 1000ºC.

DWPS and DWVS samples showed similar values for loss of mass during the firing process, as shown in Figures 3. After one hour firing at 200°C, there was 54.6% and 58.7% mass loss compared to the initial quantity of DWPS and DWVS, respectively. The largest sample mass loss occurs at temperatures that are up to 600°C (95% for DWPS and 99.4% for DWVS). Therefore, if the burning temperature is raised to 1000°C, the DWVS sample mass loss relative to the previous step (600°C) would be 0.14%; and regarding the DWPS sample, the mass loss from the previous step (600°C) would be 4%.

Figure 3 shows that over 90% of the mass of all samples is lost at 600ºC by thermal breakdown/combustion of water and organic solvents present in the sludge. This finding strengthens the hypothesis that a thermal breakdown/combustion temperature of waste sludge from the paint booth in preparation for reuse allows energy saving by avoiding the increase of the furnace temperature at 1000°C.

The highest rate of mass loss occurs close to 525-600ºC temperatures. The mass loss in this range of temperature was around 89.7% (WPS), 95.0% (DWPS) and 99.4% (DWVS), which can be considered as the loss of moisture (water) and volatile compounds as VOCs present in the solvents are used in the preparations of the varnish. This is in addition to the degradation of all organic compounds, including those in paints and chemicals used in water treatment from the wet painting booth.

By evaluating Figure 4a, mass loss of approximately 92% was observed, proving that, after the temperature of 300ºC, no more significant mass losses occur, remaining only fixed residues and oxides. By analysing Figure 4b, organic compounds degraded in the deactivated varnish paint sludge after 300 °C and up to 533 °C may be from the catalysts and additives, as these elements are organic and are added in the lacquer preparation and are usually not added in *Base Coat* paints.

Particle size analizes by LD

The curves of discrete and cumulative particle size distribution of the samples are shown in Figure 4. There is the occurrence of particles with diameters between 1.375 µm and 837.1 µm for WPS, 1.156 µm and 703.9 µm for DWPS and 3.89 µm and 703.9 µm for DWVS.

The discrete distribution of the particles (solid bars) shows the tendency of a trimodal profile for WPS and DWPS samples, while there is a tetramodal profile for BVD sample, as shown in Figure 5 (C).

Table 4 lists the equivalent diameters of the analyzed samples, wherein D_{10}, $D_{50,}$ and D_{90} represent the particle diameters underneath which 10%, 50% and 90% of the material is situated, and D_{avg} is the average particle diameter.

WPS, DWPS, and DWVS samples present 10% particles with diameters lower than 9.55 µm, 8.90 µm, and 11.27 µm. However, considering D_{90} values, all three samples show distinct behaviors with 90% of its partcles, with diameters lower than 409.20 µm for WPS, 255.60 for DWPS, and 359.40 for DWVS.

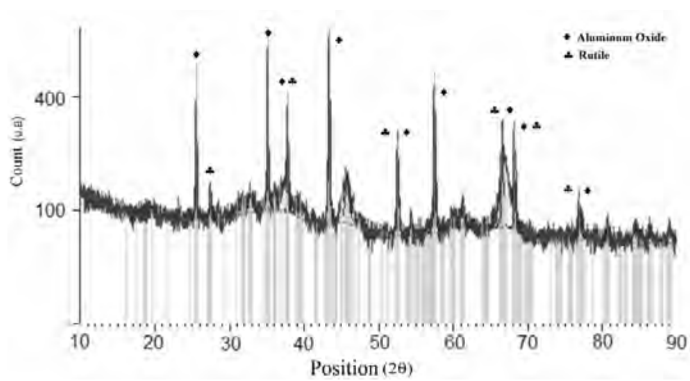


FIGURE 5
Discrete and acumulate particle size distribution of the (A) WPS, (B) DWPS and (C) DWVS samples

TABLE 4
Particle equivalent diameters of the waste sludge samples from paint booth of automotive parts.

Sample	D_{10}(μm)	D_{50}(μm)	D_{90}(μm)	D_{avg} (μm)
WPS	9.55	95.12	409.20	23.58
DWPS	8.90	64.06	255.60	18.80
DWVS	11.27	83.87	359.40	31.57

Mineralogical characterization by XRD

The crystalline phases identified in the samples of waste sludge from paint booth, as well the X-ray diffractograms are shown in Table 5 and Figure 6.

From Table 5, it appears that rutile is the only common crystalline phase identified in all three samples. However, aluminum oxide (alumina) is present in two samples, WPS and DWPS, while quartz (silica) and lazurite are identified only in DWPS and DWVS, respectively.

Alumina is a mineral obtained from bauxite and used in the manufacturing of abrasive and refractory products due to its hardness and high melting point; it can also be used to manufacture dyes (Machado *et al.*, 2014). The rutile mineral is used as a brilliant white pigment substance that is commonly employed to obtain white paint, being the only stable phase of the oxides of titanium (Viana Neto, 2006, CPRM, 2014). The quartz (silicon dioxide), in turn, has hexagonal crystalline shape, vitreous luster, and high hardness (Machado *et al.*, 2014), besides being chemically inert and insoluble in water. It is a mineral widely used to manufacture paints especially marker paints, floors and textures paints, since it promotes improvement in abrasion resistance and coefficient of friction (ALTERNATIVE INDUSTRIAL MINERALS LTDA, 2014). Lazurite is a mineral used as a source of blue pigment, which provides the pigment known as ultramarine (CPRM, 2014). Ultramarine blue pigment has a long history (ancient Egypt) where the blue mineral lazurite was ground into a powder. Ultramarine blue pigment is a sodium aluminium sulfosilicate with an empirical formula ($Na_6Al_6Si_6O_{24}S_4$) (McGoniglie, 1988 apud Pintus *et al.*, 2013). Vitreous luster can be associated with sulfur both in the form of S^{3-} and S^{2-} (Machado *et al.*, 2014), and the blue pigments contain mostly the S^{3-} chromophores with smaller amounts of S^{2-} (Del Federico *et al.*, 2006). They are present in ultramarine blue, even though the former is in by far the greater amount and therefore is mainly responsible for the blue color of the pigment (Clark *et al.*, 1983; Pintus *et al.*, 2013). Fading in acidic media paramagnetic chromophores are set free by means of sodalite framework destruction and are afterward degraded, although a larger number of β-cages appear to be destroyed, and H_2S is released (Del Federico *et al.*, 2006; Pintus *et al.*, 2013). Ultramarine blue generally has a good lightfastness and heat stability (>350 °C) (McGoniglie, 1988 apud Pintus *et al.*, 2013). In acidic environments, these free chromophores are greatly converted to H_2S and possibly elemental sulfur (Del Federico *et al.*, 2006). Comparing these results to that of mineralogical analysis by XRD presented by Praxedes (2013), which identified the presence of rutile, barite, and calcite in a study of automotive waste paint sludge, it turn out that the presence of the rutile as crystalline phase is common. Also, comparing the results of XRD analysis of the foundry sand presented by Barros *et al.*, (2013), the DWPS also contain quartz in its crystallographic composition.

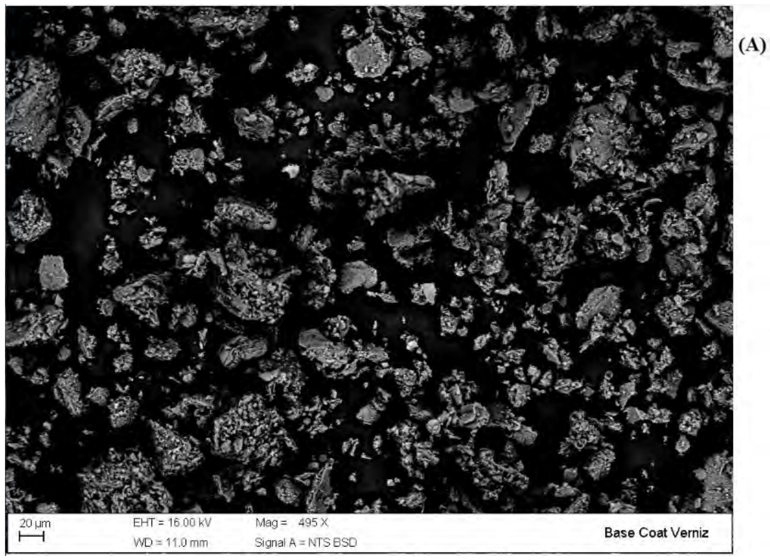
Morphological characterization by SEM

The samples were characterized morphologically from the micrographs shown in Figures 6 to 8. Although the samples were manually milled, the presence of heterogeneous agglomerates of particles with different sizes are observed; ranging from approximately 4 to 88 μm in WPS sample, 2 to 300 μm in DWPS sample, and approximately 3 to 250 μm in DWVS.

Regarding morphology, all samples showed the presence of agglomerates with irregular shape and smaller particles

TABLE 5
Main minerals identified in the respective samples of waste sludge from paint booth.

Mineral	Chemical Formula	Sample
Rutile	TiO_2	WPS, DWPS and DWVS
Aluminum oxide (alumina)	Al_2O_3	WPS and DWPS
Quartz (sílica)	SiO_2	DWPS
Lazurite	$Na_{8.56}(Al_6Si_6O_{24})(SO_4)_{1.56}S_{44}$	DWVS



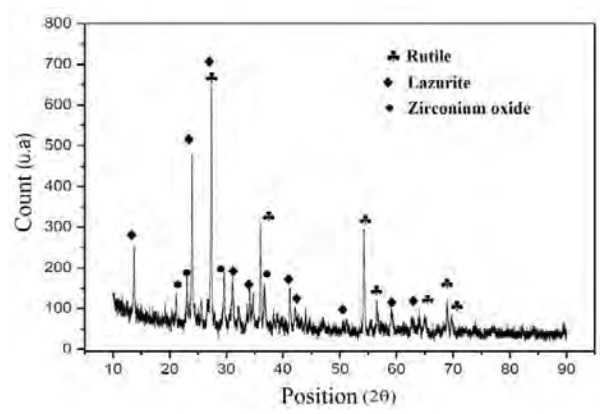


FIGURE 6
X-ray diffractograms of the (A) WPS, (B) DWPS and (C) DWVS samples

adhered to its surface area, as micrographs shown in Figures 7 to 9. The lighter regions of the DWVS' micrographs presented in Figure 8 (A) and (B) are due to loading and counting of secondary and backscattered electrons emitted by the material analyzed.

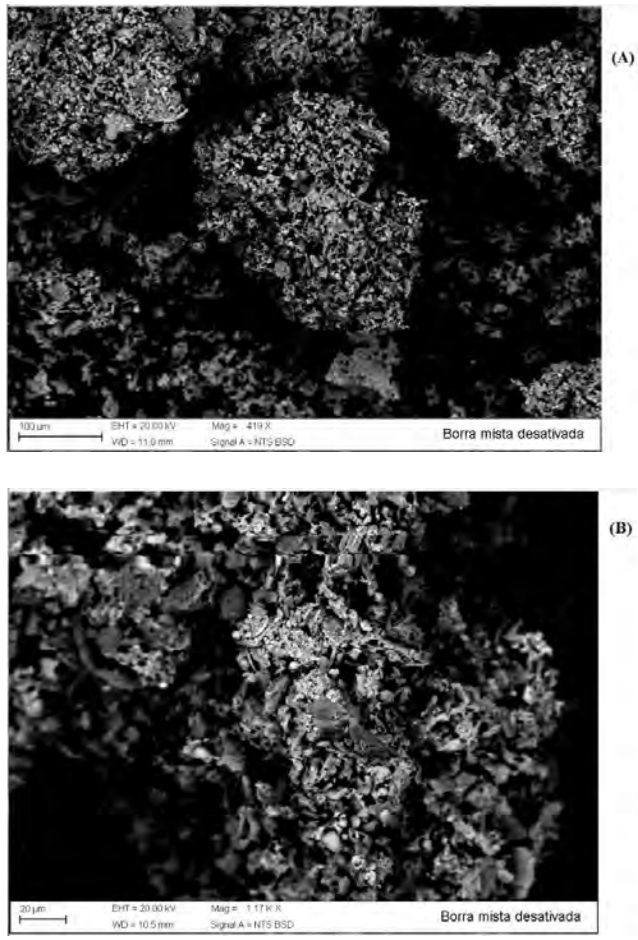


FIGURE 7
Micrography of the waste sludge from paint both: (A) and (B) WPS sample, with 495x zoom and 1990x zoom

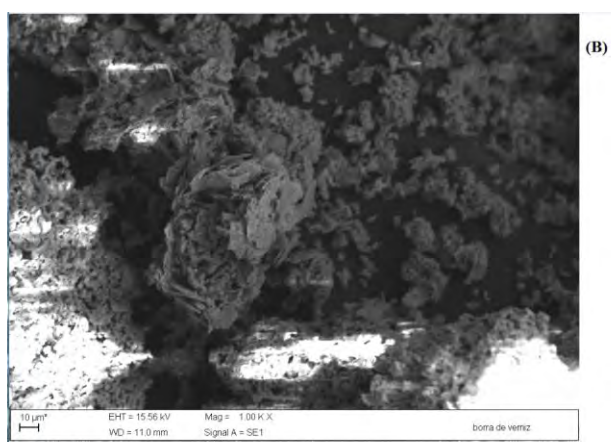


FIGURE 8
Micrography of the waste sludge from paint both: (A) and (B) DWPS sample, with 419x zoom ar

Elemental chemical characterization by EDS

The EDS analysis was performed considering generalized regions from micrographs, as shown in Figure 10, to ensure the chemical representation of the samples. Table 6 sumarizes the elemental chemical analysis results of the waste sludge from corresponding micrographs and EDS spectrums (Figure 9).

The samples are composed basically by aluminum, silicon, iron, titanium, magnesium, potassium, sodium, zinc, and

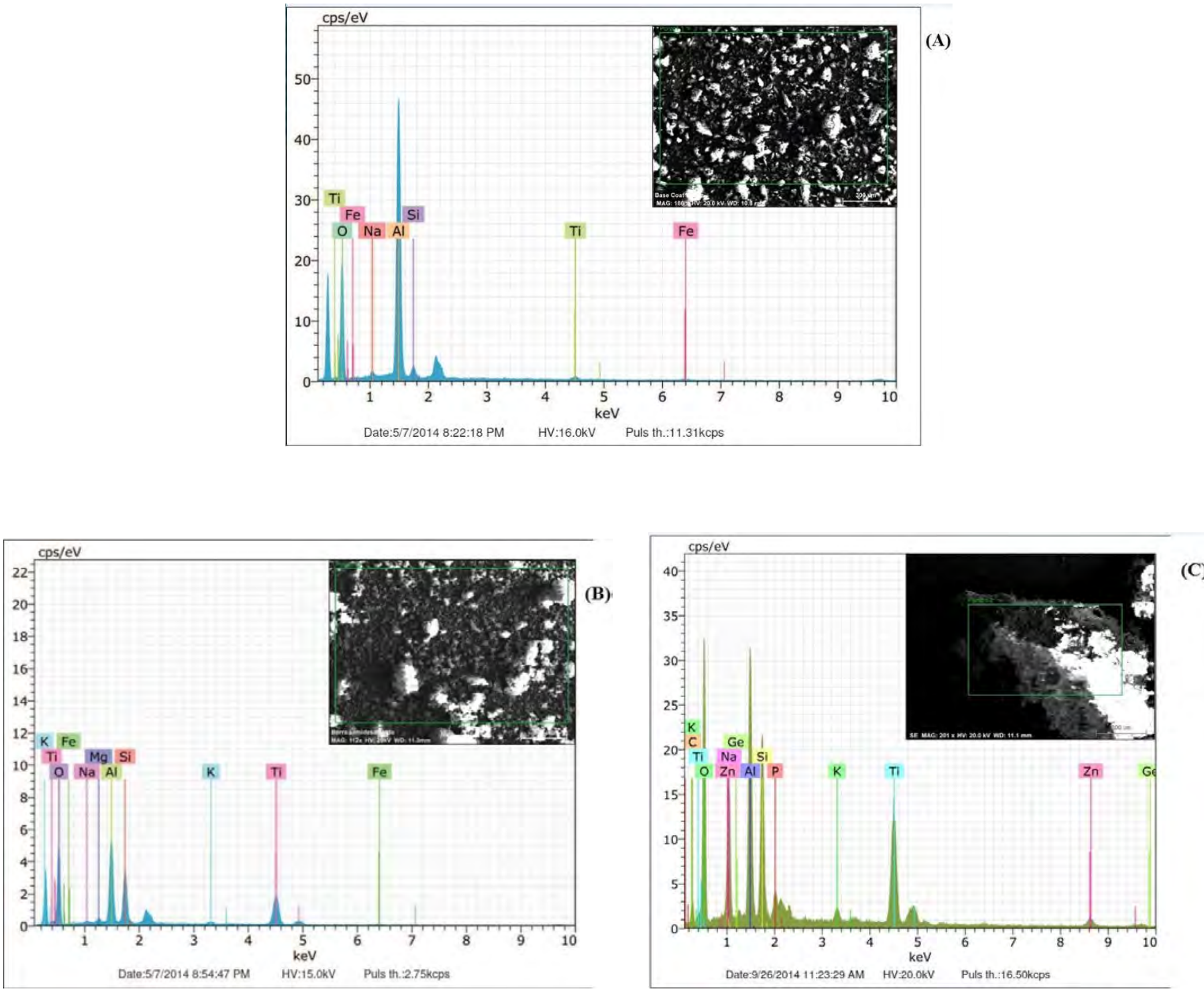


FIGURE 9

EDS spectrums of the: (A) WPS, (B) DWPS and (C) DWVS. Note that such spectrums were obtained from micrograph presented in the top right of each figure.

phosphorus. However, some elements appear in mass percentages lower than 1%. According to Nehdi and Sumner (2003), the water is around 59%, and other extender solid pigments including TiO_2 are around 25% in latex polymer. TiO_2 is the primary white pigment used by the paint industry as it is the only pigment (other than zinc oxide) that is non-toxic and easily obtainable. Also, the oxygen and carbon amount expressed in Table 6 do not correspond to the actual values, as shown by the error (last column), since SEM/EDS techniques have constraints to detect light elements, that is, low atomic number elements.

Some of these elements were identified in the mineralogical analysis by XRD, such as titanium in rutile form, mineral observed in all three samples, aluminum in alumina form in WPS and DWPS samples, silicon as constituent of quartz in DWPS; while sodium, aluminium, silicon, and sulfer are chemical constituents of the lazurite in DWVS. However, the remaining chemical elements are not present in any other mineralogical phase identified by XRD analysis, since they occur in low amount (<0.75s%).

Pintus *et al*., (2013) studied during 31 and 83 days the influence of ultramarine blue on the stability of a p(nBA/MMA) acrylic binding medium when aged under UV exposure by DSC and TG analyses. The authors (*op. cit.*) verified a reduced photo-oxidative stability of the p(nBA/MMA) acrylic binder when mixed with ultramarine blue. Therefore, ultramarine blue pigment seemed to promote some chain scission reactions in the polymer matrix observed as the loss of organic material by the evaporation of volatile compounds (Pintus *et al*., 2013). Nevertheless, as abovementioned, it usually has a low resistance to acids consequential of the conversion of the free chromophores into H_2S and possibly elemental sulphur (Del Federico *et al*., 2006; Pintus *et al*., 2013). However, it is inferred that the sulfur present in

TABLE 6
Elemental chemical analysis of the waste sludge samples from paint booth related to EDS spectrums shown in Figure 9.

Sample	Chemical element	% mass (wt.%)	Norm. C (wt.%)	% atomic (at.%)	Error (wt.%)
WPS	Al	18.50	46.49	35.94	0.89
	O	18.19	45.71	59.57	2.28
	Si	1.04	2.62	1.95	0.07
	Fe	0.87	2.19	0.82	0.07
	Ti	0.83	2.09	0.91	0.06
	Na	0.36	0.90	0.82	0.05
DWPS	O	28.42	48.42	67.01	3.55
	Ti	13.87	23.62	10.93	0.44
	Al	8.74	14.90	12.23	0.43
	Si	6.00	10.23	8.06	0.28
	Fe	0.74	1.25	0.50	0.06
	Mg	0.38	0.65	0.60	0.05
	K	0.31	0.52	0.30	0.04
	Na	0.24	0.40	0.39	0.05
DWVS	O	35.79	45.65	57.63	4.46
	Ti	10.67	13.62	5.74	0.36
	Al	8.90	11.36	8.50	0.46
	Na	6.91	8.82	7.75	0.48
	C	6.11	7.79	13.10	1.18
	Si	5.31	6.77	4.87	0.26
	Zn	3.08	3.93	1.21	0.13
	P	0.98	1.25	0.82	0.07
	K	0.49	0.63	0.32	0.04

the lazurite was volatilized during the thermal process.

Comparing the EDS analysis results of all three samples, the DWVS has the highest number of elements. However, there is a similar basic chemical composition among the samples, with amounts of aluminum, titanium, silicon, and sodium. There are some elements in common between these three samples and the automotive slugde paint studied by Praxedes (2013), such as amounts of titanium, silicon, and aluminum. There are differences in the samples as regards the presence of calcium, cerium, barium, and chloride in the waste analyzed by the author (*op. cit.*) and absent in the WPS, DWPS and DWVS samples.

Also, other elements identified in WPS, DWPS and/or DWVS samples, such as phosphorus, potassium, iron, magnesium and sodium, were found in powder glass samples as oxide form as P_2O_5, K_2O, Fe_2O_3, MgO, and Na_2O during the feasibility study of waste glass for the production of ceramic bricks by Galvão, Farias, and Souza (2013).

Environmental and practical points of view

The Brazilian legislation established the obligation of treatment and environmentally adequate disposal (Brazil, 2010a; 2010b) of solid wastes, including such industrial wastes. Industrial landfilling and co-processing are commonly the practical alternatives for the paint sludge disposal. The low cost compared to other options for treatment and disposal, as well as the possibility of being used for a wide range of industrial waste are the main advantages of this type of landfill. Costs of incineration can go up as the temperature required to achieve the complete burn are raised. The costs can also rise, if auxiliary fuel is required to accomplish the incineration. However, the higher reason related to the costs is associated with management of the diverse types of byproducts produced by non-combustibles associated with high incineration temperature VOCs, such as chlorofluorocarbons or halogens. This can happen if the concentration of VOCs in the air stream is below 1000 ppm. Refrigerated condensation and adsorption followed by refrigeration are the most important types of VOCs recovery (Pierucci *et al.*, 2005). Ruffino and Zanetti (2010 *apud* Salihoglu and Salihoglu, 2016) reported that the costs of incineration and/or landfill disposal of automotive industry paint sludge range between 250 and 350 Euro/ton. When the sludge is incinerated in a hazardous waste incinerator, the cost is 250 Euro/ton, according to Turkish automotive manufacturers. An alternative route of disposal by combustion at cement kilns provides a lower management cost of approximately 100–150 Euro/ton paint sludge to automotive manufacturers in Turkey.

In Brasil, for instance, if these solid waste treatment/final disposal values for industrial landfilling is 0.28(US$/kg), co-processing as 0.48 (US$/kg), and incineration as 0.91 (US$/kg) are considered, it can be noted that the incineration would present the highest value, but some aspects must be considered. These values were consulted in Lima and Ferreira (2007) and were up-to-dated, and the currency was changed by the Central Bank of Brazil (2016).

On the other hand, there is a large environmental liability left by these landfills. Industrial landfills tend to be located farther away from production and consumption centers, which may alter the financial viability of a scenario of industrial landfill disposal on the long run. As recommended by PwC (2006), the cost of transportation of waste generated by small and medium-sized enterprises located far from treatment units may be higher than the cost of the treatment itself, considering the relatively low amount of waste to be treated. In this sense, transportation is considered as a critical link in the chain of services related to industrial waste. In addition, co-processing could generate very variable by-products due to the fuels used, which compromise the use of the material studied and the potential for reuse in the production chain.

According to Salihoglu and Salihoglu (2016), current research is currently being conducted on new application techniques to increase the effectiveness of paint transfer. This can help to avoid the generation of paint sludge. In addition, improvements in paint and coating chemistry, for instance the reduction in the coating layers with its thickness also help to reduce the level of paint sludge production. Researches on the effects of the chemicals on the recycling potential of paint sludges and consideration of these effects by the chemical manufacturer companies would be very important (Salihoglu and Salihoglu, 2016).

Even though a limited number of investigations exist in the literature, recycling of paint sludge at macro level is not very common. The most common application is the distillation of solvent-based paint sludge (Salihoglu and Salihoglu, 2016). Patent 5,573,587 provides a process for producing building materials, for instance, concrete, mortar or asphalt, from water-based paint sludge (WBPS) by mixing the paint sludge with caustic soda, quick-lime and agitation (St. Louis, 1996 *apud* Salihoglu and Salihoglu, 2016).

CONCLUSIONS

This study presented the characterization of the waste sludge from paint booth of autoparts, aiming at its reuse. From the characterization of the samples of deactivated and mixed paint sludge, and deactivated varnish sludge, both generated by the process of painting of automotive parts, it can be concluded that:

- Thermal analysis showed there was no significant mass change above 600°C, which allows inferring that this is a reasonable burning temperaure of the waste sludge in preparation for recycling, thus enabling energy saving by preventing the raisins of the muffle temperature to 1000°C.
- The paint sludge mixed and disabled after thermal treatment showed particles with diameters between 1,156 and 703,9 μm. The sample of varnish paint sludge showed the occurrence of particles with diameters between 3.89 and 703.9 μm.
- The only crystalline phases identified in common among the samples is rutile, which is identified in all three samples and aluminum oxide (alumina), identified in at least two of the samples (WPS and DWPS). Also, rutile and quartz were identified in XRD analysis in other studies of waste for use in ceramic or concrete, such as discarded foundry sand and automotive paint sludge.
- Also, micrographs showed the presence of heterogeneous particle agglomerates with sizes ranging from 2 to 300 μm, as well as irregular morphology and particles adhered to the surface.
- These analyses provided more information on the paint sludge waste; however, to improve this information, there is a need for more analysis of Infrared Vibrational Spectroscopy, Atomic Absorption Spectroscopy, Flame Spectroscopy, and analysis of the particle size distribution. The experimental studies are required to determine whether or not the reusing of waste paint sludge after burning is viable as aggregates into other materials such as ceramic or concrete.

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SPENT SUBSTRATES FROM THREE SPECIES OF MUSHROOM AS ALTERNATIVE FEED RESOURCES FOR RUMINANT LIVESTOCK

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ABSTRACT

Three species of mushroom (*Pleurotus tuber-regium*; *Volvariella volvaceae*; *Pleurotus ostreatus)* were studied to determine their feed value using proximate composition, *in vitro* gas and methane production techniques. Dry matter (DM), organic matter (OM), neutral detergent fibre (NDF), and crude protein (CP) contents differed ($P < 0.05$) amongst the three mushroom species while, acid detergent fibre (ADF) and ash contents were similar ($P > 0.05$). *Pleurotus ostreatus* on sawdust reached peak gas production (7.5 mL) at 15 hours after incubation while, peak gas production was recorded at 21 hours post-incubation for both *V. volvacea* on cotton (7.5 mL) and *P. tuber-regium* (5.5 mL). Significant differences ($P < 0.05$) were also observed for the effective gas production at the 4% and 5% rumen outflow rates. *Pleurotus ostreatus* on sawdust recorded the least ($P < 0.05$) methane gas production (2.0 mL) while, *V. volvacea* on cotton gave the highest (6.5 mL). The results indicate that, spent mushroom substrates (SMS) could be converted into economic benefit as meat for humans rather than being left as environmental nuisance. It was concluded that, *P. ostreatus* on sawdust produced the best utilized SMS in terms of digestibility and methane gas production.

INTRODUCTION

The farming of mushroom in Nigeria has been promoted in recent times due to the high internal rate of return on investment for its product. Mushroom is an edible fungus that is very nutritious and consumed by humans and especially useful for those with medical concerns. Although not all mushrooms are edible, there are a handful of very healthy edible mushrooms including the three species (*Pleurotus tuber-regium*; *Volvariella volvaceae*; *Pleurotus ostreatus*) investigated in this study. Thus, the world production level of mushroom, based on a 2009 estimate, was put at 6,535,542 tons (FAOSTAT, 2011) with production still on the rise especially with increasing campaign on the health, nutritional and medicinal benefits of mushroom crop. Just as mushroom species differ in their genetic makeup so, they also differ in their level of performance when cultivated on different substrates ranging from sawdust from wood, paddy straw, ground corn cob, and so on (Ukoima *et al*., 2009; Adedokun, 2014).

Thus, these differences in species and substrate sources imply that, the feed value of the resulting SMS will also differ knowing that the mushroom crop would have helped to degrade some cellulose in the substrate before being fed to ruminant livestock (Sánchez, 2010). Production of mushrooms, however, is accompanied with the generation of million tons of residues referred to as spent or used mushroom substrates (SMS/UMS), which remains after the

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mushroom crop has been harvested. The SMS has been used for various purposes including its use as compost for soil conditioning and crop production, source of fuel, utilization as feed resource for ruminants, amongst others. In a report by Rinker (2002), used mushroom growing substrates are far from spent and can be put to various other uses. One of such uses into which SMS can be put for economic benefits include evaluating it for feed quality attributes in ruminant livestock. Therefore, this study investigated the potential use of SMS as an alternate feed resource for livestock. The specific objective of the study was to investigate the nutritive value of spent mushroom substrates from three mushroom species (*P. tuber-regium*; *V. volvaceae*; *P. ostreatus*) cultivated on either sawdust or cotton substrate.

MATERIALS AND METHOD

Experimental Site and Sample Collection

The site for sample (spent mushroom substrate, SMS) collection for the experiment was the Mushroom Unit of the Faculty of Agriculture Demonstration Farm, University of Port Harcourt, Choba, and Bazaleel Mushroom Farm, Port Harcourt. The SMS used were obtained from the substrates (sawdust and cotton) used for cultivating three species of mushroom namely: *Pleurotus tuber-regium*, *Pleurotus ostreatus* and *Volvariella volvacea*. The *P. tuber-regium* and *P. ostreatus* were cultivated on sawdust while, the *V. volvacea* was cultivated on cotton. The SMS for *P. tuber-regium* and *V. volvacea* were got from Bazaleel Mushroom Farm in Port Harcourt.

Cultivation and Management of the Mushroom

Pleurotus ostreatus was cultivated on sawdust substrate, with the mycelia allowed to ramify the substrate for a period of 4 weeks before the mushrooms were harvested while, the used growing substrate was then analyzed as possible feed resources. The *P. tuber-regium* species was cultivated on a sawdust substrate for a period of eight weeks, scletotia were harvested from the substrates and the used substrates were analyzed as feed resources. The *V. volvacea* species was cultivated on waste cotton substrate for a period of 4 weeks before harvesting the mushroom crops, and the spent substrate analyzed as feed resource, as well.

Chemical Analysis of Spent Mushroom Substrates

Duplicate samples of spent substrates from three edible fungus species were collected, weighed then, taken for chemical analysis, in duplicates. Dry matter (DM) content was determined by drying samples at 60°C for 72 hours or until no further loss in weight was recorded ('AOAC 2002': Official Method 934.01). The crude protein (CP) content was determined using Kjeldahl method with the nitrogen (N) content multiplied by the factor 6.25 to derive CP content ('AOAC 2002': Official Method 954.01). The ash content was analyzed according to standard procedures ('AOAC 2002': Official Method 923.03). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were also determined as described by Van Soest *et al.,* (1991).

In Vitro Gas Production

Rumen fluid was obtained from West African Dwarf (WAD) goats, passed through cheese cloth, mixed with buffer and mineral solutions then mixed in a 2:1 ratio and used for estimating the *in vitro* gas production according to the procedures described by Menke and Steingass (1988). About 200 mg of the 1 mm ground sample was measured into a 120 L syringe in triplicates before adding 30 mL of the rumen liquor mixed with buffer and mineral solutions. The liquor and samples were well-shaken and gentle too to determine post-incubation production of measure gas volume recorded after 0, 3, 6, 9, 12, 15, 18, 21 and 24 hours. Data obtained from gas production were then fitted to the non-linear model, $Y = b\ (1-e^{-ct})$ as revised by McDonald (1981); where Y = the volume of gas produced at time t, c = gas production rate; b = potential extent of gas produced from the insoluble 'but' fermentable fraction, and t = incubation time in hours. Effective gas production was computed as, $EGP = bc/(c + k)$, where b and c are as defined above while, k is the rumen outflow rate assumed to be 3%/h, 4%/h and 5%/h

Statistical Analysis

Parameters were analyzed using three treatments from the three different spent mushroom species (edible fungus) with two replicates and were subjected to analysis of variance (ANOVA) in a completely randomized design according to the procedures of SAS (2002). Significant F-tests for means were subjected to the New Duncan's Multiple Range Test (NDMRT) of SAS (2002) for mean separation.

RESULTS

Chemical Composition of the Spent Mushroom Substrates

Table 1 presents the chemical composition of spent substrates from three mushroom species grown on either sawdust or cotton. The results indicated that, acid detergent fibre (ADF) and ash were similar ($P > 0.05$) amongst the spent mushroom substrates (SMS) while, there were significant differences ($P < 0.05$) in dry matter (DM), organic matter (OM), crude protein (CP), and neutral detergent fibre (NDF) contents. Generally, DM content ranged from 70.6 g/100g DM for *P. tuber-regium* on sawdust to 87.4 g/100g DM for *V. volvacea* on cotton. Organic matter content varied from 96.8 g/100g DM for *P. oestratus* on sawdust to 98.2

TABLE 1
Chemical composition (g/100g DM) of spent sawdust and cotton substrates from *Pleurotus tuber-regium*, *Volvariella volvacea* and *Pleurotus oestratus* mushroom species

Chemical Composition	Spent mushroom substrate			Mean	S.E. (df = 3)
	P. tuber-regium on sawdust	*V. volvacea on cotton*	*P. oestratus on sawdust*		
Dry matter	70.6[c]	87.4[a]	74.4[b]	77.5	0.98
Organic matter	98.2[b]	97.3[ab]	96.8[a]	97.4	0.31
Crude protein	14.9[a]	8.8[b]	5.3[b]	9.6	2.65
Neutral detergent fibre	67.0[b]	84.3[a]	84.5[a]	78.6	8.50
Acid detergent fibre	60.9	59.0	58.5	59.56	25.84
Ash	1.76	2.78	3.25	2.60	0.311

[a-c]Means with different letters in same row are significantly different ($P < 0.05$)
S.E. = Standard Error

g/100g DM for *P. tuber-regium* on sawdust. The CP values ranged from 5.3 g/100g DM for *P. oestratus* on sawdust to 14.9 g/100g DM for *P. tuber*-regium on sawdust. Similarly, NDF contents varied from 67.0 g/100g DM in *P. tuber-regium* on sawdust to 84.5 g/100g DM in *P. ostreatus* on sawdust.

Gas Production Rate and *In Vitro* Dry Matter Digestibility

Table 2 shows differences ($P < 0.05$) in gas production rate and estimated *in vitro* dry matter digestibility of spent sawdust and cotton substrates from three mushroom species. Gas production rate from incubated spent substrate samples ranged from 0.054 mL/h in *P. ostreatus* on sawdust to 0.174 mL/h in *V.* volvacea on cotton. What this translates to is that, the cellulose in the spent cotton substrate would be degraded faster by rumen microbes when fed to goats or ruminants. Similarly, *in vitro* DM digestibility values varied from 90.1 g/100g DM in *P. tuber-regium* on sawdust to 97.3 g/100g DM in *V. volvacea* on cotton. Interestingly, *V. volvacea* on

TABLE 2
Gas production rate and *in vitro* dry matter (DM) digestibility of spent sawdust and cotton substrates from *Pleurotus tuber-regium*, *Volvariella volvacea* and *Pleurotus oestratus* mushroom species

Spent substrate	Digestion parameters	
	Gas production rate (mL/h)	*In vitro* DM digestibility (g/100 g DM)
Pleurotus tuber-regium on sawdust	0.095	90.1
Volvariella volvacea on cotton	0.174	97.3
Pleurotus oestratus on sawdust	0.054	96.5
Mean	0.110	90.0
S.E. (df = 3)	0.022	12.93

cotton appears to produce, relatively, more digestible roughage material for ruminants amongst the three studied.

Figure 1 shows the trend in *in vitro* gas production from spent sawdust and cotton substrates inoculated and grown with three mushroom species. The results showed that, while *in vitro* gas production for spent substrates from *P. ostreatus* cultivated on sawdust peaked at 15 h post-incubation, those on spent substrates from *V. volvacea* on cotton peaked at per with *P. ostreatus* on sawdust only at 21 h post-incubation. Although *P. tuber-regium* on sawdust also peaked at 21 h post-incubation, it peaked at a, relatively, lower *in vitro* gas production level compared to the other two spent substrates (5.5 mL vs. 7.5 mL), respectively. Thus, gas production ranked in decreasing order showed that: *V. volvacea* on cotton > *P. tuber-regium* on sawdust > *P. ostreatus* on sawdust. The differences in post-incubation *in vitro* gas production peak periods, partly, explains recorded *in vitro* DM digestibility variations in Table 2.

Methane Gas Output from Spent Substrates

Figure 2 indicates that, the methane gas outputs from spent sawdust and cotton substrates from three mushroom species were similar ($P > 0.05$). The volume of methane output ranged from 2.0 mL in spent substrate from *P. ostreatus* on sawdust to 6.5 mL from *V. volvacea* on cotton. Thus, it would appear that although the latter spent substrate was amongst the two that recorded better *in vitro* DM digestibility (Table 2), it also recorded the highest methane gas output (one of the greenhouse gases) and hence energy loss. Thus, *P. ostreatus* on sawdust could record more efficiency in energy utilization, if fed to livestock. This consideration is essential in the present global fight against food and nutrition insecurity, climate change and global warming. Thus, *V. volvacea* showed more potential to contribute, relatively, more greenhouse gas emission than spent substrates from the other two mushroom species.

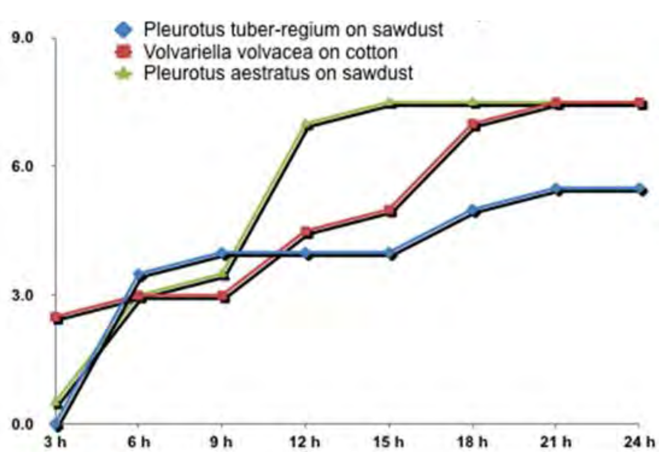

FIGURE 1
In vitro gas production characteristics of spent mushroom substrates from three species

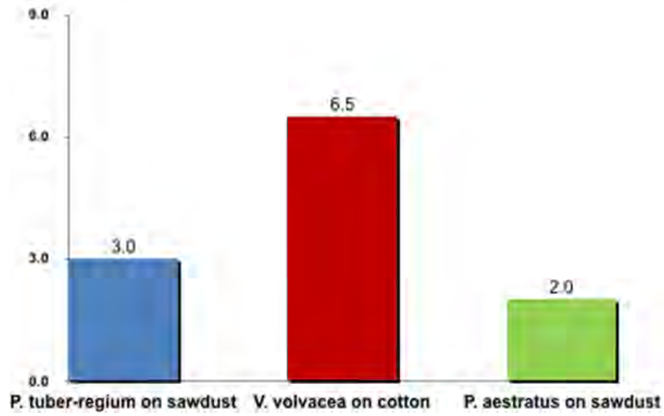

FIGURE 2
Methane gas output by spent sawdust and cotton substrates from three mushroom species

Effective Gas Production from Spent Substrates

The effective gas production values estimated at three assumed rumen outflow rates of 3, 4 and 5 per cent recorded by spent sawdust and cotton substrates from three mushroom species are shown in Figure 3. Generally, effective gas production differed ($P < 0.05$) amongst the three sources of spent substrates, which decreased, steadily, from the assumed rumen outflow rates in the pattern: 3 per cent > 4 per cent > 5 per cent. Similarly, the spent substrate from *V. volvacea*-inoculated cotton, consistently, recorded the least values while, spent substrates from *P. ostreatus* on sawdust recorded the highest estimated effective gas production of over 60 per cent.

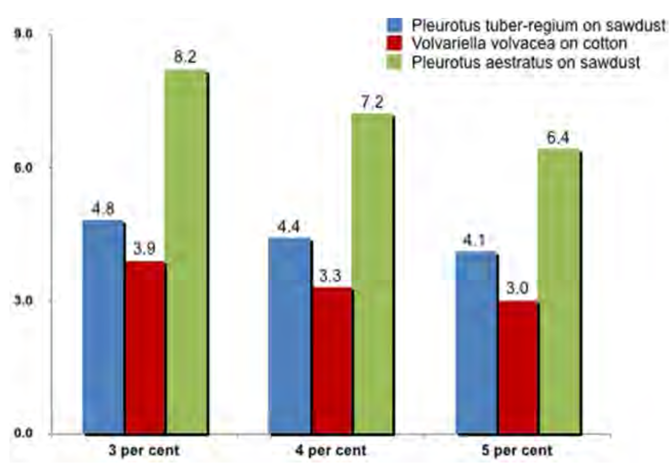

FIGURE 3
Effective gas production by spent sawdust and cotton substrates from three mushroom species

DISCUSSION

Chemical Composition of the Spent Mushroom Substrate

The chemical composition of feed helps to estimate its rate of digestion because, the higher the NDF, the lower the digestible energy content of a plant (Minson, 1990). The recorded NDF and ADF contents for *V. volvacea* on cotton and *P. ostreatus* on sawdust are similar to values reported by others (Akinyele and Akinyosoye, 2005). The NDF contents for the three SMS used in the study were above 60%, which signifies that, cellulose was the bulk of chemical contents in the SMS. The NDF contents of the spent substrates give a measure of plant cell wall contents (lignin, cellulose and hemicellulose). The higher ash content in *P. ostreatus* on sawdust indicates that, *P. ostreatus* on sawdust contained more minerals than the rest spent substrates investigated.

Gas Production Rate and *In Vitro* Dry Matter Digestibility

The *in vitro* gas production technique is used to determine the feed value of diets for farm animals. Digestibility can then be estimated from *in vitro* gas production. This technique, which has the advantage of not only being less expensive but, less time consuming too (Makkar, 2002; Fievez *et al*., 2005). Thus, the higher the gas production, the likely higher the digestibility. The high NDF contents might have resulted to the increase in gas production, which is in agreement with earlier studies that reported correlations between volume of gas or moles of volatile fatty acids (VFAs) produced and the mass of fibre digested in the NDF samples (Calabrò *et al*., 2002). Methane, which is one of the main greenhouse gases contributing to global warming is considered energy loss in ruminants (IPCC, 2001; Babayemi and Bamikole, 2006). The level of methane produced by *V. volvacea* on cotton was the highest, which suggests a significant level of energy loss due to inefficient digestion resulting from the activities of methanogenic bacteria such as *Methanobrevibacter ruminantium* and *Methanosarcina barkeri*. The higher rate of gas production (Table 2) may have contributed to the higher methane gas production by *V. volvacea*.

In terms of *in vitro* DM digestibility, the SMS from *P. ostreatus* cultivated on sawdust recorded optimal performance. The high *in vitro* DM digestibility and low methane gas production at a low gas production rate and high ash content of *P. ostreatus*, compared to the other two, suggest that it might be a better option for serving mixed mushroom-livestock diets as on-farm ruminant livestock feed. The results also indicate that, the least in terms of ruminant utilization was *V. volvacea* on cotton, which had the highest gas production (7.5 mL) at 21 hours after incubation. However, it was observed that *P. ostreatus* got to the peak of gas production of 7.5 mL at 15 hours after incubation while, *P. tuber-regium* was only able to produce its peak gas volume of 5.5 mL at 21 hours after incubation (Figure 1). The differences in NDF levels among the three SMSs appear to influence the time of incubation after which the peak gas production was attained although this observation is contrary to that by others (Maseri-Sis *et al*., 2007)

Effective Gas Production from Spent Substrates

The use of effective gas production as a tool for assessing ruminant feed quality has been shown to produce reliable results. Getachew *et al.,* (2004) reported from their study that, the *in vitro* gas production technique could be used for examining the level of animal waste components produced and with potential to negatively impact the environment and proactively develop the right mitigation method.

CONCLUSION

Spent substrates (SMS) from three mushroom species (*P. tuber-regium* on sawdust; *V. volvacea* on cotton; *P. ostreatus* on sawdust) were investigated for their potential feed value for ruminants. Results from the study suggest that, SMS can be, further evaluated for utilization by ruminant animals. The SMS has the potential of solving several agriculture-related problems based on the findings from the present study. Based on results from the study, it is recommend that further research be conducted to verify and or identify new opportunities about the findings from the present study.

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COMPARATIVE STUDY OF BIOGAS YIELD FROM PRE-TREATED RICE HUSK CO-DIGESTED WITH ANIMAL MANURES

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ABSTRACT

Rice husk (RH), a readily available lignocellulosic waste was pre-treated by soaking and boiling in water before co-digestion with three animal manures (chicken, cow and swine) in a batch type anaerobic digester. Raw RH and no RH treatments were also set up. Results showed that manure type had significant ($p \leq 0.05$) effect on substrate temperature, pH, biological oxygen demand (BOD), total bacterial count and biogas yield (BY) while RH treatment method had on pH, BOD and biogas yield. Cow dung treatments had the highest BY due to the low RH content. Treatments with RH had low BYs due to the high acidic nature of the RH and low available biodegradable total carbon content. In addition, treatments with RH showed no significant ($p > 0.05$) difference in their yields. It is therefore concluded that co-digesting RH with animal manures using the pre-treatment methods adopted is not promising for biogas production.

Keywords: Anaerobic co-digestion, Rice husk, Animal manure, Pre-treatment method, Biogas yield

INTRODUCTION

Rice husk (RH) is the tough protective cover of the rice grain and it is removed as a waste during the processing of rice. It is mostly indigestible to humans because of the high lignin content. Given the large-scale production of rice annually in Nigeria (Onu et al., 2015), large quantities of RH are produced at the rice processing mills. Rice husk dumps are mountainously available in alarming proportion at these mills and this contributes immensely to environmental pollution, degradation and hazards. This agro-industrial waste can be transformed either by chemical, mechanical and/or biological means (Vigil et al., 1993). Past records showed that it has been employed as fuels in process steam and in the technology of fluidized bed combustion boilers (Aggarwal, 2003). Rice husk can also be used as livestock feeds (Nour, 2016), composted and converted into an organic fertilizer (Leconte et al., 2009), digested for biogas production (Uzodinma et al., 2007; Iyagba et al., 2009) or used for building and insulation

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materials (Nnamdi, 2011). Due to the high percentage of lignin content, RH has distinctive structural characteristics which make it resistant to attack by anaerobic microorganisms (Yanfeng et al., 2009). However, an effective pre-treatment method can weaken all these hindrances (Taherzadeh and Karimi, 2008) by removing the lignin seal to increase the surface area of cellulose, solubilizing hemicellulose, disrupting crystallinity, and increasing pore volume and then making it amenable for enzymatic hydrolysis or microbial biodegradation with higher enzyme production (Sridevi et al., 2011). Many pre-treatment methods have been proposed for lignocellulosic biomass including mechanical, biological, chemical, steam explosion pre-treatment and others (Zheng et al., 1995; van Walsum et al., 1996; Mosier et al., 2005; Hendriks and Zeeman, 2009; Karunanithy and Muthukumarappan, 2011; Ofoefule et al., 2011; Wang et al., 2012). Specifically, some previous studies carried out on biogas production from RH (Uzodinma et al., 2007; Iyagba et al., 2009; Ofoefule et al., 2011; Sharma et al., 2014) have shown promising results when the waste was pre-treated and/or co-digested with animal manures. However, most of the pre-treatment methods experimented were chemical, which may not be adaptable on a large scale or in a rural setting. Therefore, the need to exploit simple pre-treatment methods to optimize biogas production from RH co-digested with animal manures has become imperative considering the large volumes of RH waste and the energy challenges faced by both rural and urban populace in Nigeria. This study focused on the pre-treatment of RH by soaking and boiling in water and co-digesting it with animal manures. Raw RH and no RH treatments were also set up and the biogas yields of all treatments were compared.

MATERIALS AND METHODS

The RH used was collected from a rice mill in Ikole Ekiti while raw chicken manure (CM), cow dung (CD) and swine manure (SM) excreted within four days were collected from the Obafemi Awolowo University Teaching and Research Farm, Ile-Ife both in South West of Nigeria. The digestion was carried in a laboratory at ambient conditions at the Department of Agricultural and Environmental Engineering of the University.

Analytical procedure

The feedstocks' samples were analysed for total solids (TS) content (oven drying at 105 ^oC for 24 h); volatile solids (VS) content (ashing of TS at 550 ^oC for 5 h); total nitrogen (TN) (regular-Kjeldahl method; Bremner, 1996); pH (using a digital pH meter) and total organic carbon (TOC) (Titrimetric method; AOAC, 1995). The total carbon (TC) content was estimated from the ash content according to the formula (Mercer and Rose, 1968):

$$TC\,(\%) = [100 - Ash\,(\%)]/1.8$$

Biological oxygen demand (BOD) and total bacterial count (TBC) of the substrates were analysed using the pour plate technique by Olutiola et al., (1991).

Experimental set up

The batch digestion experiment was a *two-factor* completely randomized block design with three manure types (CM, CD and SM) and four RH treatments (raw rice husk (RRH), soaked rice husk at ambient temperatures for 72 hours (SRH), boiled rice husk at 100 ^oC for 30 minutes (BRH) and no RH (NRH). The set up comprised of digesters, water tanks and water collectors (Figure 1). The digesters were adapted using cube-shaped 25 dm^3 plastic kegs. The kegs were positioned to give surface (dm^2) and height (dm) dimensions of 2.50 × 4.65 and 2.15, respectively. A drain plug was fitted at the base of each digester for collection of samples for pH, BOD and TBC analysis. Each digester had a digital thermometer probe fitted to it for temperature measurement. Similarly, the water tanks and water collectors were adapted using 10 dm^3 and 5 dm^3 rectangular plastic kegs, respectively. Rubber hose was used to connect each digester to the water tank and the water tank to the water collector.

Feedstocks preparation

The C:N ratios of the manures and RH mixtures were adjusted to between 35 and 37:1. The RH was then pre-treated accordingly before mixing with the manures. Three digesters comprising of the three manures without RH addition were also set up. Each treatment's moisture content was adjusted to 92% with portable water for optimum anaerobic digestion (Zennaki et al., 1996). Each digester was filled to 70% (17.5 dm^3) capacity with the substrates and replicated thrice. The biogas produced exited the digester via the hose to the water

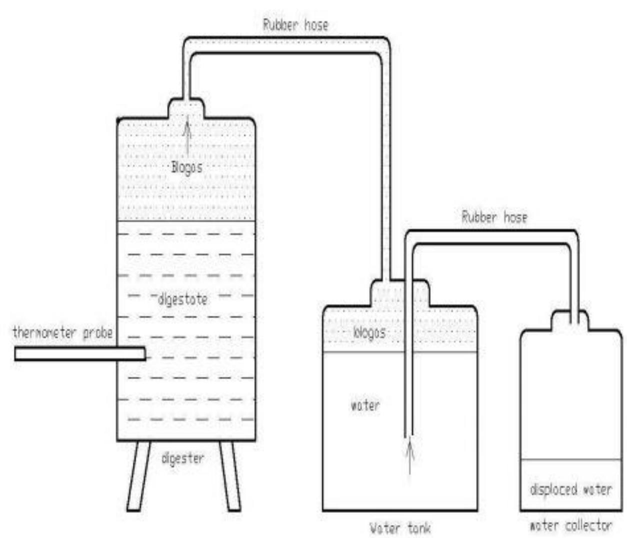

FIGURE 1
Schematic diagram of the experimental set up

tank and subsequently displaced equivalent volume of water to the water collector (Archimedes' principle). The digesters were manually agitated twice daily at twelve-hour interval to ensure intimate contact between the microbes and the substrates and to release gas bubbles that may have been trapped within the substrates. The digestion lasted for 16 weeks during which ambient and substrates temperatures and biogas yield were monitored daily, pH was monitored weekly and BOD and TBC were monitored every three weeks.

Statistical analysis

The data obtained were subjected to statistical analysis. Two-way analysis of variance (ANOVA) was performed using the Statistical Analysis System (SAS, 2000) software to compare variations within the monitored properties. Where significance was indicated, Duncan's multiple range test was used to establish which treatment(s) was significantly different. Pair-wise correlation of parameters was carried out to determine significant relationships. Significance of data was established at $p \leq 0.05$.

RESULTS AND DISCUSSION

Cow dung treatments had the least quantity of RH addition because of the high initial C:N ratio of the CD (Table 1). On the other hand, CM treatments had the highest quantity of RH because of the low initial C:N ratio of the CM. The TOC of CD was found to be the highest, while that of the rice husk was the least (Table 1). However, CM had the highest percentage of TOC in TC, implying that percentage of the TC available for biodegradation was very high.

Temperature

The mean and standard deviations of the ambient and substrate temperatures during digestion were in the range of 36.4 $^oC \pm 3.29\ ^oC$ and 31.9 $^oC \pm 0.38\ ^oC$, respectively. The fluctuations were partly related to the microbial activities during digestion as evident by the significant ($p \leq 0.05$) correlation ($R^2 > 0.49$) between substrate temperatures and TBC in more than 75% of the treatments. However, despite the fluctuations, the digesters operated within the mesophilic temperature range (25-35 ^oC) considered optimal for the support of biological-reaction rates (Tchobanoglous et al., 2003). Manure type affected ($p \leq 0.05$) the substrate temperatures differently (Table 2). Cow dung treatments exhibited the highest temperatures followed by CM treatments. The daily ambient and substrate temperatures were averaged weekly and presented in Figure 1. The profile exhibited a sinusoidal pattern in all the treatments. The peak temperatures were recorded during week 3 in CM and CD treatments (Figure 2a,b) and week 8 in SM treatments. Low and insignificant R^2 values (0.003-0.227; $p > 0.05$) were established between the ambient and substrate temperatures during digestion, indicating that the digester temperatures may not have been influenced by the ambient temperatures. However, it was observed that

TABLE 1
The initial concentrations of the feedstock materials
Mean ± standard deviation are shown ($n = 3$)

Parameter	Feedstock material			
	Rice husk	*Chicken manure*	*Cow dung*	*Swine manure*
Moisture content* (%)	9.56 ± 0.68	63.6 ± 1.31	67.2 ± 0.81	42.3 ± 0.96
Ash (%)	0.18 ± 0.06	22.4 ± 3.15	14.8 ± 1.62	16.8 ± 2.17
Total C (%)	54.5 ± 0.05	42.4 ± 2.21	46.6 ± 1.47	45.5 ± 1.78
Total OC (%)	15.8 ± 2.01	40.2 ± 1.97	42.9 ± 2.86	39.3 ± 1.09
Total OC/Total C (%)	29.0	94.8	92.1	86.4
Total N (%)	1.47 ± 0.53	4.48 ± 0.05	1.26 ± 0.87	3.15 ± 1.11
Total P (%)	1.37 ± 0.43	1.93 ± 0.81	1.63 ± 0.28	1.06 ± 0.65
Total K (%)	2.37 ± 1.01	1.43 ± 0.66	0.44 ± 0.13	0.46 ± 0.19
C:N ratio	37.1:1	9.47:1	36.5:1	14.4:1
pH	4.20 ± 1.14	7.40 ± 1.06	7.92 ± 0.84	6.40 ± 1.23

**Moisture content was measured on wet weight basis.*

TABLE 2

The results of the ANOVA showing the effects of manure type and treatment method on anaerobic digestion properties.

Parameter	Source	Df	SS	MS	*F*-value	Pr>F
Temperature	Manure	2	4.881	2.441	50.42	<.0001
	RHT	3	0.105	0.035	0.72	0.549
	Manure*RHT	6	0.474	0.079	1.63	0.1820
	Error	24	1.162	0.048		
	Total	35	6.621			
pH	Manure	2	36.409	18.205	5563.37	<.0001
	RHT	3	2.779	0.926	283.10	<.0001
	Manure*RHT	6	4.502	0.750	229.30	<.0001
	Error	24	0.0785	0.003		
	Total	35	43.769			
BOD	Manure	2	187.380	93.690	121.42	<.0001
	RHT	3	67.795	22.598	29.29	<.0001
	Manure*RHT	6	188.924	31.487	40.81	<.0001
	Error	24	18.519	0.772		
	Total	35	462.618			
TBC	Manure	2	2299663898	1149831949	8.62	0.0015
	RHT	3	715479511	238493170	1.79	0.1764
	Manure*RHT	6	2648261417	441376903	3.31	0.0162
	Error	24	3202230845	133426285		
	Total	35	8865635671			
Biogas yield	Manure	2	1174656.009	587328.004	30.35	<.0001
	RHT	3	511438.583	170479.528	8.81	0.0004
	Manure*RHT	6	271130.511	45188.419	2.33	0.0643
	Error	24	464501.113	19354.213		
	Total	35	2421726.216			

RHT- rice husk treatment method

temperature was strongly influenced ($p \leq 0.05$) by pH in all the SM treatments (R^2 = 0.82-0.98) and NCM (R^2 = 0.64). In addition, a discerning relationship ($p \leq 0.05$) was established between substrate temperature and BOD in almost all the treatments during digestion.

pH

The initial pH of the RH was very acidic while those of the animal manures (Table 1) were within the range of 6.0-8.0 considered suitable for bacteria involved in anaerobic digestion. Low pH (5.50) had also been reported for RH in a previous study (Kafle et al., 2012). However, after mixing the feedstocks, the initial pH of the resulting substrates was raised and ranged between 5.7 and 8.0. The results of the ANOVA showed that manure type, treatment method and the interaction between the two factors had significant ($p \leq 0.05$) on the substrates pH (Table 2). The average pH during digestion showed that CD and NRH treatments had near neutral pH (Table 3). The average pH of these two categories of treatments ranged between 6.09 and 7.12 and it could be attributed to the fact that CD had high initial pH that may have possibly buffered the substrates medium and also, the absence of RH in the other treatments. However, the other categories of treatments exhibited acidic characteristic with individual average pH ranging between 4.29 and 4.90. Uzodinma et al., (2007) also reported acidic environment when RH was co-digested with some agro-industrial wastes. The acidity of the RH conspicuously reflected in the pH profiles. Figure 3a showed that NCM had consistently high and near neutral pH

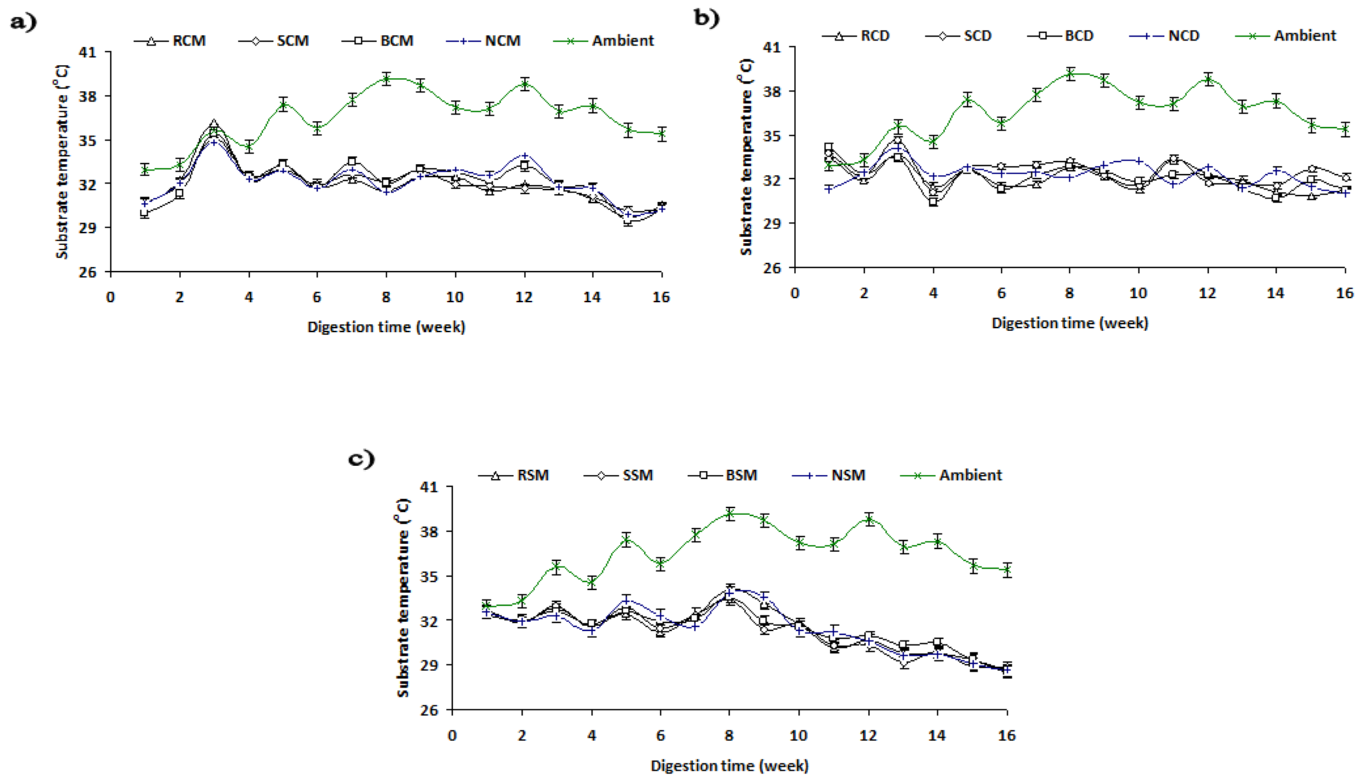

FIGURE 2

Variation of ambient and substrate temperatures during co-digestion of treated rice husk with (a) chicken manure, (b) cow dung and (c) swine manure. Error bars show standard errors of means (n = 3).

(6.13-7.40) until week 14 of digestion before it dropped to <5.0. CD treatments (Figure 3b) had pH fluctuating between 5.7 and 8.0. NSM maintained close but significantly ($p \leq 0.05$) high pH than other SM treatments (Figure 3c). While the acidity/alkalinity status of the treatments was highly related to the RH, the pH variation during digestion could also have been related to the manures used. Each manure treatments exhibited peculiar trend. In CM treatments (Figure 3a), the pH dropped to low values during week 3, rose slightly during week 4 and became relatively stable before experiencing a steep drop between weeks 14 and 16. In CD treatments (Figure 3b), only the pH of NCD exhibited a slightly different variation between weeks 2 and 9. However, all the SM treatments (Figure 3c) followed the same pattern of variation, experiencing a steep decrease between weeks 10 and 11. Generally, decrease in pH implied the production of volatile fatty acids (Cuzin et al., 1992) while increase implied transfer and consumption of volatile fatty acids by methanogenesis. The final pH values (2.83-5.71) were below the range of 6.0-8.5 recommended for organic matter compatibility with most plants (Lasaridi et al., 2006). However, the digestate could be left to cure before application to plants.

Biological oxygen demand

Biological oxygen demand is a measure of the level of biodegradable organic matter in the substrates, obtained by measuring the amount of oxygen absorbed from the substrates by the microorganisms present in it. The results of the ANOVA showed that manure type, treatment method and the interaction between the two factors had significant ($p \leq 0.05$) effect on the BOD of the substrates (Table 2). The average BOD of SM treatments was lower than those of CD and CM treatments which were significantly the same ($p > 0.05$). Similarly, NRH treatments had lower BOD (Table 3). As digestion progressed, BOD dropped gradually in all the treatments (Figure 4), indicating decrease in dissolved oxygen and depletion of biodegradable organic matter in the digesters.

Total bacterial count

The results of the ANOVA showed that manure type and the interaction between manure type and treatment method had significant ($p \leq 0.05$) effect on the TBC of the substrates (Table 2). The mean values showed that CD and SM treatments had higher and same ($p > 0.05$) TBC during digestion (Table 3). A trend common to all the manures was that the TBC of BRH and NRH treatments in each manure treatment were significantly the same ($p > 0.05$). This suggested that the contribution of BRH to the bacterial population was insignificant. The high temperature (100 ^{o}C) at which the RH was subjected to before digestion may have undermined its potential to develop or accommodate bacteria growth during digestion. The anaerobic bacteria population seemed not in-

TABLE 3

Duncan's multiple range tests showing the effects of manure type and treatment method on anaerobic digestion properties

Parameter	Manure type			Treatment method			
	CD	*CM*	*SM*	*BRH*	*RRH*	*SRH*	*NRH*
Temperature (°C)	32.2^{b}	32.0^{a}	31.4^{c}	31.9^{a}	31.8^{a}	31.9^{a}	32.0^{a}
pH	6.99^{a}	4.84^{b}	4.89^{c}	5.49^{a}	5.43^{b}	5.33^{c}	6.05^{d}
BOD	8.92^{a}	9.44^{a}	4.36^{b}	8.54^{a}	8.37^{a}	8.17^{a}	5.21^{b}
TBC	46627^{a}	30024^{b}	47310^{a}	39944^{a}	47528^{a}	42607^{a}	35204^{a}
Biogas yield	618.8^{a}	208.6^{b}	270.0^{b}	302.8^{a}	288.5^{a}	299.8^{a}	572.0^{b}

Superscripts with the same letter are not significantly different at p ≤ 0.05.
BRH- boiled rice husk, RRH- raw rice husk, SRH- soaked rice husk, NRH- no rice husk

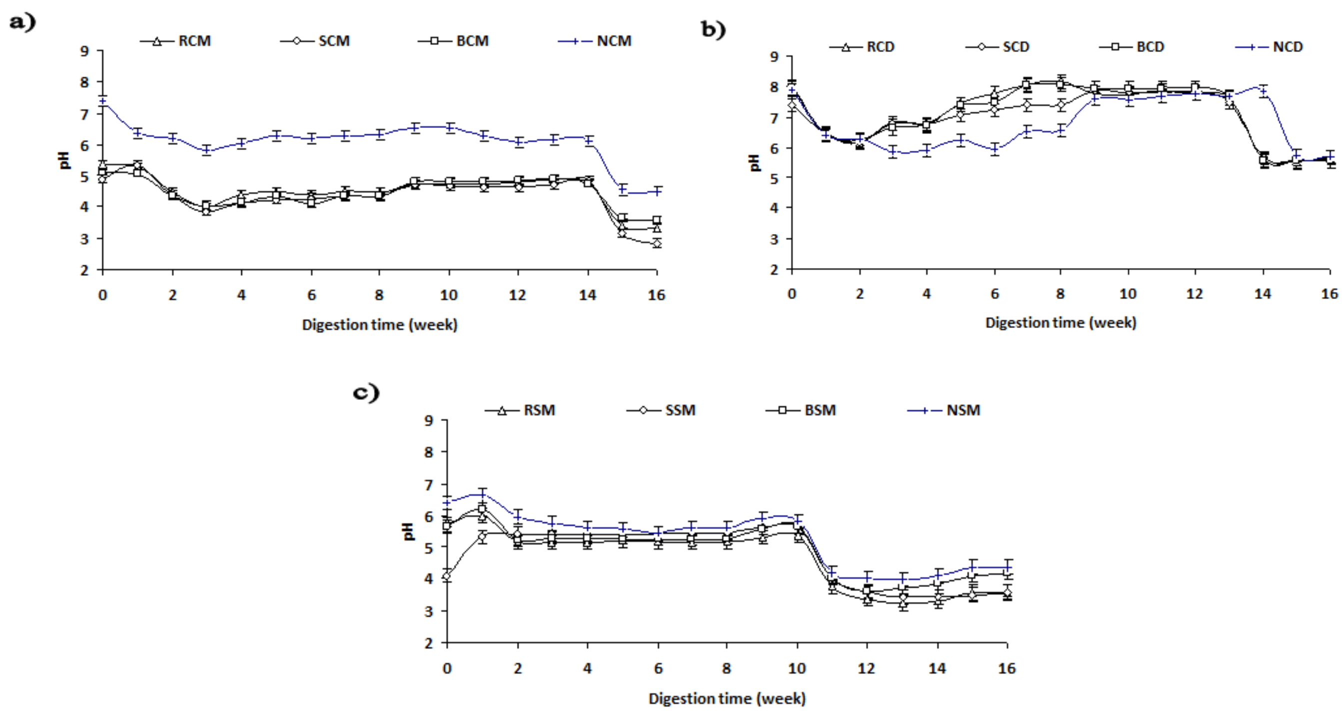

FIGURE 3

Variation of substrate pH during co-digestion of treated rice husk with (a) chicken manure, (b) cow dung and (c) swine manure. Error bars show standard errors of means (n = 3).

fluenced by variation in pH as there was no significant (p > 0.05) correlation between the two parameters in any of the treatments during digestion. This phenomenon was also observed by Olutiola et al., (2010) and it was attributed to the fact that most bacteria were able to tolerate slight pH changes. The strong and significant correlation ($R^2 \geq 0.73$, $p \leq 0.05$) observed between TBC and BOD in more than 75% of the treatments revealed why the population of anaerobic bacteria decreased as the amount of organic compounds in the substrates decreased. The TBC dropped in all the treatments as digestion progressed although some treatments had fluctuating pattern (Figure 5). This trend was also observed in previous biodigestion studies (Ofoefule et al., 2010; Asikong et al., 2014) and linked to high acidity level in substrates (Mosey and Fernandes, 1989; Sahota and Ajit, 1996). The rate of drop of TBC was highest in treatments with RH in the order: RCM (7216.9 cfu/ml every 3 weeks, R^2 = 0.89), RCD (8501.7 cfu/ml every 3 weeks, R^2 = 0.92) and RSM (10867.0 cfu/ml every 3 weeks, R^2 = 0.76). This coincided with the order of the average TBC in the animal manures (Table 3). At week 3, the bacterial population varied widely (26,000-152,750 cfu/ml) but narrowed down (2,000-18,666 cfu/ml) by week 15. This indicated the various levels of available nutrients in the substrates at the early stage and the depletion of these nutrients as digestion progressed and subsequent extinction of the anaerobic bacteria.

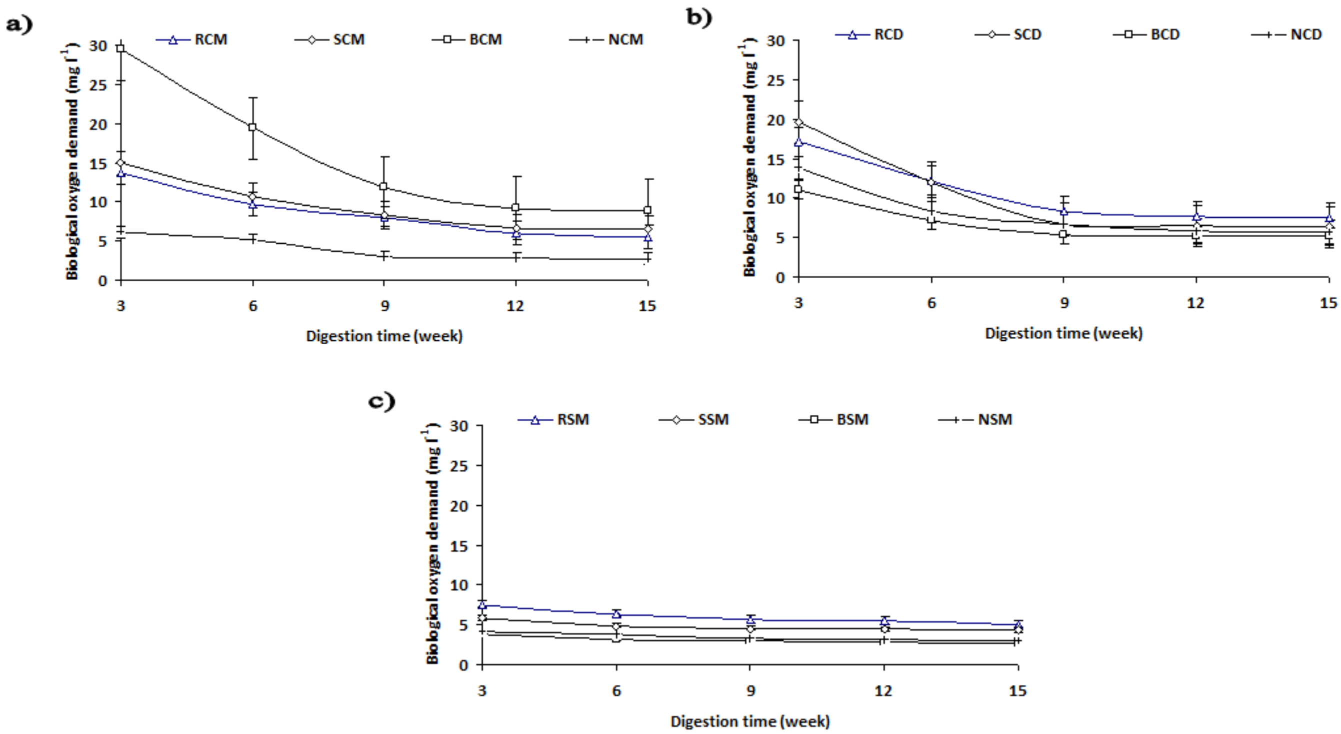

FIGURE 4
Variation of biological oxygen demand during co-digestion of treated rice husk with (a) chicken manure, (b) cow dung and (c) swine manure. Error bars show standard errors of means ($n = 3$).

Biogas yield

The lignocellulosic compounds in the RH and high initial C:N ratio of the substrates appeared not to have hindered the start of biogas production as production started within 24 h in all the treatments with rice husk (BRH, RRH and SRH) while the treatments without RH (NRH) experienced between 24 and 48 h lag period. The early production could be due to a synergetic effect due to the complementary characteristics of the feedstocks mixed (Comino et al., 2010). The ANOVA results revealed that manure type and treatment method had significant ($p \leq 0.05$) effect on the biogas yield during digestion (Table 2). The average yield showed that there was no significant ($p > 0.05$) difference among the yields of treatments with RH (Table 3). Similarly, CM and SM treatments showed no significant ($p > 0.05$) difference in their yields. The average yields observed corresponded to the quantities of RH added to the manures. The lower the quantity of RH (consequently, lower lignocellulosic compounds and available biodegradable TC), the higher the biogas yielded. The yields can be related to the average pH (Table 3) although no significant ($p > 0.05$) correlation was found between the two factors in any of the treatments during digestion. It would be noted that the manure treatments with low yields (CM and SM) had low pH (4.84 and 4.89, respectively). Similarly, the treatments with rice husk (BRH, RRH and SRH) had low and significantly same ($p > 0.05$) yields and low pH (5.49, 5.43 and 5.33, respectively) (Table 3). The low yield may have been as a result of inhibitors (high level of volatile fatty acids produced by nitrogen limitation or low biodigestibility of the lignocellulosic compounds in the RH as evident by the low available biodegradable TC (Table 1). Alexander (1977) reported that the characteristics of high value of lignin are resistance to enzymatic degradation which affects the biogas production. Negative correlation ($p \leq 0.05$) was established between biogas yield and TBC during digestion, suggesting the depletion of non-methanogenic bacteria as digestion progressed. The fact that substrate temperatures fluctuated within the mesophilic temperature range suggested that biogas yield would not have been adversely affected by temperature. The 112-day digestion experiment showed some days of no biogas production. The total non-production days ranged from 12-32 days (total = 89 days), 1-19 days (total = 31 days) and 15-29 days (total = 77 days) in CM, CD and SM treatments, respectively. The non-production phenomenon was also observed by Ogunwande et al., (2015) and Adanikin et al., (2017) and was attributed to methanogens undergoing a methamorphic growth process by consuming methane precursors produced from the initial activity (Lalitha et al., 1994) or temporary inhibition of the digestion process due to volatile fatty acid accumulation (Bouallagui et al., 2001). Remarkably, the order of treatments from least to highest non-production days was BRH-RRH-SRH-NRH in each manure treatment. The total non-production days in the manure treatments reflected in the biogas yields (Table 3). Higher days corresponded to lower yield. The daily biogas yields

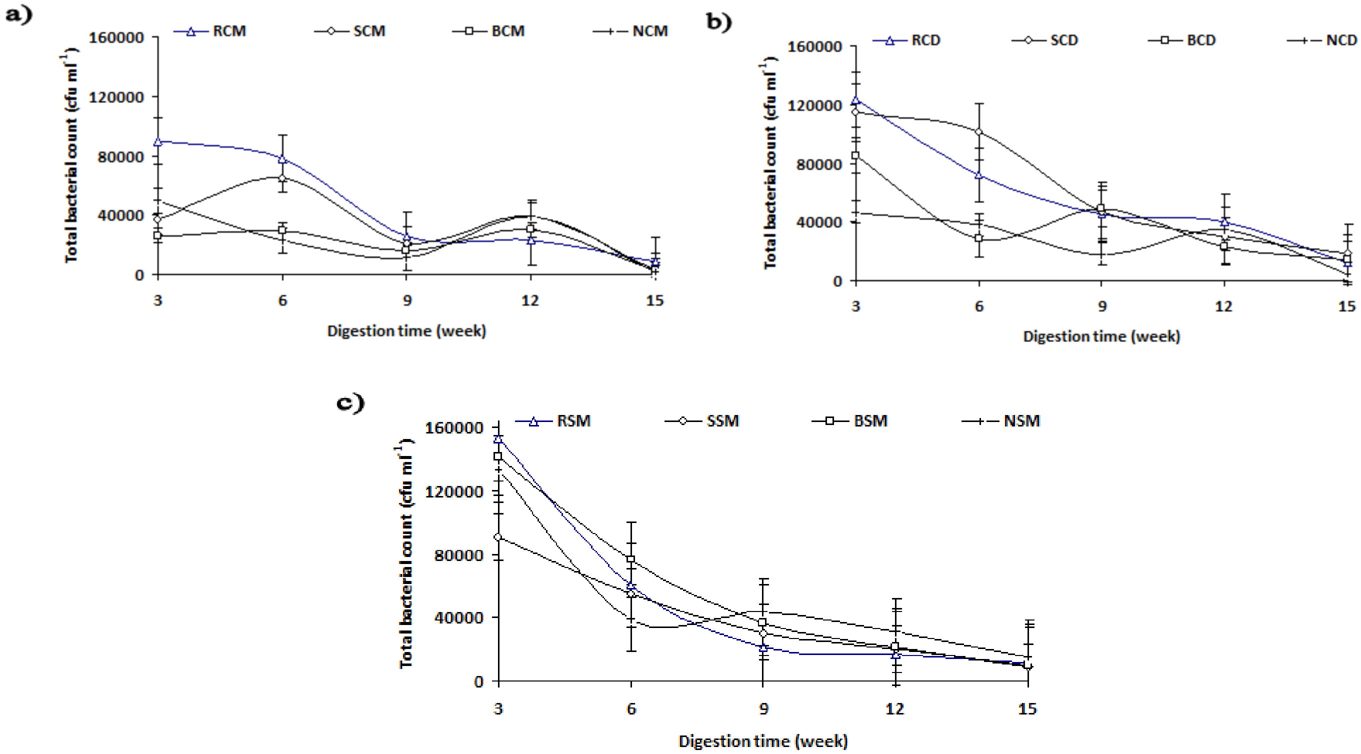

FIGURE 5

Variation of total bacterial during co-digestion of treated rice husk with (a) chicken manure, (b) cow dung and (c) swine manure. Error bars show standard errors of means (n = 3).

observed were averaged weekly and presented in Figure 6. The yield profiles were characterized by increases and drops in biogas production, with peak productions at different weeks during digestion. The peak production periods in the treatments were related in each manure: the yields of CM, CD and SM treatments peaked during weeks 12, 10 and 8, respectively. According to Odeyemi (1982), difference in peak periods could be attributed to differences in organic matter content and degree of biodigestibility of feedstocks. In this study, the difference in the peak periods could be related to the availability of biodegradable TC in the manures (Table 1). The more the available biodegradable TC, the longer it took to peak production. The yield from NCM treatment was consistently high than those of other treatments with RH (Figure 6a). This may be related to its consistent high pH during digestion (>6.1 between weeks 1 and 14) (Figure 3a). The yields from the SM treatments (Figure 6c) were not clearly separable and a comparison test confirmed that there was no significant (p > 0.05) difference among the yields. By the end of week 16, no treatment had stopped production although yields from CM and SM treatments had dropped considerably compared to the CD treatments. This showed that the substrates still contained available nutrients despite the low pH state. Although the yields from treatments with RH in each manure were not significantly (p > 0.05) different, BCM, SCD and RSM produced the highest cumulative biogas yields (Figure 7). The inconsistencies in the RH treatments as regards the highest yield substantiate the findings that the treatment methods did not affect biogas production from RH.

CONCLUSIONS

Biogas yields from pre-treated, raw and zero RH co-digested with animal manures were compared. Manure type had significant effect on biogas yield, with CD treatments producing the highest yield. Treatments with RH had low but not significantly different yields. The high acidic nature of the RH and low available biodegradable TC content in it may have contributed to the low yields recorded. Treatments without RH had higher yields, suggesting that co-digesting RH with animal manures using the pre-treatment methods adopted may not be promising for biogas production.

NOMENCLATURE

RCM, SCM, BCM and NCM-Raw rice husk, soaked rice husk, boiled rice husk and no rice husk mixed with chicken manure, respectively RCD, SCD, RCD and NCD -Raw rice husk, soaked rice husk, boiled rice husk and no rice husk mixed with cow dung, respectively RSM, SSM, RSM and

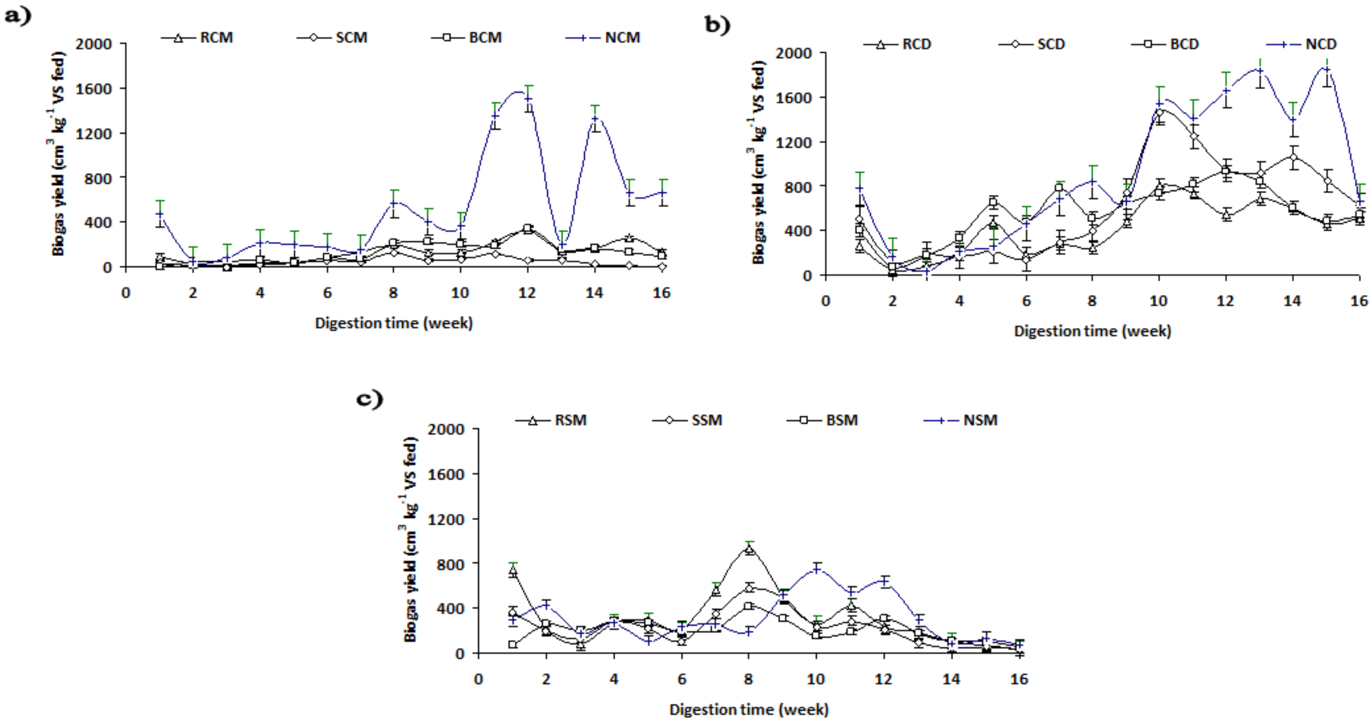

FIGURE 6

Variation of biogas yield during co-digestion of treated rice husk with (a) chicken manure, (b) cow dung and (c) swine manure. Error bars show standard errors of means (n = 3).

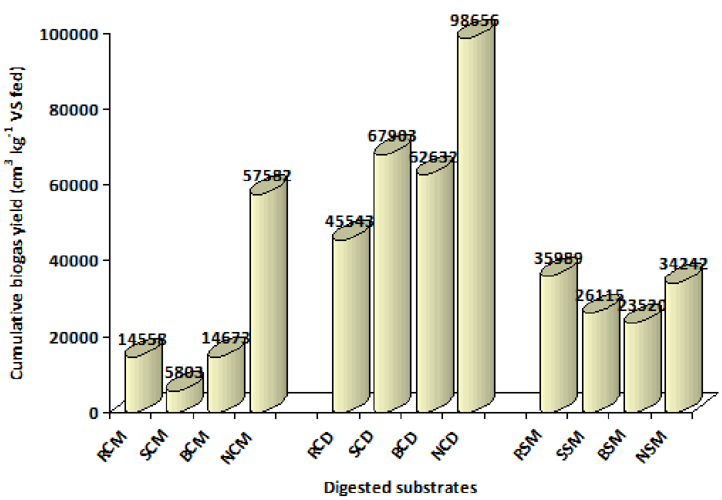

FIGURE 7

Cumulative biogas yield from digested substrates

NSM -Raw rice husk, soaked rice husk, boiled rice husk and no rice husk mixed with swine manure, respectively.

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EVALUATION OF EXISTING SOLID WASTE MANAGEMENT PRACTICES FOR SOLAN CITY–INDIA

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ABSTRACT

Management of Municipal Solid Waste (MSW) is an essential function of the Urban Local Body (ULB) of the city or town. The paper presents an overview of the existing solid waste practices followed at Salogra dumpsite located in the district of Solan, Himachal Pradesh, India. Total Solid Waste generated in Himachal Pradesh (HP) is about 350 Tons per day (TPD) of which the daily average dumping at Salogra site in Solan city is about 22.5 tons per day. The per capita waste generation in Solan city is 0.4 kg/capita/day with a collection efficiency of about 60%. Of the total budgetary provisions for management of municipal solid waste (MSW) generated under the purview of Solan Municipal Corporation (MC), about 90% of them are utilized for collection and transportation purposes. The existing waste management practice at the study location was evaluated using the *'wasteaware'* benchmark indicators which include qualitative and quantitative parameters for the assessment. In addition, a matrix method has been used for quantitative representation the results. The overall score achieved using the matrix method was only 32% indicating that there exists a significant scope for improvement in the management of the existing waste system practices in Solan. In this context, some suggestions have been proposed for improvement of the existing MSW management system in Solan.

Keywords: Municipal solid waste management, landfill, Public-private partnership, Wasteaware benchmark parameters

INTRODUCTION

Solid waste management has always been a pertinent issue for developing countries (Shekdar, 2009). This is primarily due to poor waste management practices including lack of authentic data and information to assess the waste management practices (Chang and Davila, 2008; Hancs *et al*., 2011). In reality, often these data are critically absent or are highly erroneous in nature which cannot be used further validated due to non- reproducibility of results (Couth and Trois, 2011). The quantity and composition of MSW vary from place to place, and are a reflection of the average standard of living (Hoornweg and Laura, 1999). Various different methods are utilized for prediction of of solid waste including multivariate models (Intharathirat *et al*., 2015) and ANN techniques (Abdoli *et al.*, 2012; Wu *et al*., 2015) to overcome the challenges of lack of data and for future prediction of generation of solid wastes with greater accuracy for increas-

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ing population. In an Indian context, it has been found that the rate of solid waste generation varies from 0.2-0.87 kg/day depending upon the population and the economic potential of the city (Sharholy *et al.,* 2008; Kumar *et al.,* 2009; Agrawal *et al.*, 2013). Table 1 shows generation rate of solid waste (per capita) based upon the population of cities and towns (NEERI 2010). The classifications of cities have been based on the population within those cities.

Reported literature has classified that generation of municipal solid wastes in developing countries consists of 55-80% from households and about 10-30% from commercial areas with the rest being contributed by other factors including miscellaneous and inert wastes (Nabegu *et al*., 2011). In an Indian context, it has been reported of about 48 million tons of solid waste being generated with the figure rising to about 250 million tons of waste by 2050 (Sharholy *et al*., 2008). In India, management of solid wastes in urban areas fall under the purview of municipal corporations, however the effectiveness of the management process is severely hampered by improper management practices thereby reducing the efficiency of the system. It is further compounded due to additional issues like poor land use, reduced availability, and lack of proper technical skills for management of solid waste, lack of adequate finances and its management, non-coordination between different authorities and lack of definite legislative policies (Kumar *et al*., 2009). As a consequence, open-dumping of solid waste takes place without any appropriate measures for prevention of human and environmental health (Menikpura *et al*., 2013).

In such a scenario, a safe and proper disposal method should be implemented to maintain the health and environment standards of the city. However, burning of solid wastes leads to generation of air pollutants and open dumping can cause soil and water contamination of the surrounding regions (Lebersorger and Beigl, 2009; Ramachandra, 2009). Further, in developing countries unscientific disposal methods are most common and in Indian context it has been reported that about 90% of the solid waste generated is usually dumped in non-engineered landfills in an unsatisfactory manner particularly in bigger cities and towns (Hazra and Goel, 2009). Such open dumping leads to emission of landfill gases which causes global climate change (Tan *et al*., 2014). Hence it is important to dispose of the generated solid waste in an environmental friendly manner (Nash 2009; Greene and Tonjes 2014).

Several literature studies have been carried out in Indian context for the proper management of solid wastes generated. The scope of the studies range from existing generation, collection and disposal techniques (Rana *et al*., 2015), prediction of solid waste generation in future depending on population increase (Das and Bhattacharya, 2014), characterization of solid wastes (Rawat *et al*., 2013), leachate properties generated from solid waste (Sang *et al*., 2010). Despite several studies reported in an Indian context, the efficiency of the SWM system varies for different cities being dependent on the respective waste management practices followed (Lebersorger and Beigl 2011).

The present study evaluates the performance of the existing waste management system under the purview of Solan Municipal Corporation (MC) identifying the major factors responsible for poor waste management practices. Further, the performance of the existing system has been evaluated by the '*wasteaware*' benchmark techniques to evaluate its performance and compared with other tier-II cities of Asia. Further, the results from the evaluation have been utilized for suggesting appropriate remedial measures for improving the function of the existing solid waste management system of Solan Municipal Corporation.

SITE LOCATION

Solan is located in the southwestern districts of Himachal

TABLE 1
Per capita waste generation in cities and towns (NEERI 2010)

Classification	Population Range		Per Capita *Kg/day*
Class 1	5,000,000	Above	
	1,000,000	4,999,999	0.605
	700,000	999,999	0.448
	500,000	699,999	0.464
	400,000	499,999	0.487
	300,000	399,999	0.448
	200,000	299,999	0.436
Class 2	100,000	149,999	0.445
Class 3	50,000	99,999	0.518
Class 4	20,000	49,999	0.434

Pradesh and lies between the UTM coordinates of (700384.18, 3420901.86) located in the UTM zone of 43R. As per the latest population census carried out in India in the year 2011 (National Census Report, 2011), the population of Solan district is 5,76,670 with a population density of 298 inhabitants per km^2 covering an area of 1936 km^2. The entire Solan district is subdivided into 9 tehsils as shown in Figure 1.

The Salogra dumpsite is located in districted Solan of Himachal Pradesh on National Highway (NH) 22. The Salogra dumpsite handles the entire amount of solid waste generated from the five tehsils of Arki, Kandaghat, Kasauli, Solan and Kuthar and is managed by the Solan city Municipal Corporation (total population around 1 lakh). The Salogra dumpsite is responsible for handling about 18-20% of total solid waste generated in Solan District. The location of Salogra dumpsite has been shown in Figure 2.

ASSESSMENT OF EXISTING MUNICIPAL SOLID WASTE (MSW) MANAGEMENT IN SOLAN

MSW Stakeholders

The quantity and the characteristics of MSW generated depends upon number of factors including food habits, standard of living, degree of commercial activities and different seasons experienced by the location. With increasing urbanization and changing lifestyles, Indian cities generate eight times more waste than they did in 1947 (Kumar *et al*., 2009). Presently about 90 million tons of solid waste are generated annually as by products of industrial, mining, municipal, agricultural and other processes. The composition and quantity of solid waste generated form the basis on which the man-

FIGURE 1

Map of Solan district showing tehsils from which waste are collected for Salogra dumpsite (marked in blue stars)

FIGURE 2

Map of Solan district showing tehsils from which waste are collected for Salogra dumpsite agement system needs to be planned, designed and operated (Personal communication with the employee of the dumping site, management of urban solid waste of Solan). Due to highly increased production of solid wastes from different cities and towns in India, municipal corporations of major cities and towns and have entered into Public Private Partnerships (PPP) for proper management of solid waste in India (Pfeiffer and Gerlagh, 2010). In this scheme, the municipal corporation of a city is responsible for collection and transportation of the solid waste while utilization of the solid waste for different purposes including production of Refuse Derived Fuel (RDF). However, there exists no such collaborative schemes for efficient management of MSW generated under the purview of the Solan MC and the total generated MSW is openly disposed off at the Salogra dumpsite.

MSW Generation

It is important to determine the characteristics of the municipal solid wastes for providing effective strategies for proper management of MSW to avoid any harmful environmental impacts (Talyan *et al*., 2008). The major sources of municipal solid waste generated in Solan and dumped at the Salogra dumpsite are Solan City under the purview of Solan Municipal Corporation, vegetable markets, and local residential areas and villages under different Panchayats. The total waste generation rate in Solan district (dumped at Salogra site) is 22.5 tons/day and average per capita waste generation is 0.4 kg/capita/day. Of the total waste dumped at the Salogra site (from the five tehsils), Solan city itself contributes about 67% of the total solid waste.

The municipal solid waste dumped at Salogra site mostly comprises of food and organic waste (26%), paper and cardboard (18.10%), plastics (14.5%), textiles (6.70%), leather (4.80%), combustibles (4.80%), non-combustibles (11.0%), metal (0.9%), glass and ceramics (1.70%) and inert materials (11.40%) (Personal communication with the authority of Solan MC). It was found that a major fraction of municipal solid waste consists of high organic matter, recyclables and inert waste. The moisture content ranges from 40-70% with a calorific value of 800-1010 Kcal/Kg. The actual percentage of recyclables discarded as waste is unknown due to some informal picking of wastes which are not accounted. The actual view of the Salogra dumpsite is shown in Figure 3.

MSW Collection and Storage Process

One of the major drawbacks in SWM system in India is appropriate collection and storage of wastes are that often a single bin for all types of wastes are used (Das and Bhattacharya, 2014). Further, the waste collection procedure is carried out haphazardly and Solan MC lacks an appropriate storage system for the total waste generated and collected. The manner of waste collection involves placement of waste collection bins or containers at places nearby to the residential and commercial areas wherein people dump their wastes. There exist no provisions for door-to-door collection of wastes. Further, the bins provided for the collection of the waste are common bins and the entire waste is collected without segregation. Hence, due to insufficient number of collection bins, inappropriate collection times, frequency of collection, waste generation is more than capacity of the bins and human tendency to throw waste out of the bins there is severe littering on the street leading to unsanitary conditions around the area.

In this context, the Solan MC has tried to collaborate with

FIGURE 3
Non-segregated waste dumped at Salogra dumpsite

private authorities to ensure door-to-door collection of wastes to increase the efficiency of the waste collection. This would also ensure container free areas and increase open space. Storage facilities for the collected wastes are severely lacking. Further, due to lack of available land the Solan MC has not been able to set up any transfer station. Reported literature states that the collection efficiency depends on available manpower and appropriate transfer capacities (Kumar *et al*., 2009; Sharholy *et al*., 2009). These both major factors are found lacking in great extent of the handling of the MSW in Solan and its appropriate disposal at the Salogra dumping site. The problem is further compounded by the unawareness among the common people (primarily from panchayat village areas) and the authorities.

Transportation of MSW

Effective removal of the total solid waste generated depends on the logistics and efficient management of the transportation system. In this context, Solan MC has made adequate provisions for collection of the disposal of the collected solid waste. In practice, waste is collected from 132 collection points with help from about 115 sanitation workers (Personal communication with the authority of Solan MC). The municipal solid waste collected from the dustbins is transported to the disposal site. Since transfer stations are unavailable the vehicle that collects the refuse from dustbins transports it to the Salogra dumpsite. The Solan MC has entered into an agreement with a few private agencies to ensure that adequate facilities are provided for transportation purposes. For transportation of solid waste generated, Solan MC has provided trucks (2), tipper (2), dumper (1), placer (2) and tricycle (3) (Personal communication with the authority of Solan MC). The trucks used for transportation of municipal solid waste are generally open body type and are uncovered leading to spillage on the road resulting in unhygienic conditions during transportation. Further, the wastes are neither cleaned nor given any treatment with disinfectants so as to avoid any contamination or spread of disease. No provision exists for use of tractors, trailers animal drawn carts and refuse collectors which severely affects the performance of the collection and the disposal system. The transportation process operated by the Solan MC is in sharp contrast to some collection procedures carried out in bigger cities in India like Chandigarh (Rana *et al*., 2015), Kolkata (Hazra and Goel, 2009; Chattopadhyay *et al*., 2009) and Delhi (Talyan *et al*., 2008) as has been reported. In practice, collection and transportation accounts for about 60-80% of the total budgetary allowances for solid waste management, hence it forms a key component in determining the effectiveness of the SWM system (Rana *et al*., 2015; Hazra and Goel, 2009). The Solan MC should improve on the collection and transfer efficiency for improving the existing solid waste management systems

Disposal of MSW

The site used for dumping the municipal solid waste of Solan district is the Salogra dumpsite. This has already been shown in Figure 2. The dumping of the solid waste at this site started back in 1998 but for administrative and financial constraints, the plant was non-operational for a period of five years (2007-2011) and was recently restarted in 2012. It came under the jurisdiction of the Solan MC in the year 2013. The total available land area for dumping the waste at the Salogra dumpsite is about 3 acres (Personal communication with the authority of Solan MC). The waste coming to the dumping site is in mixed form (since no initial segregation is done) and no segregation machines are available at the site. In practice, the wastes are separated by hand at the dumpsite. In particular, plastic, glass, clothes and other non-biodegradable materials are separated which reduces the burden on the landfill site. The recyclable waste components like papers, cloths, metals and rubber products are sold to authorized dealers in an informal recycling process. Further, major portion of the plastic waste dumped at the Salogra site is now being send to Ambuja Cement Industry for reuse (Personal communication with the authority of Solan MC).

The segregation of recyclable and non-biodegradable waste at the dumpsite reduce the quantity of waste and burden on landfill and also provide raw materials for manufacturers. This also affects the treatability of the solid waste dumped along with the physico-chemical characteristics of the waste. Since, major fraction of the waste dumped is organic in nature it is the most important factor for the treatment of the solid waste. The biodegradable waste is converted to compost. Composting is based on open aerobic composting of the organic fraction of the solid waste. The capacity of the composting unit is about 18 tons/day (Personal communication with the authority of Solan MC). Proper precautions and selection of materials are ensured for composting process to obtain good quality compost with minimum environmental effects. Produced compost is sold to the farmers of Himachal Pradesh to increase the effectiveness of the agricultural crops produced. The compost obtained from the Salogra plant has been shown in Figure 4. In practical sense, even though the compost plant exists it remains unoperational most of the times due to lack of segregated organics, non-maintenance of the plant or lack of adequate manpower to operate the plant.

In practice, the municipal solid waste dumped at the Salogra site (after segregation) is dumped openly without providing any prior treatment increasing the potential environmental and health risks. The Salogra dumpsite is a non-engineered landfill site wherein no provisions have been made to ensure environmental protection.

EVALUATION OF SALOGRA DUMPSITE USING WASTEAWARE BENCHMARK INDICATORS FOR SUSTAINABLE WASTE MANAGEMENT

System Analysis using Wasteaware benchmark indicators

An environmental friendly method of disposal of solid

FIGURE 4
Final compost after completion of the composting process at the Salogra dumpsite

waste is a global issue. It has been further complicated by the rapid increase in generation of the solid waste outpacing the effective methodology for proper management of solid waste management system. Lack of suitable and persistent data for evaluation of effectiveness of solid waste management system for comparative purposes is almost non-existent. In this context, ‘wasteaware’ benchmark indicators were introduced which consists of both qualitative and quantitative indicators (Wilson *et al*., 2013; Wilson *et al*., 2015) to determine the effectiveness of solid waste management system. The Quantitative indicators proposed by (Wilson *et al*., 2013; Wilson *et al*., 2015) comprises of Public Health-collection, Environmental controlled disposal and Resource Management – reuse, reduce and recycling (as percentages) whereas the qualitative indicators are part of governance covering user and provider inclusivity; financial sustainability; and the national policy framework and local institutions (Wilson *et al*., 2013; Wilson *et al*., 2015).

In Table 2, B1-B3 refers to the background information of the study location including income levels, population and waste generation in the city. The section beginning with W refers to information on waste generated in the study location. Hence, W1 refers to waste per capita, and W2 refers to waste composition which is further subdivided in three parts (W2.1-2.3) referring to the major composition of wastes like organics, paper and plastics respectively. Label 1 deal with Quality of Waste collection and cleaning service whereas indicator 2 denotes degree of environmental protection in waste treatment and disposal to be considered for the study location. Label or Indicator 3 is concerned with concept of 3R (Reduce, Reuse, Recycle) prevalent at the study location and to be assessed accordingly. Further parameters 1-3 are representative of quantitative or physical parameters. Label or Indicator 4 is representative of user inclusivity. This basically incorporates involvement of different stakeholders (government, public etc.) and hence is further subdivided into two components 4U (user inclusivity, i.e. public) and 4P (provider inclusivity, i.e. government). Indicator 6 represents the policies for proper management of wastes and considers its application at two stages i.e. at national/country level (denoted as 6N) and at local or state governmental level (denoted as 6L).

Reported literature on utilization of ‘wasteaware’ benchmark indicators include Chandigarh (Rana *et al*., 2015) and Surat (Wilson *et al*., 2013) for tier – II Indian cities based on the original proposed ‘wasteaware’ benchmark indicators (Wilson *et al*., 2013). However, after implementation of the original ‘wasteaware’ benchmark indicators, additional qualitative and quantitative indicators (Wilson *et al*., 2015) were introduced to determine effectiveness of the solid waste management system. Using these new additional indicators (Wilson *et al*., 2015), a ‘wasteaware’ benchmark indicator has been developed for Solan and compared with Surat and Lahore, other important tier –II cities. Table 2 shows the comparison of wasteaware parameters for Solan with Surat and Lahore city.

It is observed from Table 2 that organic waste constitutes the major fraction of the solid waste generated at all the three cities. Further, the population of Lahore is about two hundred times of Solan (only that population is considered that contributes to MSW deposited at Salogra dumpsite is considered) and generates about twice the amount of waste per capita due to higher population density. Further, comparison of the ‘wasteaware’ benchmarks parameters for Solan, Surat and Lahore shows that Lahore and Surat have very better collection efficiencies in comparison to Solan, which showed ‘medium’, and ‘medium/high’ index on wasteaware benchmark indicators respectively.

The major difference between Solan, Surat and Lahore is in the disposal methods and in the efficiency of 3R method. While Surat scores a ‘Low/Medium’ index for environmental controlled waste treatment and disposal method as reported earlier (Wilson *et al*., 2013), Solan scores ‘Low’ index (with 0% 3R) similar to studies carried out in other tier – II cities of India including Chandigarh (Rana *et al*., 2015) and Lahore

TABLE 2

Comparison of Wasteaware parameters for Solan compared with other tier –II cities of India and Asia.

No.	Category	Indicator	Solan City Results	Surat City Results	Lahore City Results
		Background Information of the City			
B1	Country Income Level	World Bank Indicator Level	Lower-Middle	Lower-Middle	Lower-Middle
		GNI per Capita	$1,420	$1,420	$1,140
B2	Population of the City	Total Population of the City	39,256	4,600,000	8,160,000
B3	Waste Generation	MSW Generation(tons/year)	8030	456,250	1,916,000
W1	Waste per Capita	MSW per capita (kg per year)	153.3	119	219
W2	Waste Composition		3keyfractions–as % wt. of total waste generated		
W2.1	Organic	Organics (food and green wastes)	56%	54%	65%
W2.2	Paper	Paper	18.20%	8%	2%
W2.3	Plastics	Plastics	14.50%	10%	12%
1.1	Public health –Waste collection	Waste collection coverage	60% (L/M)	95%(M/H)	77%(M)
1C		Quality of waste collection service	81% (M)	95%(M/H)	58%(M)
2	Environmental control–waste treatment and disposal	Controlled treatment and disposal	30% (L)	55%(L/M)	8%(L)
2E		Degree of environmental protection in waste treatment and disposal	0%(L)	37%(L/M)	37%(L/M)
3	3Rs–reduce, reuse and recycling	Recycling rate	0% (L)	30% (L)	35%(M)
3R		Quality of 3Rsprovision	12%(L)	29%(L/M)	17%(L)
			Governance Factors		
4U	User inclusivity	User inclusivity	M (70%)	M (80%)	L/M(37%)
4P	Provider inclusivity	Degree of provider inclusivity	L/M (65%)	M (82%)	L/M (50%)
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	L -55%	L/M(60%)	L/M(29%)
6L		Degree of institutional coherence	M (60%)	M (77%)	M/H (62%)

(Wilson *et al.*, 2015) scores in the same category. This is because the all the disposal sites are unsanitary landfills with no proper lining systems for prevention of leachate percolation in groundwater.

Further, Solan and Lahore scores a 'Low' index for efficiency of 3R methodology (reduce, reuse and recycle) as reported in earlier studies (Wilson *et al.*, 2013; Wilson *et al.*, 2015), however Surat scores 'Low/Medium' index in the same category as no recycling facilities exists in these cities.

System Analysis using Wasteaware benchmark indicators

A simple quantification method has been proposed using the matrix methodology and has been computed for a better understanding of the system analysis methodology carried out and explained in the earlier section. Since the proposed grading system used in the wasteaware benchmarks is low (L), Low/Medium (L/M), Medium (M), Medium /High (M/H) and High (H), a certain weightage has been assigned to each of these. The assigned weights are (L=1, L/M=2, M=3, M/H=4, H=5) on a five-point basis. The parameters excluded for the study are the background information of the cities and the composition of the waste fraction; since they are not utilized in the grading process. Using this methodology, the weights assigned for the respective indicators (in brackets) have been presented in Table 3. The final scores obtained using the matrix methodology has been summarized in Table 4.

The matrix method for evaluation showed the best possible results for Surat city with an overall score of 52%, being classified as L/M category followed by Lahore and Solan with an overall weightage of 46% and 32% respectively. Qualitative and Quantitative parameters for Surat were al-

TABLE 3
Weightage assignment for evaluation using Matrix method

No.	Category	Indicator	Solan City Results	Surat City Results	Lahore City Results
Quantitative Indicators (Public Health, Environmental Control, 3R)					
1.1	Public health – Waste collection	Waste collection coverage	60%(L/M) (2)	95%(M/H) (40	77%(M) (3)
1C		Quality of waste collection service	81%(M) (3)	95%(M/H) (4)	58%(M) (3)
2	Environmental control – waste Treatment and disposal	Controlled Treatment and disposal	30%(L) (1)	55%(L/M) (2)	8%(L) (1)
2E		Degree of environmental protection in waste Treatment and disposal	L(0%) (1)	L/M (37%) (2)	L/M (37%) (2)
3	3Rs–reduce, reuse and recycling	Recycling rate	0% (L) (1)	30%(L) (1)	35%(M) (3)
3R		Quality of 3Rs provision	L(12%) (1)	L/M(29%) (2)	L(17%) (1)
Qualitative Indicators (Governance Factors)					
4U	User inclusivity	User inclusivity	L/M (70%) (2)	M (80%) (3)	L/M (37%) (2)
4P	Provider inclusivity	Degree of provider inclusivity	L/M (65%) (2)	M (82%) (3)	L/M(50%) (2)
6N	Sound institutions, proactive policies	Adequacy of National SWM framework	L (55%) (1)	L/M (60%) (2)	L/M(29%) (2)
6L		Degree of institutional coherence	L/M (60%) (2)	M (77%) (3)	M/H (62%) (4)

most of equal score (Quantitative parameters = 50%, Qualitative parameters = 55%). In contrast, the quantitative parameters were significantly less than the qualitative parameters for Solan (Quantitative parameters = 30%, Qualitative parameters = 35%) and Lahore (Quantitative parameters = 43%, Qualitative parameters = 50%). The overall classification of the three cities was in the low categories. Interestingly, governance factors for Solan was the least with a 35% score with 55% of weightage for Surat and for Lahore with 50% weightage. The main difference between categorization of scores between Surat and Solan (also Lahore) is primarily due to increased scores for Surat cities for better environmental control facilities (2 and 2E) and recycling facilities (3, 3R). Interestingly, almost no recycling facilities exist for Solan city.

MSW PROCESSING AND MINIMIZATION

Recycling possibilities

The benchmark analysis shows the absence of recycling facilities in Solan, similar to Chandigarh (Khaiwal *et al*., 2015; Rana *et al*., 2015; Aggarwal *et al*., 2015). Even though some informal recycling activities take place at Salogra dumpsite it is not sufficient enough and is one of the significant drawbacks in the proper management of SWM in Solan. A combined recycling unit could be set up to serve the entire Solan district.

Utilization of RDF facilities in Chandigarh

Presently, Integrated Waste Management Techniques (IWMT) is utilized in achieving potential economic and environmental benefits. The Solan MC can utilize the existing and fully operational RDF unit in Chandigarh. The RDF plant located in Chandigarh has the capability of treating of 500 tons of waste per day (Khaiwal *et al*., 2015; Rana *et al*., 2015) with the average calorific value of RDF generated being 3100 Kcal/kg having moisture content less than 15% (Khaiwal *et al*., 2015; Rana *et al*., 2015). The plant utilizes about 30% of the fraction of waste received and only about 20% is converted to RDF fluff (Khaiwal *et al*., 2015) This will significantly reduce the load on Salogra dumpsite.

TABLE 4
Summary of scores obtained through matrix method.

No.	Category	Indicator	Solan City Results	Surat City Results	Lahore City Results
		Quantitative Indicators (Public Health, Environmental Control, 3R)			
1.1	Public health –Waste collection	Waste collection coverage	2	4	3
1C		Quality of waste collection service	3	4	3
2	Environmental control – waste treatment and disposal	Controlled treatment and disposal	1	2	1
2E		Degree of environmental protection in waste treatment and disposal	1	2	2
3	3Rs–reduce, reuse and recycling	Recycling rate	1	1	3
3R		Quality of3Rs provision	1	2	1
Total Score (Quantitative Indicators)			9	15	13
Maximum Score			30	30	30
Weightage (%)			30	50	43
		Qualitative Indicators (Governance Factors)			
4U	User inclusivity	User inclusivity	2	3	2
4P	Provider inclusivity	Degree of provider inclusivity	2	3	2
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	1	2	2
6L		Degree of institutional coherence	2	3	4
Total Score (Quantitative Indicators)			7	11	10
Maximum Score			20	20	20
Weightage (%)			35	55	50
Total Score (Overall)			09+07=16	15+11=26	13+10=23
Total Maximum Score			30+20=50	30+20=50	30+20=50
Overall Weightage (%)			32	52	46

EXISTING PROBLEMS IN SWM SYSTEM AND POSSIBLE SOLUTIONS FOR SOLAN

Source Separation

Source separation of waste leads to reduce loads on landfills. Similar proposals have been suggested for Chandigarh city (Khaiwal *et al*., 2015). Solan MC should undertake setup of bio-methanation systems as that will significantly reduce the organic components dumped on the site and it will also lead to generation of methane gas which can be sold separately. Further, community composting will lead to reduction of large quantities of waste and transportation will become easier.

Littering by residents after collection

Sweeping and waste collection should be carried out on a daily basis to avoid littering caused by residents. This is particularly due to wastes generated from householders particularly from the villagers, low- income and local shopkeepers who frequently throwing the waste onto streets, roads and open drains which causes excessive clogging and littering of drainage system in both the cities.

To curb this, Solan MC should notify the residents of collection time of waste to avoid the littering and also introduce financial penalties for littering. The shopkeepers should be provided with the big containers which must be placed outside the shops for waste collection. Educational programs should be set out to educate different the people.

Poor Conditions of Collection Containers and Areas around them

A large number of containers used for collection system are generally open-ended resulting in unhygienic sanitary conditions and foul smell with possible breeding of flies and other vectors. To prevent this, they should be replaced with closed containers to eliminate these problems. In practice, these containers should be thoroughly cleaned and disinfected properly before being reused for next round of collection of waste. Further, depending on the requirement proper sized bins and containers should be used to avoid any unnecessary spillage and to maintain hygienic conditions.

Recycling of waste

Recycling and reclamation of waste strongly reduce the load on the landfill site and are effective measures to prevent environmental degradation. However, the Solan MC has no formal recovery or recycling facilities. It is thereby proposed to introduce a formal recycling system to get all related benefits of recycling and increasing the lifespan of the dumpsite by this process. Presently, there exists some local informal recycling process which do not significantly contribute to the economy.

Disposal Method

The waste collected is directly dumped at the Salogra dumpsite under unsanitary conditions. There is no provision of any lining system to prevent the leakage of leachate from the waste to prevent soil and groundwater contamination. Such uncontrolled leachate percolation poses a tremendous health hazard from toxic metals. It is suggested that proper-engineered landfills with proper leachate collection and extraction systems will help in minimizing the ground water contamination at the Salogra dumpsite.

CONCLUSIONS

The paper reports that daily average solid waste dumped at the Salogra dumpsite is about 22 tons/day and that the collection efficiency of Solan MC is very poor. The paper analyses the details of the existing SWM system being followed by the Solan MC and identifies some of the deficiencies associated with it. This includes inappropriate collection and transportation methodologies which reduce the efficiency of the solid waste management system. Insufficient number of bins and bin capacity in service for collection of solid wastes and non-maintenance of collection vehicles also reduce the efficiency of the system. The paper proposes certain remedial measures including setting up of formal recycling facilities, setting up of bio-methanation plant, installing adequate number of bins and bin capacity depending the population of different collection areas, proper maintenance of collection vehicles, and upgrading to new vehicles to increase the efficiency. A PPP initiative should also be undertaken to improve the existing SWM system and is recommended. The present dumping site at Salogra has no proper lining system to control the percolation of leachate in the groundwater and appropriate lining system should be provided. Finally, evaluation of the existing Salogra dumpsite by the wasteaware benchmark indicators show very poor performance in environmentally controlled waste treatment, disposal method of waste and the *3R* methodology in comparison to Surat (tier-II cities) in India. However, its performance is slightly better than Lahore, another major tier-II city in Asia.

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MANAGING THE TECHNOLOGY FOR SELECTIVELY COLLECTING SOLID WASTE IN THE WESTERN AMAZON SUB REGION

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ABSTRACT

This study's main objective is to study the complexity of technological management of the collection of solid waste, through the prism of reverse logistics; and to propose certain specific objectives: (1) to describe the form of concentration of solid waste in the group studied; (2) to analyze the impact **of** the volume of solid waste; and (3) to propose intervention measures for solid waste management. It asks what technology management model should guide the selective collection of solid waste in the Amazon. Based on the theory of convergence, it studies the strategy of competitive advantage in understanding the organizational system in the environment in which it operates; on this theory, Nobre (2011) addresses knowledge as a source that transmits competitive edge in order to contribute to a company's organizational system. The research is qualitative and descriptive; it applies the Case Study method, and related procedures. As a study, it confirms that the investigated collector cooperatives are vulnerable, which influences the conclusions of this study. It finds that the collectors employed by these organizations are the significant environmental agents in the process of reusing and recycling materials and thus play a key role in reverse logistics because they can return the waste to the production chain adding value and promoting shared management,. The results also point to the absence of a system to promote environmental education, despite the potential viability of the materials and regardless of the possible economic and social improvements to the Amazonians and their families. The system proposed here involves the selective collection of solid waste by intelligent machines, applying reverse logistics. This study could benefit business people, the government and other stakeholders in public policy and sustainability in fragile environments such as the Brazilian Amazon.

Keywords: Amazon. Management. Innovation. Solid Waste. Technology

INTRODUCTION

Concern about global warming is creating a clear need for solutions that will modify actions that were once designed to avoid new environmental impacts and efficiently manage natural resources. The issue of water quality is of major importance in this regard, following failure in the treatment of waste. It is inconceivable that the Amazon region, location of

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the largest river basin in the world, should suffer from a lack of technology for managing solid waste. The present research takes a global interest approach, considering the advanced development resulting from the installation of hydroelectric power plants, the benefits of the inter-oceanic highway and the completion of the Pacific railroad. The consequent volume of debris exceeded any rational amount and this situation has been aggravated by a lack of appropriate policies and failure to disabuse residents and business owners of their environmental illusions.

Suitable persuasion and centers of excellence indicate one way forward, proposing a solution via research, together with techniques and interventionist measures for promoting ecological equity while seeking to minimize the impact. One such solution is the application of reverse logistics, since solid residue is essential raw material for other products required by a consumer society.

The overall objective of the present research is to investigate the complex technological management of waste collection in the Western Amazon sub region, focusing on reverse logistics. This requires (1) a description of the concentration of solid waste in the area in question and the naming of specific objectives for its deployment; (2) an analysis of its impact in the Western Amazon, focused on the state of Rondonia; and (3) suggestions for interventions to manage it. The goal is a technology management model that would cope efficiently with the selective collection of solid waste in this area.

THEORETICAL REVIEW AND CONCEPT

This study is based on contingency theory, in which Nobre (2011) translates knowledge as the source of competitive edge which contributes to a company's organizational system. According to him, this theory addresses the impact of technology and the environment on issues to do with solid waste; it sets up a model of organizational perception that formulates business strategies developed in an organizational network of solidarity, i.e. in a company with cognitive vision.

The study involves concepts of reverse logistics as set out in the National Plan of the Brazilian Government for solid waste (2010); this conceptualizes reverse logistics as a strategic instrument whereby solid waste can be collected and returned to the business market for reuse, as is environmentally proper.

Human actions have caused environmental degradation which contravenes the laws designed for environmental protection. Uncontrolled consumerism has been a key factor in the worldwide increase of solid waste. The Amazon region has suffered more acutely than elsewhere from this problem with the intensive practice of logging and forestry burning. Tachizawa (2011) states that the planet's natural systems have limited ways of containing today's rampant consumerism, and records the damage and the importance of sustainable development, but more research is needed on the effects of the surplus thus generated.

Theoretical and conceptual applications in Brazil (2010) indicate that waste represents the morphology in which it is generated, whether solid or semi-solid, organic or non-organic, urban or non-urban. It is produced by everyday activities, individual and collective. Thus, if the Ministry of the Environment in the Brazilian Federal Government indicated that reverse logistics was one of the enforcement tools for sharing responsibility in the life cycle of products it would be interpreted as encouraging the operational convergence of the logistics to counter the collapse in the study of waste treatment.

A survey in Brazil (2010) shows that solid waste can be classified as physical, chemical or biological, according to its composition; or in accordance with its origin (as industrial, hospital, urban, agricultural); also, as hazardous or non-hazardous, according to the degree of danger it presents to public health and the environment; and by being recyclable or non-recyclable. In relation to the critical analysis that the present study employs, it should be recalled that the factors which define the characteristics of solid waste are related to social, economic, cultural, geographical and climatic questions.

Solid waste in the Amazon region

A Brazilian law of 2010 conceptualizes solid waste as rejected material resulting from human action, characterized as solid or semi-solid, organic or non-organic, urban or non-urban, hazardous or non-hazardous.

The lack of public policies in the creation of landfills and the selective collection in the Amazon region, such as in the State of Rondônia, has resulted in concentrations of solid waste in open dumps. This reveals the fragility of the country's social framework regarding solid waste management. Across the country children's activities in garbage dumps have been the rule rather than the exception. Many countries, however, have already transcended this level and transformed environmental problems in their sustainable development. Dias (2014) supports the overall view that change, while urgently needed, is feasible, since only human actions caused the environmental impact in the first place.

While the threats are constant, they can be turned into strengths if they lead to the improved management and organization of technology and prompt other agents (providers) in the supply chain to become involved.

SWOT Analysis

A SWOT analysis is a technique for improving system management in strategic planning procedures; it collaborates systematically to analyze internal and external variables (D'Ambros, 2012). Having done so, it can be used to find the appropriate words for developing business strategies and facilitating a beneficial relationship between business and resources. As D'Ambros (2012) remarks, an interesting aspect of this methodology is that it is easy to involve the actors in the strategic marketing process.

Although the Amazon region works well as a reactor indicating the balance of global environmental stability, Sweden will lead the next reform in the uses of energy by practical actions that will produce efficient global business models for the management of solid waste. As Demajorovic (2014) states, companies in developing countries rarely make a habit of reusing solid waste, or have any experience of disposing of it appropriately. What has forced waste collectors to organize themselves into cooperatives or associations, thus strengthening the network of economic solidarity by cooperating through shared management and without individualism?

Public Policy

The Paraná State Environmental website in Brazil suggests that public policies, including various programs or actions developed by civil servants with the participation of organized civil society, have had an outstanding significance. They ensure, *inter alia*. that civil rights as determined by legal standards reaching all segments of society have effectively secured socio-cultural, economic, and environmental benefits, A practical example of the implementation of public policy by government can be seen in the actions of the secretariat to safeguard the effectiveness of incorporation as practiced by this governmental body. They show its institutional commitments as they arise from the regulations and legal procedures, resulting in the protection and conservation of the natural environment in the area where this research was conducted.

Denhardt (2015) considers the systemic convergence in the formatting of public policies implemented by governments and reports that environmental preservation dominates the intentions behind its waste management policy. Strategic actions in the national policy for solid waste have been instrumental in its progress, resulting in methods and procedures for maximizing the economic and social benefits of the proper treatment of waste which Denhardt outlines. The consequence has been consolidated production chains committed to the technical procedure of focusing recommendations on reverse logistics, which have tackled the applicability of the waste, regardless of the publications of more normative countries such as Brazil. The latter, it seems, consist of excessive legislation on solid waste, urged on by uncommitted managers representing many different standpoints.

Innovation Management Concepts

Tidd & Bessant (2015) state that innovation is the process of turning a good idea into a lucrative business; Tigre (2014) clarifies that innovation integrates different sectors, bringing together regions and members of the same institution to enjoy the strategic benefits of productive practices. It may be summed up by saying that technology management directs and coordinates organizations in their strategies to comply with sectors of the enterprise. Its actions are essential for the optimum use of equity and financial and human resources.

According to Starec (2012), innovation is a business strategy. It should be incorporated anywhere in a firm that involves people. In an increasingly competitive market, these actions add in different ways to the business capital. For this reason the concepts inherent in innovation technology should make intervention studies fundamental to the required change in complex social systems based on entrepreneurship.

Mattos & Guimarães (2012) define technology as scientific, empirical or intuitive knowledge, developed jointly. Human beings depend on technology to meet the demands made in global emergencies. The changes required to serve the mainly strategic interests of markets can at times exert particular pressure. This constitutes the conceptual profile for the management of technological innovation that unifies contemporary research tasks in the problematic context of technologies for waste management.

Burgelman (2012) addresses the area of technology and innovation management as a new issue at the tip of biotechnology, predicting the possibility of innovation for three kinds of conceptual change: they will perhaps be incremental, such as the generation of cell phones and other mobile communicators; radical, such as those involving advanced digital communications; or architectural, such as reducing the size of physical components while increasing their capacity.

Appelt et al. (2014) discuss the global scenario involving the disposal of electronic solid waste. Their research work was approved by a scientific committee, and reported in the Minutes of the Thirtieth International Conference on Solid Waste Technology and Management in Philadelphia, USA; as the authors make clear, technological innovation tends to move forward systemically and without limits, causing irreparable damage to the environment from the irresponsible disposal of waste.

Managing Sustainability

In the view of Gomes (2014), sustainability can be seen as a set of strategic actions seeking solutions to problems relating to the environment. World Conferences on the environment, such as Rio 92 and Rio + 20, particularly emphasise urban centers. They cannot do otherwise, because the multiple threats from cities to the environment must generate opportunities, including those involving selective garbage collection. This invites citizens to share the reciprocal benefits of protecting the environment according to their per capita income. Gassenfurth et al. (2015) state that the preservation of forests, pollution of rivers, and biodiversity are all directly associated with environmental responsibility, but the authors warn that care must also be taken to safeguard urban conditions, since the management of sustainability in towns has received little consideration, though it should raise the same environmental concerns.

Dias (2014) discusses the green economy, with a new vision of ways to use natural resources efficiently while fostering sustainable economic growth. The mere presence of an individual in the environment is enough to result in degradation: this fact recalls to us that subsistence involves the exploitation of nature. It is from nature that man extracts the resources for existence, but for a green economy he should also be committed to considering the impact he makes and the benefits he might bring to balance it.

METHODOLOGY OF PREPARING

Scientific method is understood to mean a set of core standards applied in a data search, aiming to get results close to a degree of certainty. The present study takes a qualitative and descriptive approach to nature which resembles the scientific method. It uses a case study to organize the data and environmental information which are addressed in the course of the research.

The procedures adopted here are common to case studies; in the literature, they are conducted by visiting an organization and cooperating with its workers (in this case, the rag-pickers) in order to interpret its situation, as found in its strengths, weaknesses, opportunities and consistent threats. An analytical technique was considered for assessing the behavior of individuals and groups and its internal and external conflicts were thoroughly surveyed. Notes were taken, as Lacerda advises (2012), to ensure that the context was fully reported and the research is validated by the data collected and the problem areas tackled. A report was prepared, following the required research procedures, to describe the objectives to be pursued, always in accordance with the recommendations made by the authors.

THE TECHNOLOGICAL MANAGEMENT OF WASTE COLLECTION IN THE WESTERN AMAZON SUB REGION

The complex management of the technology for collecting solid waste in the Western Amazon sub Region raises many issues, the main ones for the present research being those which are contained in the conceptual theoretical framework of the topic itself. The proper disposal of solid waste is a recurrent problem in most municipalities in the State of Rondônia. As can be seen in the material published on the Internet, an unusual effort has been put into setting up a customized management system. It cannot be denied that the process is subject to entrepreneurship in the business of recycling, but its effects do not outweigh the needs of the region. Professional enablers proffer advice and make promises with regard to the characteristics of large metropolitan areas; they understand the possibilities of managing waste in the largest river basin in the world, since their clientele is cosmopolitan.

It should be kept in mind that it is impossible to manage the disposal of solid waste without jointly tackling environmental management, which requires skill and technical mastery in the preparation of reports, GIS, environmental records, waste management planning, licensing, inventories, audits, water management, reporting, and above all environmental education. It is worth noting that efficient strategies can only be created when management has an adequate profile; only those who know the region in depth can be said to have it.

Interpretation of the form of concentration of solid waste in the group studied

The documentation from the United Nations Conference on the Environment and Development (UNCED), held in Rio de Janeiro in 1992, reveals the need to provide the basic prerequisites of survival, such as adequate food, decent housing, employment, health and education, especially to people in extreme poverty (Dias 2014). Brazil recognizes that the municipalities running these programs in part or in whole in the State of Rondônia are currently in a minority and that rag-

TABLE 1
Definition of terms in the above diagram (concentration of solid waste)

Element	Definition
1. Contingency theory	This theory addresses the impact and influence of technology together with the environment, on bringing up issues in the study of solid residues
2. Solid waste	The slurry of the residue contaminates the water table as the result of the operation; gases are also significant pollutants
3. Selective collection	Urban dumps cause bad smells, vectors, insects, bacteria
4. Reverse logistic	Cooperating to enter the field of perception among the scavengers to constitute an organizational network
5. Technological innovation management	The complex technological management of solid waste collection in the western Amazon, considered from several standpoints
6. Sustainability management	This element reveals the fragile social framework which obtains in the Amazonian region
7. Public policy	Organized civil society for protecting the environment through reverse logistics and strong strategic action
8. Socio-economic environmental and institutional principles	Strong values of sustainability, economic viability, social justice and environmental soundness

Source: Authors (2016)

pickers generally work in unsanitary and degrading conditions, in open dumps, exposed to diseases of all sorts and subject to accidents, mostly without any form of protection.

One of the risks to the Amazonian environment is the unsuitability of transport for carrying waste away from the disposal sites; the slurry of garbage contaminates the water table, while the gases emitted by it are significant pollutants, to say nothing of the bacteria and diseases carried by the vectors of this inadequate management operation. Therefore, it may

Analysis of the positive impact of the disposal of solid waste in the Amazon region

Under a SWOT analysis, the internal strengths of the region seem to be green manure production, tillage, soil conservation, preservation areas, eliminating pollution from the atmosphere.

Thus, it is a strong strategic action to employ advanced technology in a system used by citizens as a tool to strengthen consumer collaboration; it can organize civil society in support of environmental protection through reverse logistics. According to Mattos and Guimarães (2012), using the appropriate technology in a system gives a company sustainable advantage, stimulating the way in which it makes strategy making and thus securing its competitive advantage. It may be useful to consider the information contained in Table 2 below as a proposal.

Table 3 shows the results of this research which are organized according to the SWOT model. The elements are located as part of the internal or external conditions, whose implications should be taken as criticism from those interested in this approach.

Intervention proposal for multiple benefits to the waste collection management process in the Amazon region

The study calls for a valid proposal for intervention in its fragile scenario. The present situation involves individuals in the Amazon basin and, so long as the region's strong and weak points remain as previously interpreted and the current opportunities and threats continue to affect the area, it would consist of training and qualifying some of the residents. In such a scenario, the residents would be committed and motivated, to their great advantage, to practices which are aligned to sustainability.

The National System Collection Selective Awarded E-Recycling – SINCOSPER – supported by institutional pillars, works for economic, social and environmental sustainability; it originated the view that sustainable advancement is the practical result of environmental education and its mission is to enhance the personalized relationship between industry and the distributors to consumers.

Economic viability for the users of a system of waste disposal (known as ecological holders of shares in Reverse Vending Machine Intelligent E-Recicla) is via an investment that offers immediate benefits from acquiring products and services from an ecological network. Meanwhile social viability search leveling would consider the social dignity of the collectors and remove them from their sometimes unhealthy current workplaces, such as landfills and dumps, training and then directing them to the social environment of public access areas for the concentrated collection of solid waste materials. In this activity, a sustainable environment would be aided by an environmental database. In addition, the sources of global warming would be reduced and people and institutions would be inspired, motivated and educated to consistently dispose of recyclable waste through the award of ecological collection points. Despite Tachizawa's warning (2011) that reckless human actions permanently change the ecological system, uncontrollable consumerism in contempt of the laws designed for environmental protection, has been a key factor in the increase of solid waste worldwide. Consumers mindful of consequences will be focusing on price, product quality and the social responsibility of manufacturing companies which have the same concerns. Through the combination of technologies and disciplines applied in the energy renewal cycle by the selective collection and recycling of waste, SINCOSPER provides economic sustainability. It promotes environmental conservation through sustainable marketing by

TABLE 2
Description of the problems identified

Problems	Descriptive of the situation problem
1. Current problems in the selective collecting chain	The concentration of waste in landfills and dumps; unhealthy manual sorting of collected waste; excessive accumulation of waste in urban dumps causing foul odors, vectors, insects, including flies, and clogged culverts.
2. Waste destination	Association of rewards with incentives for the proper disposal of waste, promoting economic inclusion coupled with the social demand for sustainable consumption, renewable energy and skills.
3. Environmental education	Integrating industrial business strategies, modes of distribution with commerce, on the part of public and private companies to promote environmental education and give social inclusion to rag-pickers and collectors

Source: Authors (2016).

TABLE 3
SWOT analysis applied to solid waste management

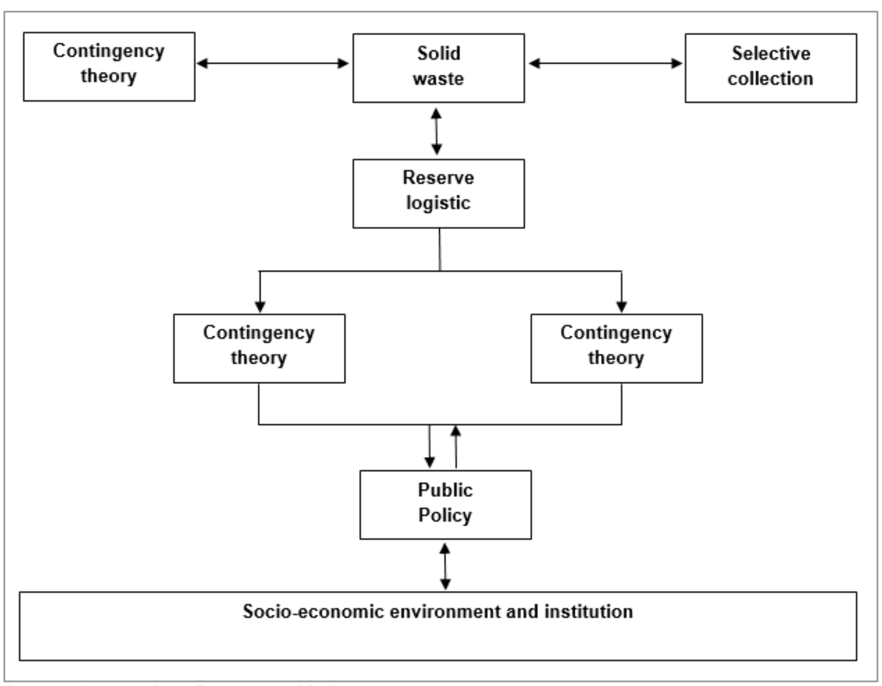
Strengths (S)	Weaknesses (W)
1. Motivation to cooperate; 2. Possibility of action in a solidarity network; 3. Augmenting the family income; 4. Added quality in the life of societies; 5. Collective participation for sustainability.	1. Lack of selective collection; 2. Volume of waste; 3. Logistics; 4. Vulnerability of those involved; 5. Lack of environmental education.
Opportunity (O)	**Threats (T)**
1. Resource capacity; 2. Social inclusion to improve the quality of life; 3. Change in the concept from examples; 4. Generation of new enterprises whose primary material is waste; 5. Generating wealth through reverse logistics opportunities	1. Ineffectiveness of the government; 2. The existence of addiction due to corruption; 3. Inveterate consumerism; 4. Environmental, economic and social degradation; 5. Lack of environmental responsibility on the part of the waste generators.

Source: Authors (2016).

generating ecological credits (greenback) as illustrated in Figure 1. Table 4 shows the operational flow of the reverse intelligent machine sales which are organized according to Figure 2, showing how the system works.

CONCLUSION

This study addressed the following question: What technology management model would be adequate for the selective collection of solid waste in the Amazon region? The



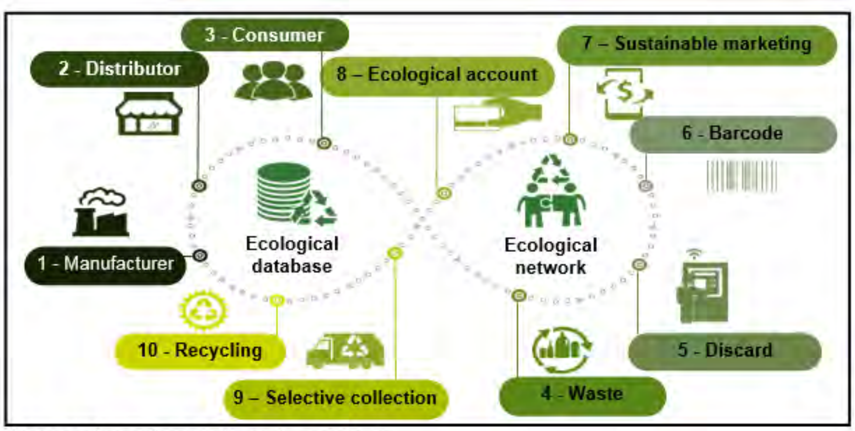
Source: Adapted from Burgelman (2012)

FIGURE 1
Concentration of solid waste

TABLE 4
Operational Flow

Object	Tasks or definitions for the objects in the situation
Consumer's tasks	Make sure the waste is for disposal. Choose to win individual benefits or donate then to philanthropic institutions.
Ecological accountholder's task	Choose, as a citizen (consumer) to dispose of waste and earn beneficial points to an individual ecological account.
Waste	Discard waste using the machines of reverse intelligent selling E-Recycle, sponsored by sustainable marketing.
The machine's tasks	Make the discarded residue recyclable. Store it in selected internal deposits. Update it in real time; the ecological database allows data collection.
Ecological database (defined)	Relational database making market research easier.
Tasks for Software	When depositing the residue, the user always adds new information to an individual ecological account or institution chosen to receive the donation. Structure selective collection geographically mapping the Amazon region with indicative classification by generator, manufacturer or collected waste, per machine, per customer, per geographic location, by the quantity collected and all segments of the database. When reaching the maximum capacity of the collecting machine after calculating the selective load, produce an electronic form requesting dispatch (removal of the collected waste) to the approved collector in the system.
Ecological account (defined)	The ecological points provided when the waste is collected by the machine. These can be exchanged for benefits, through the ecological card in the ecological network E-Recycle, listing public and private companies.
Collectors (defined)	Cooperatives that are legitimized by public policies to give the correct destination according to Figure 2, The value chain.
Ecological network (defined)	Group of public and private companies that promote environmental education practices, through the new economic motor green coin generated by the system, assigning discounts and benefits to ecological holders in the acquisition of products and services.

Source: Authors (2016).



Source: Lucrative E-Recycle recycling

FIGURE 2
Value Chain

present paper answered the question by suggesting possible ways of bringing about the complex technological management of solid waste in this region. From the beginning, by organizing cooperative associations and networking, it focused on the task of reverse logistics and cooperation to enter the field of perception of scavengers who form themselves into organizational networks based on contingency theory.

To begin with, this paper interpreted the way in which solid waste was concentrated in this area. It went on to suggest a contingency look at intervention that might create multiple benefits from managing waste collection, noting the positive impact generated by minimizing the volume of solid waste in the Amazon basin.

The practical exercise of the quadrants (strengths, weaknesses, opportunities and threats) collectively known as SWOT highlighted the positive environmental impacts of an initiative to concentrate the disposal of solid waste in the Amazon; for example, green manure, tillage, soil conservation, preservation areas, suppression of air pollution as well as the reduction of negative events such as fires, deforestation and contaminated soil. This initiative formed a strategy that lets researchers transform informational data gathered over time, allowing facts to be interpreted and reported as intended. Thus, a system can be presented involving smart selective collection machines carrying the enterprise symbol, based on technology management in the above task and it is suggested that the system could encourage cooperation to support the progress of the skills essential to the development of proper ways of managing solid waste.

In this sense, this study admits that cognition does not offer any degree of environmental certainty, but it confirms the value of technology management for the collection of waste in an organized, dynamic and sustainable way. Reverse logistics are addressed as a solution, with a primary chain of sustainability values, economic viability, social justice and environmental soundness. The elimination of a significant amount of solid waste in this region echoes the positive impacts of such an intervention anywhere and at any time.

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SIMULATION OF HEAVY METALS MOVEMENT AND CHANGE IN CONCENTRATION IN SHALLOW UNCONFINED AQUIFER IN NORTH CENTRAL NIGERIA USING VISUAL MOFLOW AND MT3DMS

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ABSTRACT

Shallow groundwater is a major water source for rural people in Minna, a rapidly growing city in North-central Nigeria. However, indiscriminate dumping and poor poultry waste management in and around the city have threatened the quality of this water source. Visual MODFLOW was used to study the loading, dynamics fate and transport of some heavy metals in Minna shallow aquifer while MT3DMS was used to predict the concentration of the heavy metals in one, three and five years' time. Conceptual model approach was employed for the simulation with the model domain discretized into 50cells each in *x* and *y* directions. Results showed that the whole aquifer was strongly contaminated with arsenic, copper and Zinc. This was presented as colour shading by visual MODFLOW. Initial concentrations of arsenic copper and zinc were 0.74mg/L, 8.43mg/L and 11.63mg/l respectively as against 0.01mg/l, 2.00mg/L and 5.00 mg/L recommended as maximum allowable contamination (MAC) for drinking water by WHO. MT3DMS predicted a progressive reduction in heavy metals concentration. For instance, a reduction in value to 0.60 mg/L, 7.51 mg/L and 4.20 mg/l were predicted for arsenic, zinc and copper respectively over five-years period. The study also revealed that the polluted shallow aquifer in Minna can be cleaned up of these heavy metals after some years.

Keywords: Contamination, prediction, shallow aquifer, heavy metals, concentration change and visual MODFLOW

INTRODUCTION

Numerical modeling technique has become an important tool in groundwater quality assessment in recent times. As a result, many visual numerical modeling softwares for groundwater have been developed and used. For instance, Finite Element Subsurface Flow system (FEFLOW), Groundwater Modeling System (GMS) and Uncertainty Analysis Visualization software package (UNCERT) have been developed and used in different parts of the globe by researchers (Wang et al., 2008). Use of software becomes imperative because water monitoring in groundwater and tracing of contaminant migration are very complicated. Researchers have observed that groundwater investigation and monitoring are difficult exercise and attention is then shifted to modeling and software techniques since the modeling

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methods are more reliable and easier to handle, though it employs mathematical equation and was also based on reasonable assumptions (Ghoraba et al., 2013).

Visual Modflow, a groundwater monitoring software which has a separate package to resolve special hydro geologic problem was developed using FORTRAN 77 language environment with the finite difference method to describe movement of groundwater and contaminant migration within aquifers (Ghoraba et al., 2013). Modflow is able to simulate a wide range of flow in porous media while MT3DMS, a 3-dimentional multi-species contaminant transport interfaced on Modflow monitors solute transport process and concentration change in the subsurface (Saghravani, 2010). Both are based on the advection-dispersion relationship to study and predict change in concentration of contaminants as they travel through a porous media. Visual Modflow uses cell-by-cell data which are computed by MODFLOW to establish results (Saghravani and Mustapha, 2011). While visual MODFLOW deals with flow hydrodynamics through porous media, MT3DMS, a solute transport model solves the problem of contaminant transport and change in concentration in the subsurface (Ghoraba et al., 2013). It simulates movement and fate of any miscible contaminant in groundwater after taking into account the advection, digestion, diffusion and other basic chemical reaction and equation (Zamri et al., 2013).

Groundwater quality monitoring is an important practice in environmental studies. It has been observed that once groundwater is contaminated, it may remain so for many years before it can be cleaned (Lautz & Siegel, 2006). Groundwater contamination sources are many; they vary from human activities and can be categorized as domestic, agricultural and industrial. Even if the sources of groundwater contamination are difficult to trace because they may come from either point or non-point sources, monitoring the contaminant movement to be able to design clean up measures is as important as groundwater treatment. Recent studies have showed that anthropogenic activities can impact natural composition of groundwater. Indiscriminate disposal of animal waste that contains harmful chemical components and microbial matter overland can have harmful effect on groundwater. Many activities have been reported (Lerner & Harris, 2009) to have the potential to increase heavy metals concentrations in groundwater if indiscriminate animal waste dumping and poor waste management process continue to be unchecked.

In Minna, a semi-arid town in North central Nigeria, for instance, importance of shallow groundwater cannot be overemphasized. Chukwu et al., (2004) research on water sources in Minna metropolis revealed that on an average, 21.67 % of Minna inhabitants use bore hole, 50.83 % use shallow wells, 14.67 % use tap, 3.5 % still depends on surface water from rivers while 9.3% use springs which dry up in the dry season and are forced to join the percentage using the shallow wells. Water consumption is high, climate being tropical, and people using shallow wells engage in manual work and crop and animal production. Therefore, it is expected that their water consumption rate will be as high as about 5-6 litres per day (Sanusi & Akinbile, 2013). Moreover, they still use water from these shallow wells to prepare food for themselves and their family members. These people therefore ingest more of these contaminants than expected and are therefore at the risk of water - borne diseases.

Arsenic and other heavy metals are metalloid element toxic to humans even at low concentration. Nickel, chromium, zinc and manganese though have good affinity for soil, there have been evidences of their presence in shallow groundwater where waste materials that are rich in heavy metal concentrations are dumped very close to shallow wells and are then released at quantities far greater than what the soil can sorb at that particular time (Pitt et al., 1999). Removal of these heavy metals by soil is also pH-dependent and their solubility increases as the solution pH decreases. It is therefore common to detect traces of heavy metals in groundwater where the overlying soil is acidic in nature (Arnade, 1999).

Epidemiological studies have shown that consumption of water containing 500μg/L of arsenic may cause internal cancer like lung and liver cancers. Smith and Smith, (2004) reported that consumption of inorganic arsenic may cause multiple illnesses in different organ of the body but the most documented are bladder, kidney and liver cancer. It is therefore reasonable to focus on cancer for the long-term risks resulting from arsenic in drinking water. Though nutritional zinc deficiency was reported in a number of countries, acute toxicity arises from ingestion of excessive zinc in water as it leads to fever, nausea, vomiting, stomach cramp and diarrhea. In some cases, acute toxic effects of cancer and cardiovascular diseases have been linked to the consumption of zinc in water above guideline value. The acute lethal dose of copper for adult is between 4 and 400 μg per kilogram of body weight after which it may lead to gastrointestinal bleeding, intravascular heamolysis, hepatocellular toxicity and renal failure. At lower dose, it may just cause nausea, vomiting, diarrhea and abdominal pain (Araya et al., 2003). Buschmann et al., (2008) assessed the quality of drinking water resources in Mekong Delta floodplain and listed the health effect of heavy metals that are present at concentrations higher than the WHO recommended value including cancer and skin damage, neurological disorder, haematological and kidney damage.

To meet nutritional requirements of the birds, several metals are supplemented in poultry feeds. It includes, iron, copper, manganese, zinc, iodine and chromium. These metals are also excreted and form major component of poultry manure. Because of mobility (though slow) of these metallic ions in the subsurface, they can also migrate into groundwater and lead to pollution though their environmental risk is a function of the ability of the soil to absorb and desorb the metals and leachability of the metals. Arsenic and chromium are often included in poultry diets because of their coccidiostatic properties. They are added in the form of 3-nitro-4-hydroxy-phenylarsenic acid (roxarsone). Average broiler feed contains about 45kg of roxarsone per one ton of feed. Arsenic is also added to the feed to increase the bird weight gain and improve feed efficiency. Consequently, arsenic and chromium are largely excreted in poultry manure. Arsenic in poultry litter is easily mobilized but strongly absorbed by most soil, thus the leaching rate into groundwater appears to be slow except in a soil with high hydraulic conductivity. Preliminary results of heavy metals analysis conducted on the poultry manure samples in Minna (Adeoye et al., 2014) revealed that arsenic in poultry manure in Minna ranged between 3.50 and 45.6mg/l, copper ranged from 19.3 to 116.3mg/l, while zinc ranged from 52.6 to 396.2mg/l. Personal interview conducted revealed uniformities in the dosage of all the trace elements addition to the feeds in all the farms visited. However, from the analysis, it was discovered that there is a wide variation in composition of these metals in the manure analyzed. Within species, farms and age of the birds and this has been attributed to a number of factors like environmental conditions and the management systems on the farms. The major concern of the heavy metals in manure which are dumped or are applied to agricultural land is loading of heavy metals in the receiving soil.

MATERIALS AND METHODS

The study area for this research is Minna, capital of Niger State, a semi – arid town in North central Nigeria, (Figure 1). The city lies in latitude 90 36’ 50’’N and longitude 60 33’25’’. Minna has two local Governments, *Chanchaga* Local Government which has its headquarter in Minna and Bosso Local Government with headquarter in *Maikunkele*, a peri-urban slum in Minna. The population of Minna as in 2012 was 613,246 (NPC 2012). River *Chinchaga* is the major river in Minna which drains into River Kaduna at about 45km in the Northwestern side. Geology of Minna belongs to central portion of Nigerian basement complex rock of Precambrian in age though some of them are found in the early Paleozoic. The rocks have been grouped into four lithological units by Shekwolo & Brisbe (1999) as gneiss-quartzite complex, schist belts, granitoids and metamorphosed basic rocks. Aquifers in Minna are either confined or semi-confined or unconfined. The unconfined aquifer has generally a shallow water table of about 20meters in thickness though, perched conditions exist in some places, (Alabi, 2011). Minna aquifer is recharged through rainfall. Other climatic conditions in Minna are presented in Table 1.

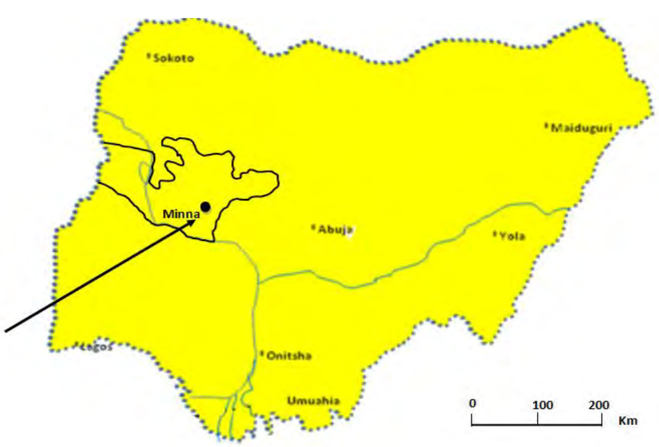

FIGURE 1
Map of Nigeria Showing Location of Niger State

Recharge to the shallow aquifer based on soil-moisture balance approach conducted by Adesiji & Jimoh, (2012) on dynamics of groundwater flow in Minna revealed that rainfall is the major source of recharge to Minna aquifer and the recharge is estimated to be 22% of the total annual precipitation. The major source of groundwater supply in Minna is shallow open wells (depth usually less than 15m) because of their high yield and relatively cheaper method of construction. The average static water level in Minna has been found to be 5.86m by Idris-Nda, (2010) when he conducted an aquifer test in Minna metropolis to assess the hydraulic properties of the shallow aquifer using Cooper-Jacob method.

Groundwater Quality in Minna

Many groundwater quality assessments have been carried out in Minna and the shallow aquifer of Minna has been discovered to be vulnerable to pollution from agricultural, domestic and industrial wastes. This was attributed to high permeability of the top soil which offers little protection to underlying aquifer. Shekwolo & Brisbe, (1999) and Alabi, (2012), reported poor bacteriological quality of groundwater close to domestic and industrial waste dumps in Niger State. Also, Jimoh et al., (2003) found high concentration of electrical conductivity (EC) and total dissolved solids in shallow groundwater in Minna peri-urban environments and the concentrations were attributed to various industrial effluents and concentration of abattoir activities in the area. Salami et al., (2008) attributed high concentration of lead, arsenic, and chromium in Minna shallow groundwater to contamination from petrol chemical industries which directly release their effluents to soil without any treatment. Seasonal variations of all these parameters have been recorded by all the researchers.

During the course of this research, information and available data were sought from the archives of Niger State Ministry of Health and Minna General Hospital on the prevalence of water borne diseases in Minna. The result showed a high trend in water borne diseases, the prevalence of which were high at present and will rise if water quality of these shallow wells is allowed to worsen further. There is a sharp increase in prevalence of typhoid, diarrhea and cholera, the three most deadly water borne diseases with few records of Amoebiasis, blue baby and giardiasis. Findings from the hospital also showed that the out-patient and in-patient in the hospital increased by almost 33 % during the wet season. This may likely confirm the linkage of diseases in Minna hospitals to poor water supply since research has confirmed poorer water quality from Minna shallow wells in the wet season (Adeoye et al., 2012). It is believed that one tenth of the diseases in Minna, Nigeria can be prevented by improved water supply and efficient management of water resources and animal wastes.

Simulation with Visual Modflow

To be able to simulate contamination of groundwater and

TABLE 1
Climatic and Aquifer Conditions in Minna

Climatic Factors	Minimum	Maximum
Annual Precipitation	1100mm	1300mm
Daily Sunshine Hours	6.4	9.2
Average temperature	19^0C	40^0C
Evapotranspiration	25mm	90mm
Aquifer Permeability	0.44m/day	0.6m/day
Aquifer Transmisivity	55m^2/day	185m^2/day
Storage coefficient	2.6 X 10^{-3}	4.4 X10^{-3}

Source: Edoga & Suzzy, 2008, and Adesiji & Jimoh, 2012.

to determine groundwater movement in Minna, the following data were used as input parameters into visual MODFLOW to study the conditions of Minna shallow aquifer with respect to heavy metals concentration and movement.

- The elevation of each of the well sampled above mean sea level (AMSL)
- The initial concentrations of the chemical parameters under consideration.
- Soil and aquifer characteristics of the area like thickness of the soil layer, hydraulic conductivity, dispersitivity, bulk density specific storage, evapotranspiration, specific yield, effective and total porosity (Table 2).

Apart from soil properties, other input parameters into the model are concentration of the contaminant, groundwater level above mean sea level, evapotranspiration and groundwater recharge. The visual MODFLOW 4.2 was used to develop the loadings, dynamics, fate and transports of all these chemical parameters in shallow groundwater of Minna. It gives a better understanding and quantification of fate and transport of these chemical parameters in shallow groundwater.

Conceptual Model Development

Table 3 presents the initial aquifer parameters used in conceptual model development. The conceptual model approach was used because the geometry of the model domain is very complex.

The Sampling points in Table 3 are the poultry farms where the shallow wells from which samples were collected are located. The coordinates of the farms were employed to develop the base map used for the conceptual model.

This approach represents the essential part of the groundwater system by mathematical terms. Because of the way the shallow wells are pumped, steady- state condition occurs around the wells and cone of depression is assumed to be constant. The geological and geographical map of the study area was

TABLE 2
Soil Properties Used in Visual Modflow

Properties	Values
Soil Type	Sand
Hydraulic Conductivity K (m/s)	9.91E-6
Total Porosity	0.47
Effective Porosity	0.36
Specific Yield	0.24
Specific Storage	2.7E-3
Dispersivity (m)	0.19

TABLE 3
Heavy Metal Values in the Shallow Wells Sampled

Parameters	Arsenic (mg/L)	Copper (mg/L)	Chromium (mg/L)
	MAC = 0.01 mg/L	MAC = 2.00 mg/L	MAC = 5.00mg/L
SAMPLING POINTS	*Average values obtained*	*Average values obtained*	*Average values obtained*
ABD	0.64* ± 0.00	2.96 ± 0.29	5.21 ± 0.98
ABT	0.52 ± 0.00	3.03 ± 0.08	0.00 ± 0.00
ALA	0.06 ± 0.00	1.61 ± 0.00	0.00 ± 0.0
BAC	0.72 ± 0.01	3.61 ± 0.32	6.69 ± 1.03
ELK	0.69 ± 0.03	5.61 ± 0.15	3.21 ± 0.07
FUT	0.00± 0.00	0 .00± 0.00	5.21 ± 0.21
IK	0.71 ± 0.07	3.64 ± 0.92	8.29 ± 0.68
JAM	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
JML	0 .00± 0.00	0.00 ± 0.00	0.00 ± 0.00
JOE	0 .29± 0.00	3.34 ± 0.20	0.00 ± 0.00
JUM	0.66 ± 0.10	3.91 ± 0.03	7.64 ± 1.04
JMR	0.00 ± 0.00	0.96 ± 0.04	1.48 ± 0.00
LIM	0.74 ± 0.03	6.96 ± 1.02	8.48 ± 0.42
MIL	0.61 ± 0.02	8.43 ± 0.68	11.63 ± 1.02
NAD	0.62 ± 0.09	3.43 ± 0.57	4.21 ± 0.11
NAB	0.00± 0.00	0 .00± 0.00	0 .00± 0.00
NAN	0.04 ± 0.00	0.00 ± 0.00	0.90 ± 0.03
NAT	0.00 ± 0.00	4.21 ± 0.11	0.00 ± 0.00
NGS	0 .05 ± 0.00	0.71 ± 0.08	2.36 ± 0.00
SRY	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

**Values are means of Triplicate reading ± standard deviation. MAC- Maximum Allowable Concentration*

imported and registered and they were used to develop the conceptual model. The three-dimensional groundwater flow equation for confined and unconfined aquifer that assumes the groundwater movement occurs in heterogeneous and anisotropic medium was used, (Equation 1)

$$S\frac{\partial h}{\partial t}=\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)-Q \quad (1)$$

Where K_x, K_y and K_z are hydraulic conductivities to x, y and z orientation (m/d), h is the water head (m), S is the storage coefficient of the aquifer (1/m) and Q is the source and sink items (1/d). This equation was combined with the three-dimensional equation to describe the rate of contaminants transport, equation 2.

$$\frac{\partial c}{\partial t}=-\frac{\partial}{\partial x_i}\left(cv_i\right)+\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right)+R_c \quad (2)$$

Where c is the concentration of the solute (mg/l), R_c is the radius of sinks, D_{ij} is the dispersion coefficient tensor and V_i is the velocity tensor.

Boundary Conditions

Boundary conditions are necessary when running a MODFLOW program to describe the exchange of flow between the model area and external system. For this particular study, the boundary conditions considered are Constant Head Boundary (CHB) conditions and Wall Boundary (WB) Conditions. CHB act as an infinite source of water entering the aquifer system while the WB is material of low permeability features which obstruct the movement of groundwater. The domain was discretized into 50 cells each in x and y direction. The modeling domain was selected according to natural hydrogeological boundaries, over an area with *x* coordinate 222222 – 245000 m, and *y* coordinate 1052400 – 1071000m. The base map that was super-imposed on the model was digitized map of the study area. The conceptual model receives lateral infiltration recharge from *Chanchaga* River from the east side. In the west, Tagwai dam was defined as CHB and below is the river *chanchaga* as another boundary. The model also receives recharge from precipitation and the only discharge from the model is through evapotranspiration. Figure 2 shows the model domain and the coordinates. The conceptual model was developed based on the following assumptions that the groundwater flow directions and head are constant during the period of simulation for steady state modeling condition.

It is also assumed that the aquifer is homogenous unconfined aquifer and that hydraulic head is constant (Saghravani et al., 2011). K_y in equation 3.6 is assumed to be 10% of K_x and K_z is assumed to be 10% of K_y (Ghoraba et al., 2013).

Calibration of the Model

The developed conceptual model was run under steady-state condition with a 1 day simulation period as starting point. The calibration process is a process whereby the model input parameters are adjusted until the observed data matched the computed data. For model suitability, the calibration exercise was done with the real historic data and adjusting the model until it produced results within a reasonable error to determine which factors of the model is sensitive to understand better the real system and practically to evaluate the worth of the data collection (UPM Hydrogeological Research Team, 2012). The output parameters expected from the models are predicted concentration of selected heavy metals in Minna shallow aquifer for 1, 3, and 5 years. These outputs are expected to be presented in form of colour shading in the aquifer.

RESULTS AND DISCUSSIONS

Visual MODFLOW Simulation

The summary of simulation results is presented in Table 4. The overall simulation results for each contaminant considered is presented in form of colour shading for 365days, 1095 days and 1825 days. From Figures 3 -11 which are results for copper, zinc and arsenic, it was revealed that the whole aquifer under investigation is contaminated with heavy metals. The predicted concentrations of the contaminants are higher than MCL even after five years though with decreased values if compared with initial concentrations. There are zones of zero contaminants (Blue zone) very close to Constant Head Boundary (CHB) that was very distinct after one year but there is migration of the contaminant towards the CHB after 3 and 5 years. This may mean that the contaminant plume is also migrating towards the lake and as a result, leading to reduction in concentration in the main aquifer. A sharp reduction in concentration of nitrate was also observed between 3 and 5 years. This may be as a result of fast subsur-

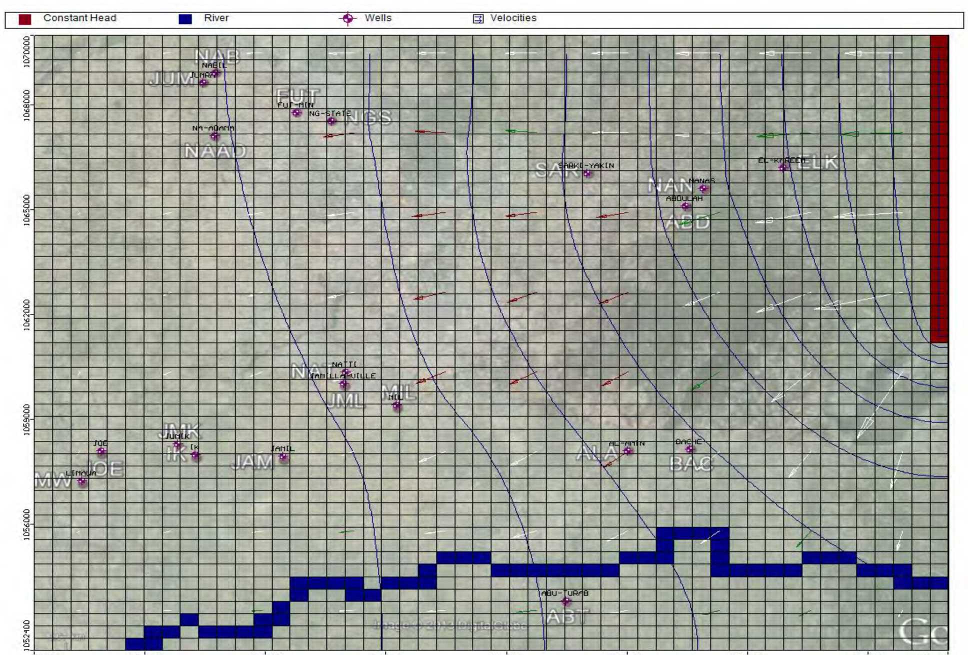

FIGURE 2
The Conceptual Model Domain Showing Flow Direction and Boundaries

TABLE 4
Summary of Observed and Predicted Contaminants Concentrations

Contaminants		MAC* (mg/L)		Initial (mg/L)		Predicted(mg/L)			
				365 Days		1095 Days		1825 Days	
		Min	Max	Min	Max	Min	Max	Min	Max
Arsenic	0.01	0.00	0.74	0.00	0.63	0.00	0.61	0.00	0.60
Zinc	0.05	0.00	11.63	0.00	7.64	0.00	7.64	0.00	7.51
Copper	2.00	0.00	8.43	0.00	7.02	0.00	4.41	0.00	4.20

**MAC- Maximum Allowable Concentration*

face nitrate migration into deep aquifer or dispersion into reservoirs adjacent the study area. The reduced concentration may also be as a result of decay function because MT3DMS model incorporate a first order decay reaction and sorption of the solute to predict what the concentration would be in the specified days.

Generally, Visual MODFLOW predicted the concentrations of the five contaminants considered based on the as-

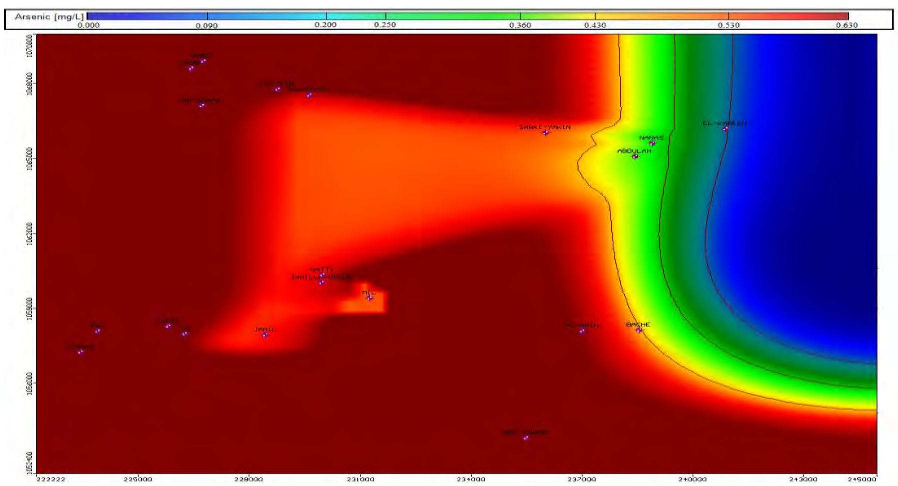

FIGURE 3
Predicted Arsenic Concentration after 365 Days

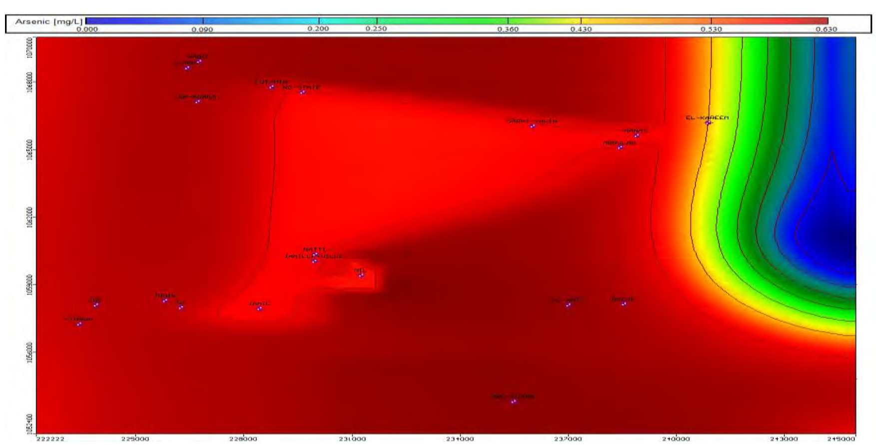

FIGURE 4
Predicted Arsenic Concentration after 1095 Days

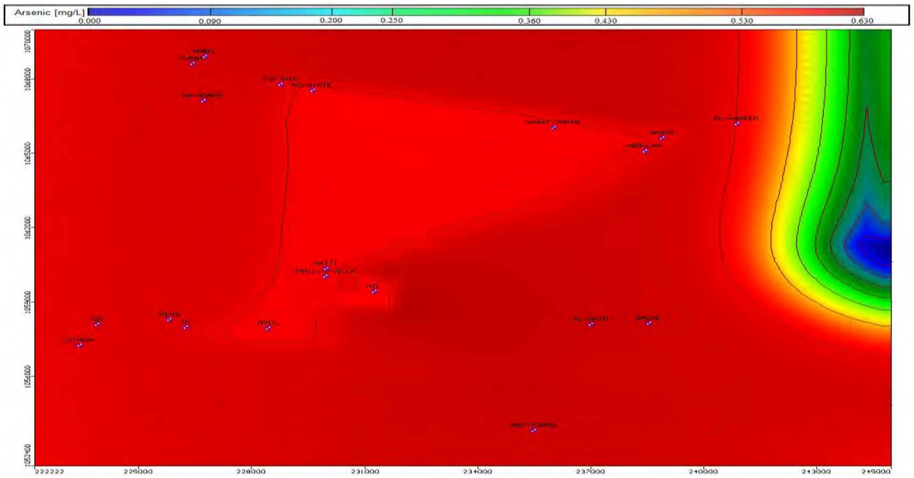

FIGURE 5
Predicted Arsenic Concentration after 1825 Days

sumption that the polluting sources release no contaminants to the aquifer during the simulation period, therefore, if the activities of the poultry farmers and other pollution sources are checked in terms of henceforth indiscriminate manure dumping, over the years, the aquifer would be cleaned after a long time through vertical and lateral migration though the deeper aquifer and adjacent water bodies may receive some of these pollutants.

Change in Concentration of arsenic and zinc for the specified simulation period behaved in a similar manner. From Figures 6 to 11, the reduction in concentration of Arsenic and Zinc was very slow which may indicate a serious difficulty in cleaning up any aquifer contaminated by these heavy metals even after many years.

The only mean through which arsenic and zinc can be attenuated in the aquifer is by sorption into the soil grain and this also depends on the existing affinity between the two. After the adsorption capacity of the soil has been reached, the remaining concentration will migrate with groundwater but at a very slow rate (Han et al*.,* 2000). Though manganese and chromium were not included in the simulation because of low chromium concentration detected during sampling, it is expected that the two heavy metals will behave the same way because of similarity in their decay function with arsenic and zinc.

Predicted Copper Concentration

Copper behaved in a different way from other heavy metals considered. There is a wide clean zone close to CHB after one year and higher concentration in the other aquifer body. However, after 3 and 5 years, there is a sharp reduction in the concentration which informs the change in colour shading of the main aqhufer from brown to green colour though with traces of brownish green. Copper has been known to have good affinity with clay soil grain and can react with other chemicals in the soil to produce another compound. However, the concentration of copper after five years (4.20mg/L) is higher than MCL (2mg/L) which also indicate that the aquifer is still contaminated with copper. Cleaning up may be possi-

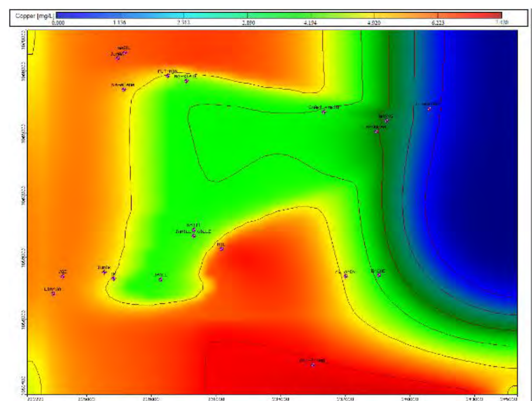

FIGURE 6
Predicted Copper Concentration after 365 Days

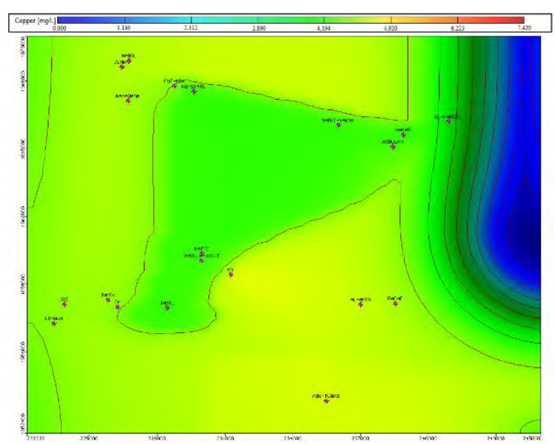

FIGURE 7
Predicted Copper Concentration after 1095 Days

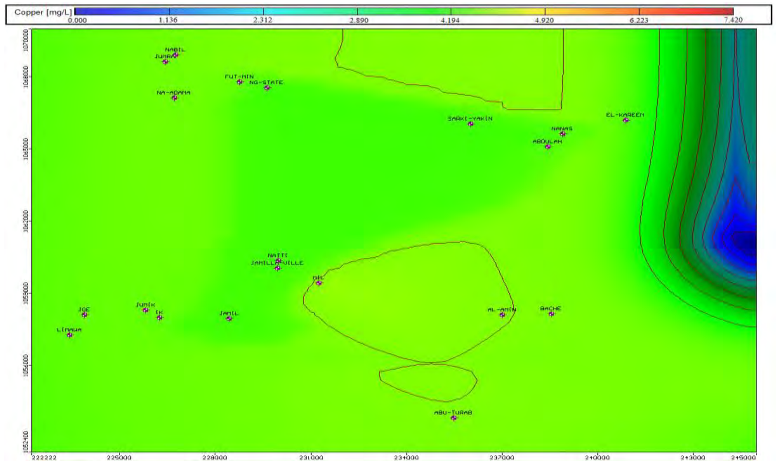

FIGURE 8
Predicted Copper Concentration after 1825 Days

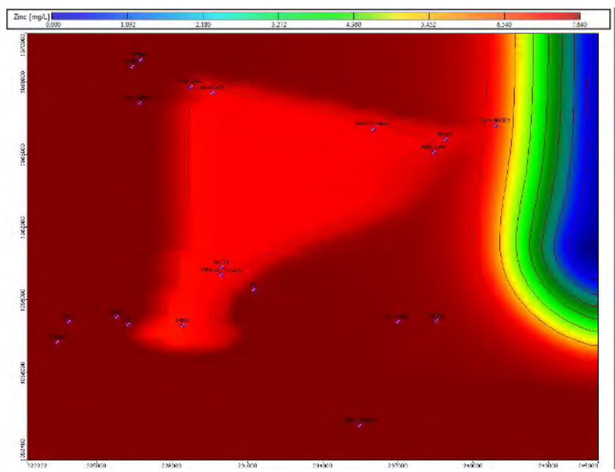

FIGURE 9
Concentration of Zinc after 365 Days

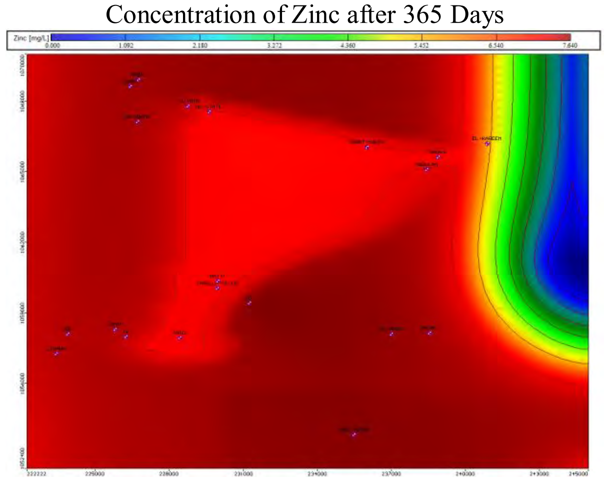

FIGURE10
Concentration of Zinc after 1095 Days

ble in 5 to 10 years if no contaminants are introduced into the aquifer within that period.

Generally, Visual MODFLOW predicted the concentrations of the heavy metals considered are based on the assumption that the polluting sources release no contaminants to the aquifer during the simulation period, therefore, if the

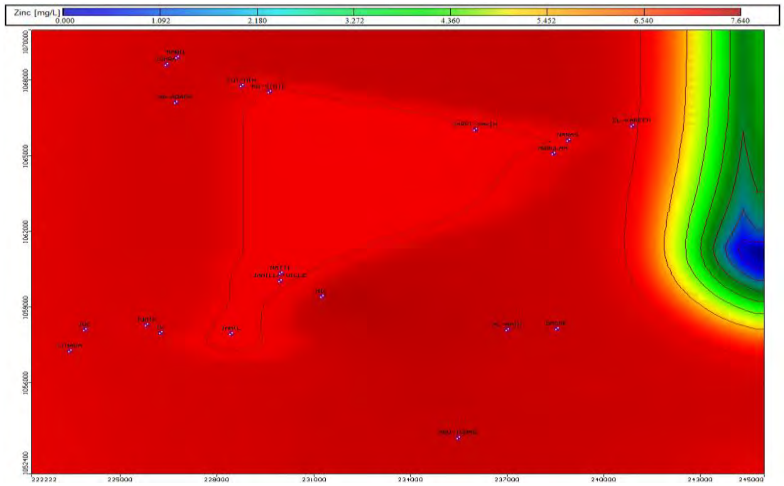

FIGURE 11
Concentration of Zinc after 1825 Days

activities of the poultry farmers are checked in terms of henceforth indiscriminate manure dumping, over the years, the aquifer would be cleaned after a long time through vertical and lateral migration though the deeper aquifer and adjacent water bodies may receive some of these pollutants.

Since in the case of Minna, one of the major sources of shallow aquifer pollutants identified is poultry manure dumps, the cleaning up exercise may begin by providing alternative use of poultry manure. Whenever return to land method is to be practiced, the manure should be applied at a rate of 170kg/ha recommended by Nigerian Agricultural Development Programme. The left over can be used for biogas production or composted and stored for future use. Ghoraba et al*.,* (2013) has recommended installation of a set of shallow wells and pumping of contaminated water out of the aquifer for treatment as a method of cleaning up of a contaminated aquifer, this may also be practiced in Minna to quicken up the cleaning exercise. Groundwater flow direction in the study area according to the model and calculation is towards river *chanchaga,* there is every tendency for the groundwater to pollute the river with parameters considered, periodic sampling of the river is therefore recommended to know the quality of the river and to ascertain if the river dilution factor can stem the effect of increase in nitrate, phosphate and heavy metals influx from contaminated adjacent aquifer.

Prediction by visual MODFLOW and MT3DMS revealed that if the poor management of poultry manure in Minna in checked, there will be a reduction in concentration of arsenic, after five years, from 0.74 to 0.60mg/L, zinc from 11.63 to 7.51mg/L and copper from 8.47 to 4.20mg/L. This may also mean that complete cleaning up of Minna shallow aquifer is possible though after many years of environmental friendly poultry manure management.

CONCLUSION

Prediction by visual MODFLOW and MT3DMS revealed that if the poor management of poultry manure in Minna is checked, there will be a reduction in concentration of arsenic, after five years, from 0.74mg/l to 0.60 mg/L, zinc from 11.63 mg/l to 7.51 mg/l and copper from 8.43mg/l to4.20 mg/l. This may also mean that complete cleaning up of Minna shallow aquifer is possible, though after long years of environmental friendly poultry manure management.

Knowledge of heavy metals migration in Minna shallow aquifer is still vague. More sampling needs to be carried out and bio-availability of these compounds in poultry waste need to be studied vis- a-vis their movement method into groundwater. This should include loading rate and site specific best management practices for safe and beneficial use of poultry manure.

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COMPARISON IN THE PHYSICOCHEMICAL AND MICROSTRUCTURAL CHARACTERIZATION OF WASTE COAL COMBUSTION RESIDUES (CCR) GENERATED FROM FBC AND PCC BOILER USING THE SAME ORIGIN OF COAL

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ABSTRACT

In the present study comparison in the physicochemical and microstructural characterization of waste coal combustion residues (CCR) generated from fluidized bed combustion (FBC) as well as pulverized coal combustion (PCC) boiler was done. CCR were collected from two different types of the boiler having an almost same capacity as well as uses the same origin of coal for combustion. Due to lower temperature in FBC boiler, generated CCR are relatively denser in structure as comparison to CCR generated in PCC boiler. The generation of temperature is more than the ash melting temperature in PCC boiler which results the presence of alumina and silica in CCR as combined form of aluminosilicate. In FBC boiler, due to lower temperature, CCR have silica and alumina in free form. Oxides of both CCR like silica, alumina, and iron oxide are same but its percentage quantity is different in each CCR. Heavy metal content (like iron) is higher in bottom ash than fly ash in both PCC as well as FBC. At high temperature, ash got melted, and volatile material got entrapped to form cenosphere in PCC boiler which causes hollow cenosphere in major quantity. In FBC boiler, mainly solid structure of Fly Ash is observed due to absence of such phenomenon for lower temperature generation. Due to the presence of aluminosilicate in PCC Fly Ash, it can be used as a hard wear-resistant material. On the other hand, presence of free, uncombined alumina and silica in FBC Bottom Ash can facilitate for easy recovery of alumina, silica. Based on the different physicochemical properties it can be concluded that these wastes (CCR) should be exploited for preparing commercially viable products like bricks, tiles etc. apart from land filling. It will also control environmental problems by avoiding solid waste dumping.

Keywords: Coal Combustion Residues; FBC and PCC boilers; Fly Ash; Bottom Ash; Physico-chemical characterization

INTRODUCTION

Coal is composed of a combustible organic substance with a variety of inorganic mineral inside it. In India, ~490 million tons of coal was burned to generate electricity during the year of 2013-14 (CEA 2013-14, 2014). The combustion process produces solid coal combustion residues (CCR) from the non-combustible part of the coal. It is being expected that over 190 million tons of CCR will be generated in India annually by the year of 2020 including fly ash (FA), bottom ash (BA), slag, and flue gas desulfurization products, etc. (Mandal & Sinha, 2014).

The types of coal and boiler as well as operating conditions of the boiler control the physical and chemical characteristics of CCR (David et al., 1984; Kim, 2002; Senior et al., 2000). In a pulverized coal combustion (PCC) boiler, the furnace operating temperature is more than 1400°C (Kutchko & Kim, 2006). At these high temperatures, the mineral matter inside the coal may oxidize, decompose, fuse, disintegrate or agglomerate. Rapid cooling in the post-combustion zone results in the formation of spherical, amorphous (non-crystalline) particles. Expansion of trapped volatile matter can cause the particle to expand to form a hollow cenosphere. Minerals with high melting points may remain relatively unchanged. The heating and cooling have a significant effect on the composition and morphology of each particle (Kutchko & Kim, 2006).

Fluidized bed combustion (FBC) technology has been known as a clean coal burning technology due to its advantages in fuel flexibility,(Jia et al., 2010) low combustion temperature, the long residence time of fuel inside the furnace, low cost of in-furnace desulphurization and low NOx discharges during combustion (Duan et al., 2011, 2014). Another advantage of FBC technology in the context of oxy-fuel firing is that external solid heat exchanger, used to extract heat from the combustion process, allows a significant reduction of the amount of recycled flue gas required for combustion temperature control. This feature permits the use of a much higher oxygen concentration in the combustor, which improves the economics of oxy-fired FBC over that PCC (Hotta et al., 2008; Liljedahl et al., 2006; Stamatelopoulos & Darling S, 2008). These are the reason for gaining popularities of FBC technology day by day. In India about 80 % of the total electricity generation capacity is based on thermal route and Indian coal is used in power plants has high ash yield and of low quality (Mandal & Sinha, 2017; Rai et al., 2013), which encourages the installation of small to medium scale industries having FBC boiler.

For the reason above, this is the crucial time to study the CCR characteristics generated from these types of power plants. The present study consists of the physico-chemical properties of CCR produced in FBC boiler and PCC boiler, where the same origin of coal was used.

MATERIALS AND METHODS

The ash samples used in this study were collected from two different types of power plants in India having FBC boiler of 300MW and PCC boiler of 250 MW capacities respectively. Both of the plants use the same source of origin of coal for combustion and also having the dry disposal system of FA and BA separately. Both FA were collected directly from the electrostatic precipitator (ESP). FBC BA was collected from the bottom of the FBC boiler while in the case of PCC BA, it was collected from the chute of conveyer belt after crushing. Figure 1 shows the typical photographs of CCR obtained from different types of boiler.

Size, shape, and texture of the materials were observed by Scanning Electron Microscopy (SEM) image (done on model no Quanta 200F at 20kv on scan rate of 10µs with ETD detector) (Figure 2). The Bulk Density was calculated as per procedure mention in ASTM D6683 (ASTM D6683, 2014) . The specific gravity of the samples was determined with the help of water pycnometer as per method mention in ASTM C135 (C135-96, 2015) . The specific surface area was measured by the standard BET (Model- Smart Sorb 92/93) gas absorption-desorption isotherm of liquid N_2 at 77K as per ASTM C1069 (ASTM C1069, 2014) (Table 1) . Particle size distribution was carried out for particles <75 µm size by wet sieving followed by hydrometer analysis as per ASTM C117 (ASTM C117, 2013) and >75 µm by screen analysis using sieve shaker according to ASTM C136 method (ASTM C1069-09, 2014; ASTM C136M-14, 2014) (Figure 3 and Table 2). Proximate analysis of bottom ash was done to understand the volatile matter and carbon content as per ASTM D7582 (ASTM D7582-15, 2015). The chemical composition of the various industrial wastes was determined using Energy Dispersive X-Ray Fluorescence Spectrometer as per ASTM C1365 (ASTM C1365, 2011). The mineral phases in the wastes based on ASTM D3906 (ASTM D3906, 2013), were identified by XRD (Rigaku D-max IIIB). The pH was measured using pH meter (Contech Instruments model PH-102/103) as per ASTM E70 (ASTM E70, 2015) to know whether the dissolved chemicals cause the soil to be acidic or alkaline (Table 3).

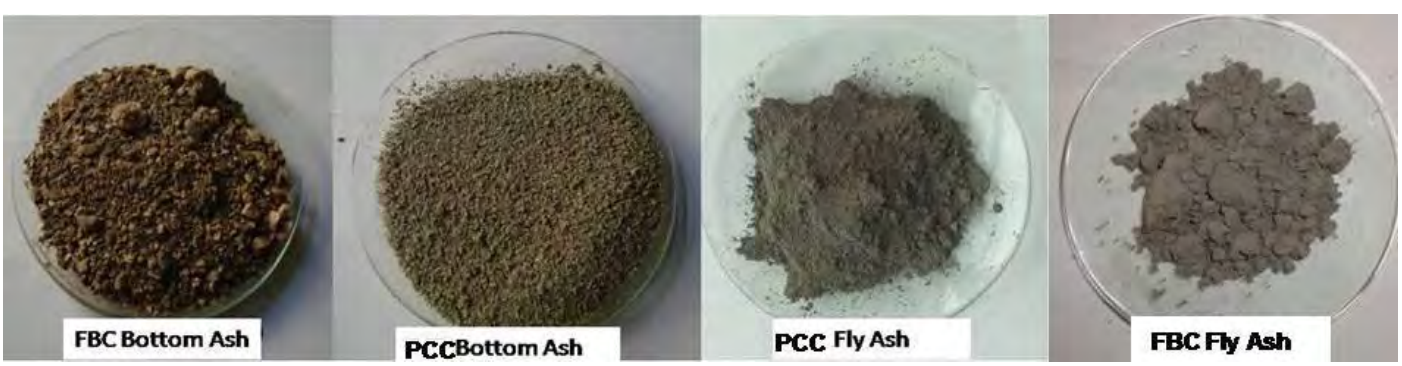

FIGURE 1
Different raw materials

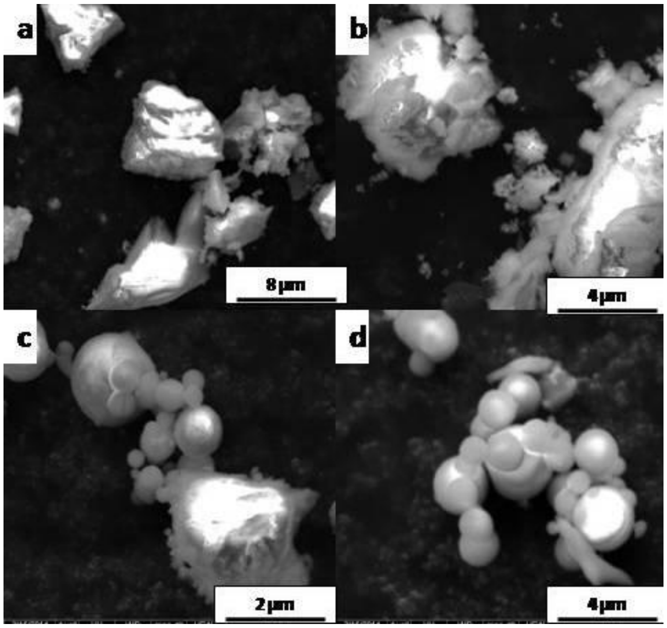

FIGURE 2
Size shape and texture (a-FBC BA, b-PCC BA, c-FBC FA, d-PCC FA)

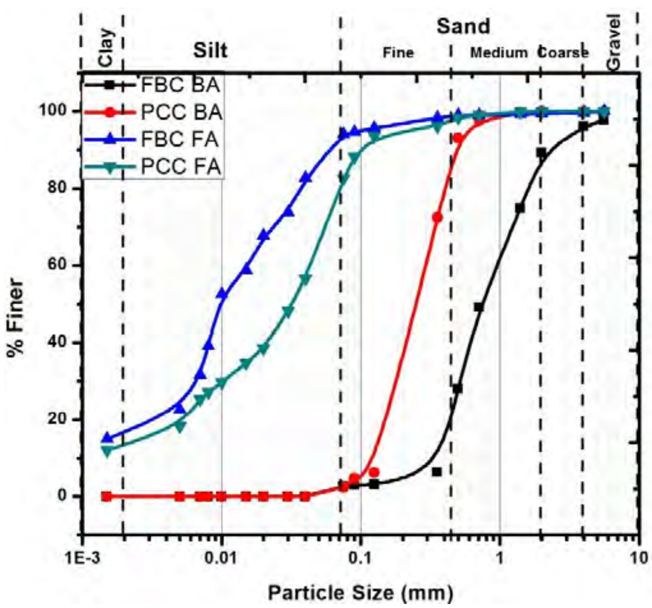

FIGURE 3
Particle size of ash samples

RESULTS AND DISCUSSION

Size shape and texture

In the case of fluidized bed combustion, the temperature of the combustion is lower than the ash melting temperature of coal, which results the formation of loose coarse uncombined solid particles as shown in Figure 2a (Stevens et al., 2009) while, coal ash got agglomerated in lumpy form by melting due to high combustion temperature in PCC boiler. After crushing of lumps, porous irregular sized popcorn like particles are formed as shown in figure 2b. Particles show relatively finer porous structure compared to FBC bottom ash (Figure 1). Fly Ash produced in PCC boiler having cenosphere (hollow spherical ball) due to entrapment of volatile material (Kutchko & Kim, 2006). Fly ash produced from FBC boiler are irregular and solid in nature having relatively finer size than PCC due to the absence of cenosphere (Stevens et al., 2009). Hollow nature of cenosphere, easily fly from boiler to electrostatic precipitator relatively larger in size than solid particles. It results the larger size of fly ash in PCC compared to FBC (Figure 2) (Kutchko & Kim, 2006).

Density and specific gravity

Specific Gravity of all samples varied from 1.78 to 2.72. Reasons of low specific gravity may be; the existence of unburnt carbon and cenospheres may perhaps be attributed to a combination of factors like gradation, particle shape and chemical composition, the presence of hollow cenospheres from which entrapped air cannot be removed (Table 1). The specific gravity of BA in FBC is more than PCC due to a large amount of Fe_2O_3 content. Due to the presence of heavy metal content more in the case of BA than FA, the specific gravity of BA is more than FA. The bulk density of almost all samples was less than 1.000g/cc except FBC BA due to the absence of hollow cenosphere and sand like solid structure. The bulk density values of all the samples are less than that of typical soils. It can again be attributed partly to the presence of hollow cenospheres. PCC FA shows lower density due to the presence of very fine hollow cenosphere as compared to FBC FA, which is solid and irregular in nature. It is interesting to mention that PCC BA has lower bulk density even than PCC FA, although the specific gravity of PCC BA is more than PCC FA. This observation strongly indicates the popcorn like hollow structure of PCC BA.

Surface area and particle size

The surface area of different Bottom Ash and Fly Ash are shown in Table 1, which indicates that Fly Ash is finer than all Bottom Ash, which is also evident by the particle size graph illustrated in Figure 3. Specific surface area of Fly Ash is more than of Bottom Ash. The PCC Bottom Ash is finer than FBC Bottom Ash as discussed in *Size, shape and texture* section above. Due to the spherical shape, PCC FA shows least surface area as compared to FBC FA.

Particle size analysis graph also indicates that FBC Bottom Ash particles are coarser than PCC Bottom Ash (Figure 3). Calculated fineness modulus of FBC bottom ash is determined by sieve analysis and it is reported as 2.82 whereas 1.24 for PCC Bottom Ash. As per gradation of soil, FBC Bottom Ash lies in the well-graded medium sand category whereas PCC Bottom ash in fine sand category. Both of them having zero clay content, therefore, could not be self-bound

TABLE 1
Physical properties of different CCR

	Specific gravity	Bulk Density (kg/m^3)	Surface area(m^2/kg)
FBC BA	2.72	1230	1280
PCC BA	2.25	612	1650
FBC FA	1.81	655	4270
PCC FA	1.78	625	4000

without an addition of appropriate binder (Table 2). In the case of FA both lies under silt category having 12-15% clay. Therefore, self-binding properties, as well as pozzolanic properties, became more than BA.

Chemical Constituents and pH

The moisture content of the samples depends on the type of storage, disposal and the method of sample collection. Therefore, the proximate analysis was done on the dry basis and is reported in Table 3. It is a significant parameter as it helps in finding out the amount of moisture to get proper compaction. Volatile matter of samples is more in the case of FA compared to any BA. Due to the higher melting temperature of PCC boiler, the VM content is less in PCC BA than FBC. Sometimes pulverized coal of very fine particles easily move through off gas without combustion and catch in ESP resulting increases in volatile materials inside the FA. In the case of FBC, the lower temperature could not dissociate complete organic materials into volatile materials results the presence of more volatile materials than PCC BA. An increased amount of volatile material present in FA may be due to condensation of volatile material in presence of alkali in ESP at lower temperature. Compared to BA, FA contains

TABLE 2
Gradation analysis of different CCR

Raw Materials	FBC BA	PCC BA	FBC FA	PCC FA
		Composition (%)		
Clay	0	0	16.94	13.56
Slit	2.26	2.98	77.14	69.3
Fine sand	15.91	79.54	4.73	10.89
Medium sand	71.61	17.44	0.28	5.16
Coarse sand	7.02	0.04	0.91	1.09
Gravel	3.2	0	0	0
		Gradation		
D_{10}	0.3250	0.1178	0.0025	0.0015
D_{30}	0.5236	0.1794	0.0101	0.0068
D_{60}	0.9239	0.2829	0.0431	0.0154
C_c	0.913	0.966	0.947	2.00
C_u	2.84	2.4	17.24	10.26
Fineness Modulus	2.82	1.24	-	-

TABLE 3
Chemical properties of CCR

Materials	Proximate			Ultimate									pH
	VM	FC	Ash	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	P_2O_5	TiO_2	SO_3	K_2O	
FBC BA	1.5	3	95.5	67.32	25.20	3.71	0.45	0.86	0.81	0.28	0.19	0.09	10.00
PCC BA	1.1	4.2	94.7	70.04	22.05	2.49	1.18	0.32	0.59	0.34	0.16	0.10	7.33
FBC FA	5.7	2.2	92.1	68.05	26.02	2.46	-	2.02	1.13	0.33	1.46	0.06	9.90
PCC FA	5.8	2.0	92.2	64.84	24.38	1.92	1.98	0.22	1.2	.27	0.36	1.92	8.42

more VM due to the possibilities of easy escaping out of volatile material through off gas without dissociation. In the case of FBC boiler, coal particles are suspended and react with air resulting least carbon content inside the FBC BA. During injection of coal through the nozzle in PCC, some coal particles fall under gravity over the melted bottom ash before reaction, resulting increase in carbon content inside PCC BA although PCC had much higher temperature. Carbon content in the BA is 3-4.2% reveals that the bottom ash is collected at the time of full phase running of a power plant, otherwise newly started boiler shows much higher carbon content. Major constituents of the bottom ash are silica and alumina as indicated by XRF results (Table 3). The chemical components of bottom ash and fly ash are quite identical except the relative amount. Both samples having the primary constituents are silica, alumina, and hematite. The quantity of Fe_2O_3 is more in FBC Bottom Ash rather than PCC bottom ash. FBC unit has ultimate benefit of environment due to FBC fly ash not fused, high sulphur content than PCC FA resulting less SOx or NOx emission through off gas.

The pH values indicate the wastes are alkaline in nature. If disposed on open land would further increase the pH, i.e., the alkalinity of the soil (Table 3). Alkaline soils with high pH (> 8.5), have a poor soil structure and a low infiltration capacity (Table 3). Coal-fired boilers or power plants when using coal or lignite rich in limestone produces ash containing calcium oxide (CaO). CaO readily dissolves in water to form slaked lime or $Ca(OH)_2$ and carried by rainwater to rivers irrigation water. Lime softening process precipitates Ca and Mg ions removes hardness in the water and also converts sodium bicarbonates in river water into sodium carbonate. Alkaline soils are difficult to take into agricultural production. Due to the low infiltration capacity, rain water stagnates on the ground easily and, in dry periods, cultivation is hardly possible without copiously irrigated water and good drainage. Agriculture is limited to crops tolerant to surface waterlogging (e.g. rice, grasses) and the productivity is low.

CCR from FBC boiler is more alkaline than PCC due to the addition of lime for desulphurization during combustion. PCC BA and FA having almost equal distribution of alkali oxides show roughly equivalent pH values. In the case of PCC boiler, high combustion temperature enhances alkali vaporization which increases the transportation of alkali oxides through off gasses. After reaching relatively lower temperature, alkali oxides are condensed and captured in ESP with FA resulting higher pH values in PCC FA than PCC BA (Table 1).

Phase analysis

Major mineralogical phases in CCR detected through XRD analysis are quartz, alumina as a free form or as a combined form of kyanite, sillimanite and in some case as a mullite. Formation of such combined phases depends mainly on the composition of coal, boiler temperature and the reaction time. Due to major constituent of silica in CCR, quartz phase is observed as a most predominant phases in all CCR samples. At the lower temperature, formation of sillimanite followed by kyanite is occurred. Therefore, sillimanite is present in all CCR. PCC produces higher temperature, resulting formation of more high-temperature phases. Therefore, the presence of mullite phases is only observed in the CCR of PCC boiler. Kyanite may exist at a lower temperature as well as at higher temperature, therefore in all FA kyanite phase was observed. Sillimanite to kyanite transformation occurred at a relatively lower temperature and higher pressure before it captures in ESP. Most prominent mullite phases were observed in the case of PCC BA where particles hold at a high temperature for a long duration (Figure 4).

CONCLUSIONS

From the above study, it is clear that CCR having major silica-alumina content can be used as a potential material for making usable component apart from land filling. The chemical composition of all CCR is quite similar where relative quantities are different. Due to the high temperature of the boiler in PCC (~1400°C), coal ash got melted during combustion and forms aluminum silicate. Due to the high pressure of injection of coal, some portion of melted ash forms a spherical shape by entrapping volatile matter inside the sphere. Rests are deposited at the bottom of the boiler as a boiler slag. Lower temperature generation of FBC boiler (~900°C) could not combine alumina, silica. Therefore, major content of silica-alumina exists in CCR in free form. The particle size

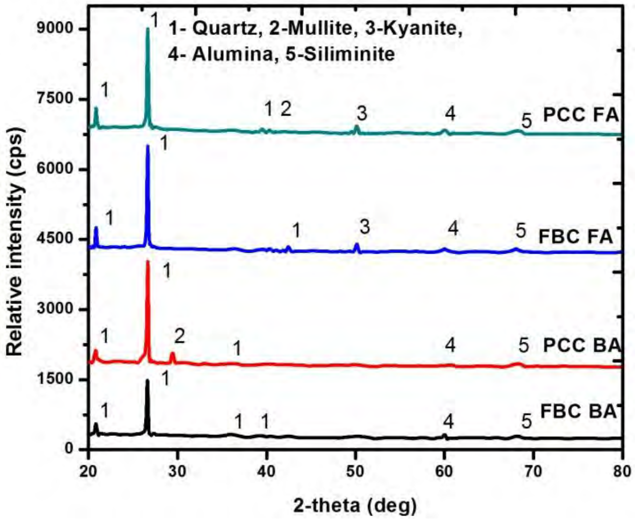

FIGURE 4
XRD analysis of BA and FA

of FA is finer than Bottom Ash and also less dense. PCC boiler FA is relatively coarser in size than FBC FA due to the presence of cenosphere. The specific gravity and bulk density of BA are more (~20-30%) than FA due to presence of more heavy metal content. The specific gravity difference of FBC BA (2.72) and PCC BA (2.25) is less as compared to the bulk density. The bulk density difference of FBC BA (1230 kg/m^2) and PCC BA (612kg/m^2) clearly indicates the presence of excessive porous structure of PCC BA.

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A PRELIMINARY COMPARISON OF MSW BIOREFINERY CONFIGURATIONS BASED ON PROCESS AND MATERIAL FLOWS, POWER PRODUCTION AND VALUE-ADDED PRODUCTS

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ABSTRACT

This study investigated the potential of a biomass-based biorefinery in Mauritius using municipal solid wastes (MSW). Process selection and scenarios were worked out and the scenarios selected for the MSW biorefinery were anaerobic digestion (scenario A); material recovery facility system (scenario B); scenarios A and B (scenario C (a)); scenario C (a) with production of levulinic acid (scenario C (b)) and gasification (scenario D). The useful products from the MSW biorefinery were power, digested matter for composting, digestates for fertiliser, metals, glass and levulinic acid. The scenarios selected were analysed based on technical and economic parameters. For the technical analysis, 19.98 ton/h to 53.96 ton/h of MSW were processed in the MSW biorefinery. Ash produced varied from 0 to 3.76 ton/h. Carbon dioxide emissions were 2.83-26.97 tCO_{2e}/h. The discounted payback period for the scenarios varied from 6.86-12.11 years, and the internal rate of return ranged from 15.47 to 24.56%. This study has shown that the best MSW biorefinery option is a combined process comprising anaerobic digestion, material recovery facility and the production of levulinic acid.

Keywords: Municipal solid wastes; biorefinery; sustainability; payback; emissions

INTRODUCTION

A biomass-based green biorefinery unifies the concept of biomass supply chain management wherein technical analysis, economic assessment and green engineering and sustainability considerations all form part of the supply chain management (Toka et al., 2010). The technical analysis includes the type and quantity of biomass, process conversions and useful output products whereas the economic analysis comprises estimation of costs associated with the biorefinery, and the green engineering and sustainability dimensions encompass essentially the social, environmental and technological criteria. According to Maity (2015), the fraction of renewable energy in the world represented by biomass is considered to be more than half of the total amount of renewable feedstocks. Biomass being a renewable resource and due to conflicts of fossil fuels with the environment and their uncertain availability, the concept of biorefinery was first introduced in the late 1990s and the concept of green biorefinery followed in 1997 (Maity, 2015). Before selecting the biomass, the chemical and phase structure are important features to look at along with

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desirable fuel properties, quality, potential applications and environmental risks associated (Vassilev et al., 2010). The choice of feedstocks for a biorefinery must be thoroughly made as it must be available throughout the process operation and be based on a combined economic and environmental consideration (Long et al., 2016). Municipal solid waste and sewerage sludge are readily available in Mauritius and potential candidates for a biorefinery. Municipal solid waste (MSW) is any unwanted materials generated on residential and industrial premises. MSW production and composition depends on the origin of the wastes, the season and population growth. In order to discard MSW, these are presently being landfilled. MSW is composed of paper, plastics, organics and other wastes fractions which come from a variety of activities from residential and industrial areas. From the several published data, MSW typically consists of 70-75% carbohydrates which are mainly made up of cellulose, hemicellulose, and starch, lignin and other natural compounds (Maity, 2015). Also, sanitary landfilling for MSW management could possibly not be the best and a most sustainable solution for an island.

There is currently no data on the assessment and potential for implementing a biomass-based biorefinery in Mauritius. Hence, this study aims to assess the scope for developing such a biorefinery in the local context using MSW of typical characteristics. The objectives of this work have been to develop material process flows and production schemes which constitute scenarios of biomass-based biorefineries using municipal solids wastes fractions, to assess each scenario for its salient technical and economic performance in terms of the amount of biomass being processed, production of useful products, ash and carbon dioxide emissions, total capital investment, net income, payback period and internal rate of return of each scenario.

Highlights of this work are:

- Five municipal solid wastes biorefinery configurations were compared.
- Process flow diagrams, material balances and economic analysis were employed.
- Anaerobic digestion, material recovery plus levulinic acid production was best.
- The best configuration had low ash yield and moderate carbon dioxide emissions.
- Best biorefinery model had a payback of 6.86 years and an internal rate of return of 24.56%.

MATERIALS AND METHODS

MSW biorefinery scenarios and process selection

Based on the quantity and quality of MSW produced in Mauritius, five scenarios for biorefinery have been formulated (Table 1). Ash from the MSW can be used as fertiliser and/or as a cement additive whereas the bottom ash may be used as rocks and in concrete (Raman et al., 2016)

Calculation strategy in MSW biorefinery scenarios

The amount of MSW was estimated from data available from the Ministry of Environment, Sustainable Development,

TABLE 1
MSW biorefinery scenarios in the context of Mauritius

Scenario A	
Description of processes involved	Products recovered in the process
Anaerobic digestion	− Biogas production that is used to produce power − Digested matter used as composting − Liquid stream used as fertiliser
Scenario B	
− Material Recovery Facility (MRF) − Refuse derived fuel (RDF) used in cogeneration Plant	− Recovery of precious metals, glass and RDF − Power production from RDF
Scenario C (a)	
− Scenario A − Scenario B	Products from Scenario A and B
Scenario C (b)	
− Scenario A − Scenario B − Hydrolysis from scenario A to recover levulinic acid	− Products from Scenario A and B − Production of levulinic acid which is refined and can be used in pharmaceutical, chemical, agricultural industries and as fuel and additives (Sadhukhan et al., 2016).
Scenario D	
− Gasification	− Power production

and Disaster and Beach Management (Ministry of Environment, Sustainable Development, and Disaster and Beach Management, 2016). The calculation strategy for each scenario given in Table 1 has been summarized below.

Scenario A

- Determining the chemical formula on dry and wet basis of biomass from the data available from ultimate and proximate analysis (Choy et al., 2004).
- From the chemical formula derived, the compositions of the different elements were determined on wet and dry basis.
- Determining the dry and wet content of organic fraction of the MSW.
- Using Buswell equation (Equation 1), the yield of biogas was calculated from the following balanced equation (Banks, 2009):

$$C_qH_kO_jN_fS_y + [(1/4)(4q - k - 2j + 3f + 2s)]\,H_2O \rightarrow [(1/8)(4q - k + 2j + 3f + 2s)]\,CO_2 + [(1/8)(4q + k - 2j - 3f - 2s)]\,CH_4 + [f]\,NH_3 + [y]\,H_2S \quad (1)$$

q, k, j, f, and y are the coefficients for each of the elements C, H, O, N and S, respectively, in the representative formula for MSW.

- Calculating mass flowrate of carbon biodegraded to biogas, Q
- Q = % of Biodegradability × Carbon content in MSW
- % of biodegradability = 55 (Distefano et al., 2009).
- Energy content of methane was taken to be 35.883 MJ/m^3 as per Waldheim and Nilsson (2001) and the electric efficiency of this scenario was between 30 to 40% (Distefano et al., 2009); the latter information were used to calculate the amount of power generated.
- Calculating amount of digested matter (Dry) and liquid stream from the anaerobic digestion of MSW. The digested matter (Dry) i=was considered to be 25 to 35 % of the digestate while the remaining fraction is the liquid stream (Romero-Guiza et al., 2016).

Scenario B

- Calculating composition of the MRF: recyclables namely metals and glass, organics and RDF fraction. The material recovery system consists of the following unit operations which are mostly mechanical: screening, magnetic separator, electrical separator, automatic sorting, infrared and X-ray sensor among others. The separation is performed for the following: paper, glass, plastic, food waste (organic), textiles and metals (Sadhukhan et al., 2016). After the materials have been selected for the RDF, they are aggregated to form RDF.

Composition of RDF was adapted from Scoullos et al., (2007). Based on RDF ultimate and proximate analysis (Choy et al., 2004), RDF elemental and chemical content were determined. The numerical values of parameters used in performing the above calculations are summarised in Table 2.

- Higher heating values (HHV) and lower heating values (LHV) were determined from Velzy and Grillo (2007).

Scenario C (a)

The methodology for Scenario C (a) is the same as Scenarios A and B.

Scenario C (b)

TABLE 2

Numerical values of parameters used to calculate power generation for the MSW biorefinery

Parameter	Value	Reference
Moisture content of RDF	20 %	Jannelli and Minutillo (2006)
Boiler efficiency	81.63 %	Suntivarakorn and Treedet (2016)
Cooling water inlet temperature to economiser	25 ºC	Hua et al. (2015)
Boiler pressure	60 bar	Costa et al. (2016)
Boiler temperature	400 ºC	Costa et al. (2016)
Boiler inlet temperature from economiser	140 ºC	Consonni and Vigano (2012)
Isentropic efficiency of turbine – To determine actual power output	88 %	Roy and Pradeep (2016)
Pressure losses through heat exchangers	2 %	Bianchi et al. (2014)
Quality of vapour from turbine	85 %	Hua et al. (2015)
Turbine outlet pressure	1 bar	Galeno et al. (2011)
Electrical Generator Efficiency	98.73 %	Ion and Condrut (2013)

The methodology for Scenario C (b) is similar to that of Scenario C (a) except for the production of levulinic acid. The lignocellulosic fraction of MSW is typically as follows: 33% hemicellulose, 42% cellulose and the remaining being lignin and others (Sadhukhan et al., 2016). The mass of levulinic acid was calculated using the following information: levulinic acid represents 46% of cellulosic fraction of the lignocellulosic fraction of MSW (Sadhukhan et al., 2016) and the remaining fraction of the hemicellulose and organics are directed to the anaerobic digestion system for more production of biogas.

Scenario D

- Determining the chemical component of MSW from the data available on ultimate and proximate analysis from Choy et al., (2004).
- Determining the number of moles of the product gas/ syngas from the chemical components worked out above.
- The LHV of syngas was calculated from Adhikari (2013) as per Equation 2 with

$$Y = a\ Y_{CO} + b\ Y_{CH4} + c\ Y_{H2} + d\ Y_{H2O} \qquad (2)$$

where a, b, c and d are percentages of carbon monoxide, methane, hydrogen and water respectively, Y is the lower calorific value in MJ/ Nm^3. As per Waldheim and Nilsson (2001), the values of Y for CO, CH_4, H_2, and H_2O were taken as 12.633, 35.883, 10.783, and 2.01 MJ/Nm^3, respectively.

- Determining the mass and volume of syngas.
- The following efficiencies were used when calculating the amount of power produced:
  - Efficiency of converting syngas into electrical power: 30 to 40% (Distefano et al., 2009)
  - Turbine efficiency: 27.3% (Bianchi et al., 2014)
  - Generator efficiency: 98.73% (Ion and Condrut, 2013)

Scenarios involving co-generation

- The mass of superheated steam (Equation 3) was calculated as follows:

Mass flowrate of superheated steam = Boiler efficiency × Amount of Biomass × LHV of Biomass / (Enthalpy of Boiler Outlet – Enthalpy of Boiler Inlet) (3)

The variables in Equation 3 are mass flowrate of superheated steam (kg/h), boiler efficiency (%), amount of biomass (kg/h), LHV of biomass (kJ/kg), enthalpy of boiler outlet (kJ/kg) and enthalpy of boiler inlet (kJ/kg).

- Mass of water heated in the boiler was calculated as the sum of mass flowrate of superheated steam and rate of blowdown in boiler. Blowdown is the expulsion of water in the saturated form from the boiler; to prevent corrosion in the boiler and turbine blades (Vandani et al., 2015) and according to the U.S. Department of Energy (2012), the rate of blowdown is between 4 to 8 % of the steam mass flowrate. The power generated from the steam turbine was calculated as the mass flowrate of superheated steam × change in enthalpy of the turbine outlet and inlet × isentropic efficiency × generator efficiency.

The electric efficiency (Equation 4) for all the scenarios where applicable was calculated as follows:

$$\text{Electric Efficiency} = \frac{\text{Energy Output (Turbine)}}{\text{Energy Input (Boiler)}} \times 100 \qquad (4)$$

In order to calculate the amount of power generated, the different enthalpies required were obtained from Steam Tables. The plant internal power consumption was kept at 15% of the total amount of power generated from the turbine as per Karellas et al., (2010). Hence, the net amount of power sold to the grid was the difference between the total amount of power from the turbine and the plant internal power consumption. The ash content and amount of carbon dioxide produced were calculated. The percentage of fly ash and bottom ash were 20 and 80 %, respectively (Kim et al., 2005). In addition to the latter mathematical computations, an economic analysis of each scenario was performed. This economic analysis consisted in estimating the total capital investment, total product costs, total income, gross income and net income, payback period, discounted payback period and internal rate of return for each scenario.

RESULTS AND DISCUSSIONS

Process flow diagram for biorefinery scenarios

Scenarios C and D have been designed to process 53.96 ton/h of MSW and Scenarios A and B will handle 34.54 ton/h and 19.98 ton/h of MSW, respectively. The process flow diagrams (Figures 1, 2, 3, 4 and 5) illustrate the results of the material balances performed for the five scenarios. For Scenario A (Figure 1), 34.54 ton/h of the organic fractions of MSW are to be fed and accordingly the calculations in this study have shown that the amount of power saleable to the grid system will be 4.903 MW. The carbon dioxide release to the atmosphere will be in the tune of 2.83 tCO_{2e}/h. In Scenario B (Figure 2), 53.96 ton/h of MSW have been processed in an MRF system. The results of the material balances here indicate that 17.35 ton/h of RDF may be potentially recovered and directed for generation of power; 2.63 ton/h of other recyclables comprising 0.56 ton/h metals, 1.51 ton/h glass and 0.56 ton/h bulky waste may be produced and finally 33.99 ton/h of organic wastes may be recovered. In this scenario, it may be envisaged to have a net power sale to the grid system of 13.88 MW with a net carbon footprint and ash production of 26.97 tCO_{2e}/h and 0.93 ton/h, respectively. Scenario C (a) which is a combination of scenarios A and B (Figure 3) processes 53.96 ton/h of MSW. Since a small fraction of organic will be present in the RDF, 33.99 ton/h of organic materials will here be fed to the anaerobic digestion unit instead of 34.54 ton/h as in scenario A. In scenario C (a), the net sale of power amounted to 18.7

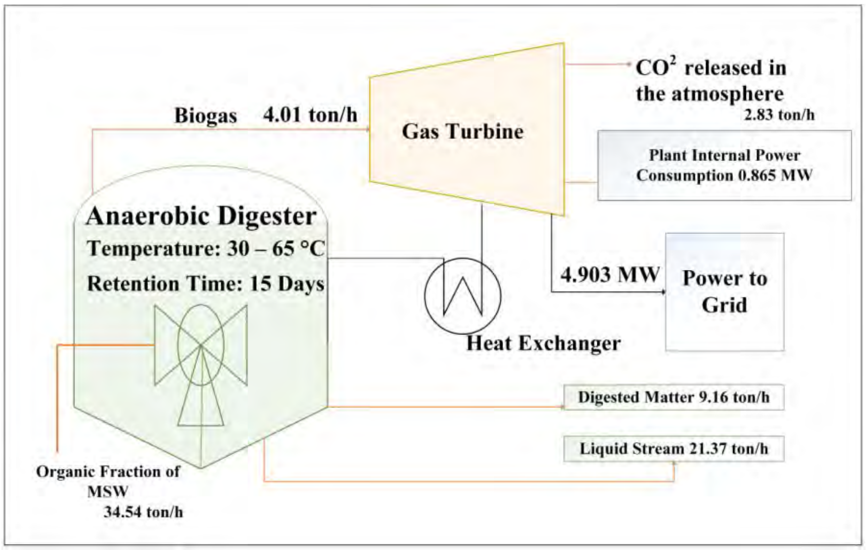

FIGURE 1
Process flow diagram of MSW biorefinery Scenario A

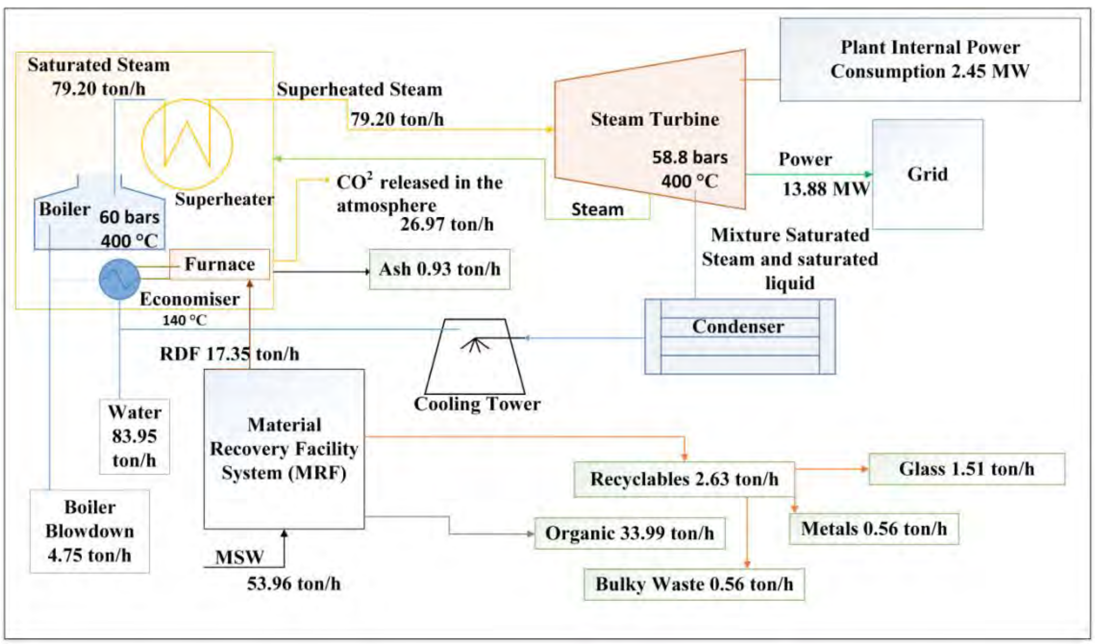

FIGURE 2
Process flow diagram of MSW biorefinery Scenario B

MW with the carbon release to the atmosphere and the ash produced being equal to 29.75 tCO_{2e}/h and 0.93 ton/h, respectively. Scenario C (b) is an improvement of scenario C (a) and processes 53.96 ton/h of MSW. In this scenario (Figure 4), the production of levulinic acid has been found to need 4.28 ton/h of organics from MSW, and hence 29.7 ton/h of organic materials will be here fed to the anaerobic digester as compared to the higher amounts processed in the previous scenarios. The net amount of power saleable to the grid system amounts to18.1 MW and with a carbon release of 29.4 tCO_{2e}/h and 0.93 ton ash/h produced. In this Scenario D, 53.96 ton/h of MSW has been processed in the biorefinery system (Figure 5). Here, the net amount of power which may be sold to the grid system amounted to 45.1 MW. The carbon released to the atmosphere has been estimated at 7.62 tCO_{2e}/h with an ash production of 3.76 ton/h.

LHV, power production and efficiency

The LHV values for the RDF and syngas have been estimated at 14.47 MJ/kg and 9.99 MJ/m^3, respectively. These values are in agreement with literature data where the

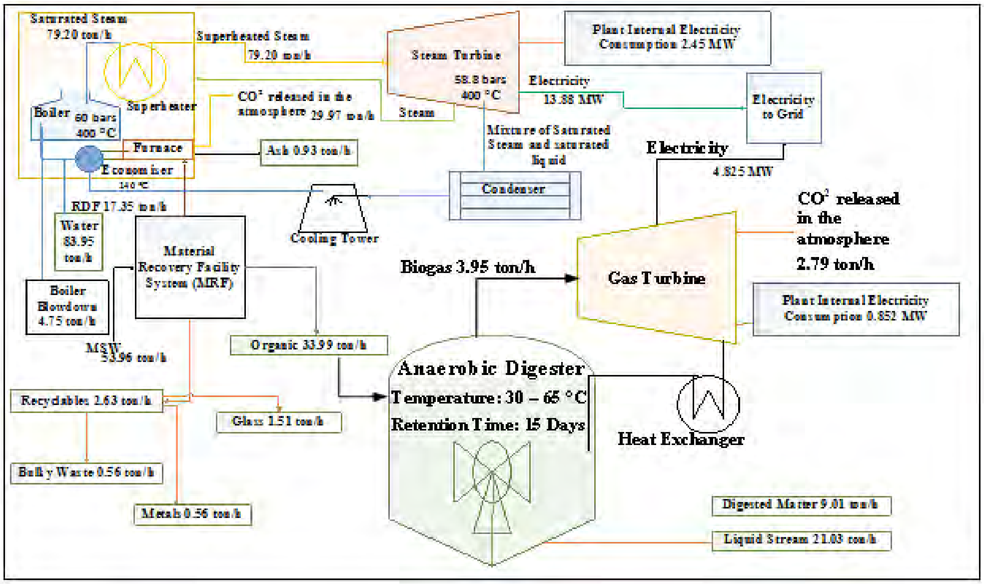

FIGURE 3
Process flow diagram of MSW biorefinery Scenario C(a)

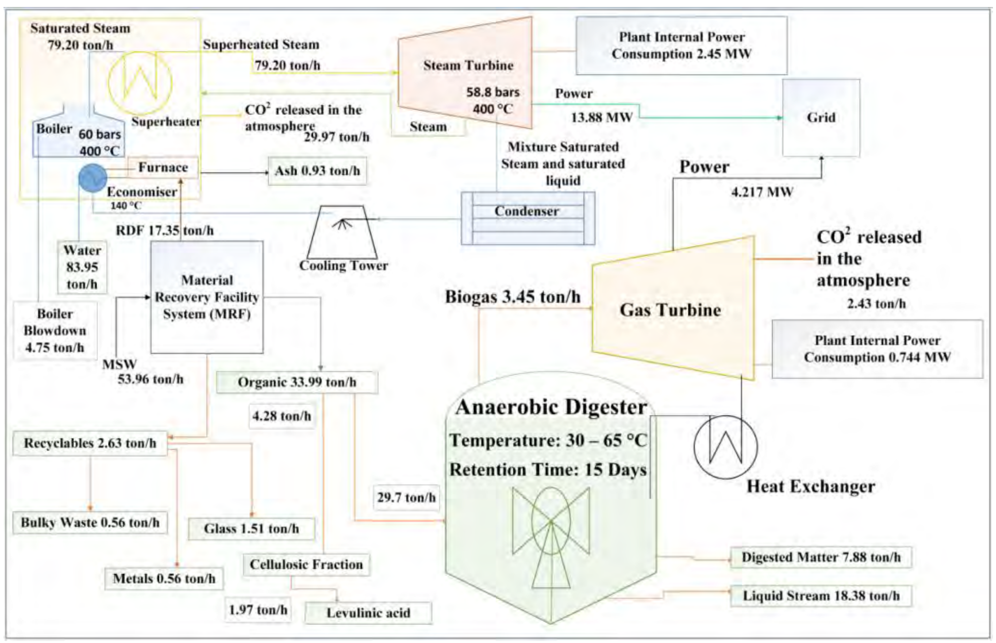

FIGURE 4
Process flow diagram of MSW biorefinery Scenario C(b)

LHV value of syngas has been reported at 9.7 MJ/m^3 by Shehzad et al., (2016) and that of RDF ranged between 10.7 and 24.18 MJ/kg (Materazzi et al., 2016). Figure 6 reports the total power generated, plant internal power consumption and net amount of power sold to the grid. In Scenario D, the gasification process has yielded the highest production of power at 53.05 MW due to high electrical power production efficiency. Scenario A is an anaerobic digestion process and has yielded the least amount of electrical power at 5.769 MW. Scenario C (b) is an improvement of scenario C (a) for more value added products; however, in doing so, the total power generation has been slightly decreased to 21.23 MW from 22 MW in scenario C (a). The electrical power production efficiencies ranged from 33% to 40% and are within the values reported by Distefano et al., (2009).

Economic analysis

From Table 3, the total capital investment and production cost increased for scenario A up to scenario D. This can be explained by the complexity of the unit operations and MSW

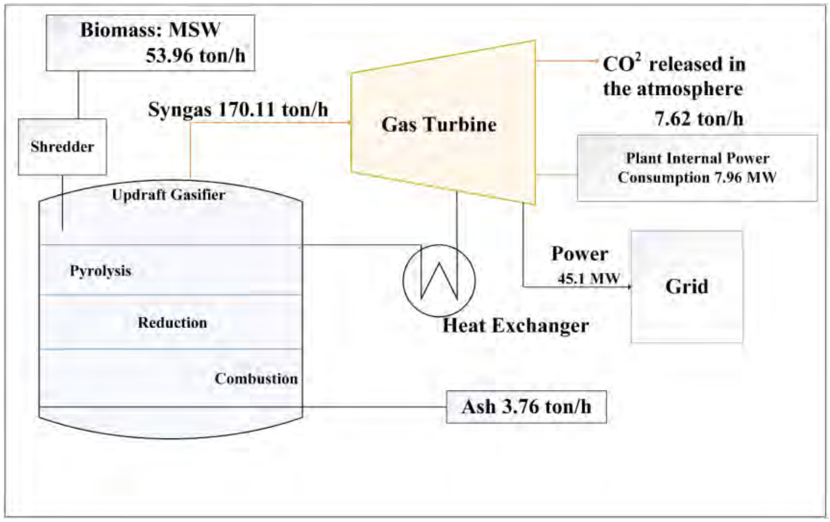

FIGURE 5
Process flow diagram of MSW biorefinery Scenario D

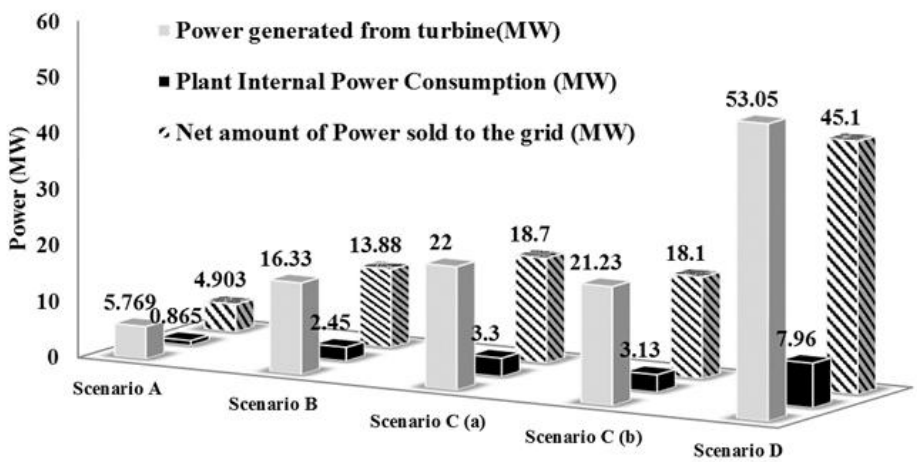

FIGURE 6
Power generation from MSW biomass for each scenario

handling processes moving from scenario A to scenario D. Anaerobic digestion processes are relatively simpler than gasification system which have more instrumentation and control systems associated with the heat control and heat recovery units. The MRF system and cogenerating unit in scenario C (a) and scenario C (b) explain the high capital investment of these two scenarios. The net income is highest from scenario C (b) which specifically is taking into account the production and sale of high-value products which are essentially levulinic acid and other useful products (Figure 4). The simple payback time ranged from 4.63 years for scenario B to 6.56 years for scenario D (Figure 7). The discounted payback time varied from 6.86 years for scenario C (b) to 12.11 years for scenario D. Scenario C (b) is seen to bring the highest internal rate of return of 24.56% while scenario A has given the lowest internal rate of return of 15.47%. According to Dolan et al., (2011) and Teghammar et al., (2014), an internal rate of return of 15% or greater is considered as being economically viable. Also, Dolan et al., (2011) specified that an IRR of 15 % enable firms/companies to recover their costs in raising the required financial resources and subsequently reap profit. As per Bankole and Robinson (2014), for a biorefinery processing municipal solid waste intended to produce high value products, the IRR can reach up to 27 %.

CONCLUSION

From this study, it is concluded that scenario C(b), which is based on a combination of anaerobic digestion of MSW, materials recovery facility system and production of levulinic acid, is the best choice for a MSW biorefinery. Hence, such a three-tiered biorefinery for co-mingled MSW promises a

TABLE 3
Capital investment and income estimates from the MSW biorefinery scenarios in million US dollars

Scenario	Total capital investment	Total product cost	Net income
A	25.4	1.02	3.94
B	57.5	2.34	12.4
C (a)	85.9	3.49	17.9
C (b)	114.6	5.43	24.7
D	184.3	7.42	28.1

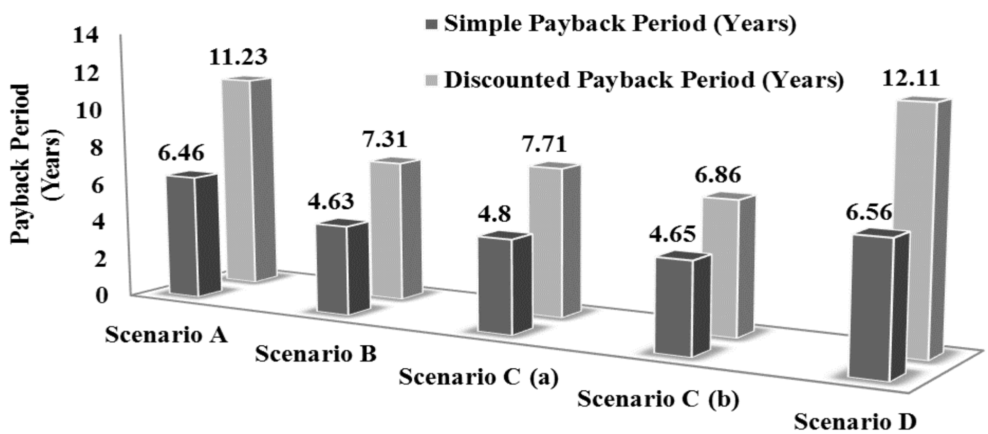

FIGURE 7
Payback times for MSW biorefinery scenarios

better technical and economic biorefinery performance in terms of power generation, quantity of digested organic matter, recovery of precious metals, glass and bulky wastes. As a future study, a detailed multivariate data analysis may be performed within a lifecycle framework to work out the optimum operational conditions of the scenario C(b) MSW biorefinery process configurations.

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IMPROVEMENT OF EXPANSIVE SOIL PROPERTIES USING SAWDUST

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ABSTRACT

This paper presents a study on using sawdust to improve properties of expansive soil. The swelling properties, unconfined compressive strength, shearing strength characteristics, and cyclic wetting-drying behavior of stabilized soil were studied. The optimum addition of sawdust was found to be 7.5%. The test results indicate that the swelling potential and swelling pressure decreases with the increased sawdust addition. The strength properties such as unconfined compressive strength, shearing strength, cohesion and friction angle increases with addition of sawdust up to an optimum value of about 7.5%, beyond which the strength properties begin to decrease. The unconfined compressive strength values increased with the increased curing period and the rate of strength gaining is initially higher and decreases after day 14. The cyclic wetting-drying tests show that the volume and cohesion of soil decrease with increased wetting-drying cycles while the friction angle values remained approximately constant. The addition of sawdust can effectively reduce the influence of drying and wetting cycles on the volumetric change and the shear strength parameters of soil.

Keywords: Sawdust; expansive soil; swelling properties; unconfined compressive strength; shearing strength; cyclic wetting-drying

INTRODUCTION

Expansive soils are characterized by considerable change in volume with change in water content, which often causes serious damages and distortion to structures founded on expansive soils, particularly light-weight buildings and pavements. One method to control the volumetric change is to stabilize expansive soils with admixtures that suppress the volumetric change. Stabilization of the expansive clay soil has been practiced over the last six decades with cementitious material such as cement and lime. The studies reported in the literature showed that the addition of lime increases the optimum water content, shrinkage limit and strength, and reduces the swelling potential, liquid limit, plasticity index and maximum dry density of the soil (Bell, 1996; Guneya et al.,2005). Cement stabilization is similar to that of lime and produces similar results (Rao et al., 1995; Ali et al., 2005). However, the increase in construction materials and the scarcity of raw materials motivated the researchers and planners to find waste materials or substitute materials that are environmentally friendly and economically sustainable. Industrial waste materials such as fly ash (Phanikumar et al., 2004; Kolias et al., 2005), cement kiln dust (Millier et al., 2000; Mohamed, 2002), steel slag (Ashango and Patra, 2016) and silica fume (Kalkan and Akbulut,2004; Goodarzi et al., 2016) are pozzolanic in nature and reduce the water absorption and bind the clay particles. Agricultural waste materials such as rice hush ash (Hajiali et al., 1992; Adrian, 2016), olive cake residue (Zalike and Salma,2006), hay fiber (Mohamed 2012), bagasse fiber and ash (Rajakumar et al., 2014; Dang et al., 2016; Hasan et al., 2016), and coir fiber (Jayasree et al., 2014) were also studied and applied to the modified expansive soils. The plant fibers are widely used when building with earthen materials. Generally, plant fibers can be most easily mixed with soil. The plant fibers serve to increase the tensile strength, reduce the density, and accelerate drying and reduce cracking by dispersing stresses. Since fibers vary in shape, size, strength, elasticity and their bond strength with earth, soil improvements with different types of fiber will vary, along with the amount of a particular fiber required.

Sawdust is a by-product of processing wood and is composed of fine particles of wood. The sawdust can be used to produce particleboard. But the most common use of sawdust is for fuel in China. This not only causes environmental pollution, but also hinders the sawdust from being fully utilized. This study evaluates the use of the sawdust as a soil stabilizer. Sawdust is cheap and easy to obtain. Due to its rough surface texture, sawdust can produce large friction that can effectively improve the strength of the soil. The main chemical components of sawdust are lignin and cellulose, which do not cause any negative environment impact. However, literature survey reveals that there are limited researches carried out on the stabilization of expansive soils using the sawdust. The swelling properties, unconfined compressive strength properties, shearing strength characteristics, and cyclic wetting-drying behavior of stabilized soil have been studied and discussed in this paper.

MATERIALS AND METHODS

Soil

The soil sample selected for this study was collected from the Nanjing Institute of Technology campus in Jiangning, South Nanjing. The soil was collected by open excavation, from a layer of 4 to 5 meters below the natural ground level. Laboratory tests were carried out to classify the soil. Particle size distributions of the studied soil are shown in Table 1. The gradation of soil reveals the percentage passing 0.075mm sieve is 97%. The physical properties of the natural soil are given in Table 2. The chemical compositions of the soil are presented in Table 3. The soil is classified as clay with high

TABLE 1
Grain size distribution of the natural soil

Grain size distribution (%)				*Cu*	*Cc*
>0.075mm	*0.075～0.005mm*	*0.005～0.002mm*	*<0.002mm*		
2.9	39.4	32.5	25.2	8	1.59

TABLE 2
Physical properties of the natural soil

Liquid limit Lw(%)	*Plastic limit Lp (%)*	*Plasticity index PI(%)*	*Optimum water content, W_{opt} (%)*	*Maximum dry density, d_{max}(g/cm^3)*	*Specific gravity, Gs*	*Free swell, FS (%)*
53.39	26.38	27.01	24.45	1.93	2.72	65

TABLE 3
Chemical composition of the soil

Chemical composition	*Quantity (%)*
SiO_2	58.1754
Al_2O_3	19.3295
Fe_2O_3	5.6402
CaO	4.5689
MgO	1.4056
K_2O	1.5534
TiO_2	0.7336
Na_2O	1.5348
P_2O_5	0.1197
MnO	0.0937
Loss on ignition	6.8452

plasticity (CH) according to the unified soil classification system (USCS). According to the chemical composition, the soil is identified as illite.

Sawdust

The sawdust used in this study was taken from the wood processing factory in Nanjing. Before the tests, the foreign objects were removed from the sawdust and only particles smaller than 1mm thin were retained. Then the sawdust was heated at 60℃ in the drying oven until a constant weight. The sawdust was added into the soil with different percentages: 2.5, 5, 7.5,10 and 12.5% by dry weight of the soil.

Swelling properties tests

To examine the essential swelling properties, the following tests were carried out: (i) Swelling potential test. (ii) Swelling pressure test.

Swelling potential has been used to describe the ability of soil to swell in terms of volumetric change and swelling pressure is equal to the pressure required to prevent swelling. Swell potential and swelling pressure of the treated soils were obtained according to the standard of ASTM D4546-14.

To start the swelling potential tests, compacted specimens in oedometer rings were placed in a consolidation cell between two air dried porous stones while a dial gauge was positioned on the cap of the cell to measure the displacement. The sample was then fully submerged in distilled water and allowed to swell as in the one-dimensional swell test. The soils were charged with 0, 25, 50, 100 and 200kPa vertical stress respectively. The reading of the dial gauge was recorded when the deformation is less than 0.01mm per hour. The volumetric change was measured in terms of the difference between the swollen and initial level, ΔH. The deformation data are expressed in terms of axial deformation ratio (ΔH / Hi) where Hi is the initial height of the specimen at the beginning of swelling.

In addition to the swell potential, the swelling pressure of specimens was estimated by using zero swell tests with a uniaxial compression apparatus. The preparation of the samples and the consolidation cell were the same as in the swell potential tests. The assembly was mounted on the loading frame so that the load is transmitted axially to the soil specimen through the connection rod. A stress of 1kPa was then applied vertically to the specimen. Immediately after the preloading step, the cell was flooded with distilled water. Upon addition of water to the cell, the specimen imbibed water and began to swell. Meanwhile, the specimen was gradually loaded in small increments gradually by means of the movable platen, to maintain the specimen's initial volume at a constant value. The adjustment was done at every 0.1mm of swell or earlier. The addition of load was continued until the deformation of the specimen could not be observed. The swelling pressure(pe) can be calculated as:

$$p_e = \frac{W \times m}{A} \quad (1)$$

Where W is the total load, m is the leverage ratio of pressure equipment and A is the cross-section area of the specimen.

Unconfined compressive strength tests

The unconfined compressive strength (UCS) was determined according to the standard of ASTM D2166 (ASTM 2006) for soil samples at a strain rate of 0.625mm/min. After mixing expansive soil with sawdust, untreated and treated soil specimens were shaped in a mould with a 40mm diameter and 80mm height, at the maximum dry density and the optimum moisture content. In order to ensure uniform compaction, the specimens were placed in three layers using the tamping technique to obtain the targeted dry density. The specimens were cured for different periods of 1, 7, 14 and 28 days. After curing these respective days, the specimens were set up in the conventional unconfined compression apparatus. The machine was set at a load rate of 0.1mm/min, and this was kept consistent for all samples tested. The loading process continued until the failure of the specimens occurred.

Direct shear tests

The direct shear test was carried out as described in ASTM D3080 standard procedures. The specimens were prepared with the maximum dry density and the optimum water content. A series of tests were carried out on the clayey samples under vertical normal stress of 100,200,300 and 400kPa, in order to obtain the values of shear strength and, finally, the values of cohesion and friction angle.

Cyclic wetting-drying tests

Wetting-drying cycle defines a process where a soil specimen is wetted and allowed to swell then dried to its initial water content at an ordinary condition, then wetted again to swell. In this study, the specimens were filled with tap water allowing it to fully swell until complete primary swelling is achieved. At this stage, the water was removed and the consolidation cell was dismantled. The specimens were then allowed to air-dry (at a room temperature, approximately 24?) to its initial water content. By saturating the specimens within the consolidation cell and drying it to the initial weight in an air-dry environment, a drying-wetting cycle was completed. Five cycles were repeated in this study. After each cycle, the volumetric change and the shear strength of specimens were measured and recorded.

RESULTS AND DISCUSSION

Swelling properties

Two swelling tests were carried out on each of the clay–

sawdust mixture. The first is the swelling potential test and the results of this test are presented in Figures 1 and 2. Figure 1 shows the effect of sawdust on the swelling potential of the soil without vertical stress. The swelling potential of the natural soil is 15.4%. The figure indicates that the swelling potential of the treated soils decrease as the percentage of sawdust added into the soil increases. With only 2.5% sawdust treatment, the swelling potential decreases by 20%. When the sawdust content is increased to 7.5%, the swelling potential decreased by approximately 39%. A sawdust content of more than 7.5% no longer produces a significant reduction in the swelling potential of the soil. This may be due to the replacement of a part of the soil by the sawdust and the subsequent reduction of the overall expansive of the soil. Additionally, after the inclusion of sawdust, soil particle and sawdust surface can be in close contact, the expansion force is offset by the friction force, limiting the expansion deformation of soil particles.

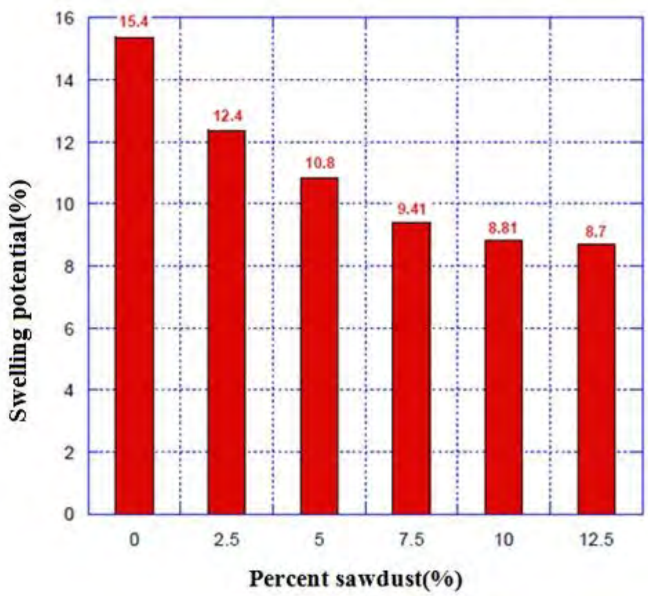

FIGURE 1
Effect of sawdust on the swelling potential of the soils

Figure 2 shows the effect of sawdust on the swelling potential of the soil with vertical stress. Based on these curves, it can be observed that the swelling potential decreases with increase in vertical stress for all specimens. This is a result of the overlying load, offsetting part of the internal forces of expansion, thereby inhibiting the expansion of soil. Under the same vertical stress, the swelling potential decreases with the increasing amount of sawdust. Because sawdust is compressed easily relative to the soil particles, when the overlying stress exceeds the expansion force into soil, the swelling potential value is negative, indicating that the soil sample is compressed. And the swelling potential is 0, namely that the expansion force is equal to the vertical stress.

The second test on the samples mixture is the swelling pressure test. Figure 3 shows the swelling pressure values of the natural and sawdust treated soils. The swelling pressure of the natural soil is 341KPa. The swelling pressure of the treated soil decreases continuously as the percentage of sawdust added into the soil increases. When the sawdust content is 12.5%, the swelling pressure reaches a minimum of 82.3kPa. This is because the sawdust isolates the soil particle, the transfer of internal force is attenuated on the sawdust particles, and sawdust particles and soil particles create friction with each other to offset the expansion force, thus the swell-

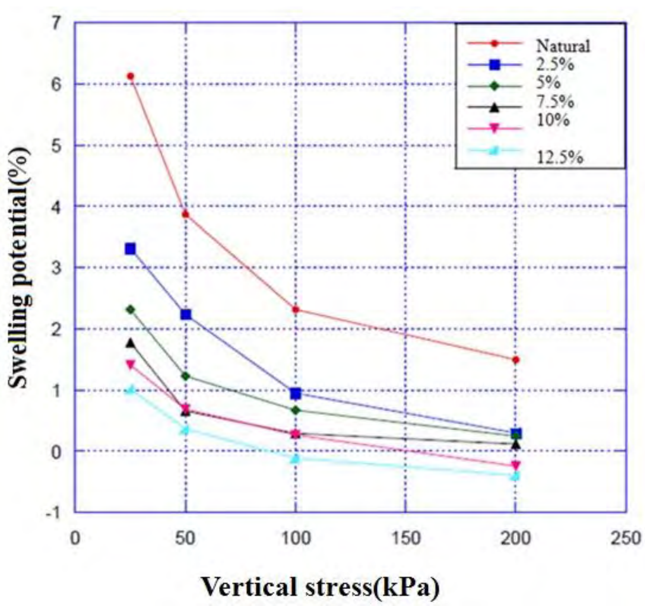

FIGURE 2
Effect of vertical stress on the swell potential of the soils

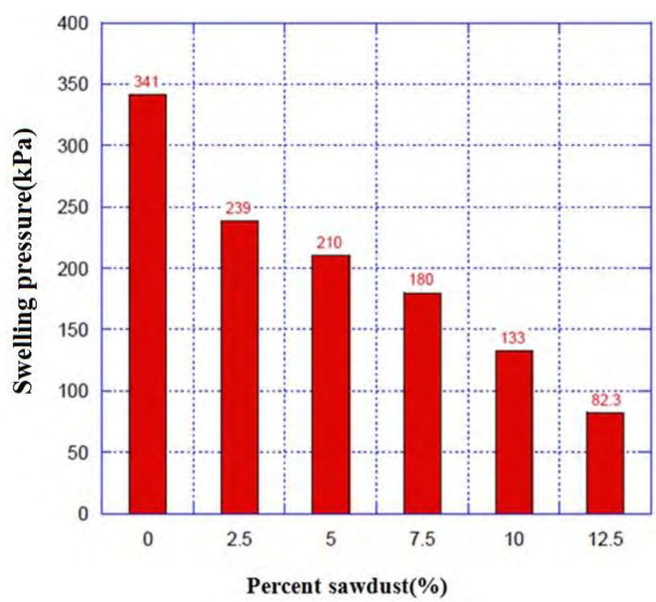

FIGURE 3
Effect of sawdust on the swelling pressure of the soils

ing pressure of soil is decreased.

Unconfined compressive strength

Effect of sawdust on the unconfined compressive strength of the soils is shown in Figures 4 and 5. Figure 4 illustrates the unconfined compressive strength diagram for different amounts of sawdust in the soil. The unconfined compressive strength increases when adding sawdust up to the content of 2.5-7.5%. However, the percentage of sawdust greater than 7.5% does not contribute to the strength while continuing adding additional sawdust gives a reduction in unconfined compressive strength. It seems that there is an optimum value of sawdust content (approximately 7.5%) for enhancing the unconfined compressive strength. The possible explanations are the rough surface of the sawdust, soil particles and sawdust particles can be a good combination, and sawdust can also package soil particles, which can form the interwoven and package structure of sawdust particles and soil particles. Under the vertical pressure, due to the protection of the double structure, the soil particles are difficult to move, and the strength of soil samples is improved obviously.

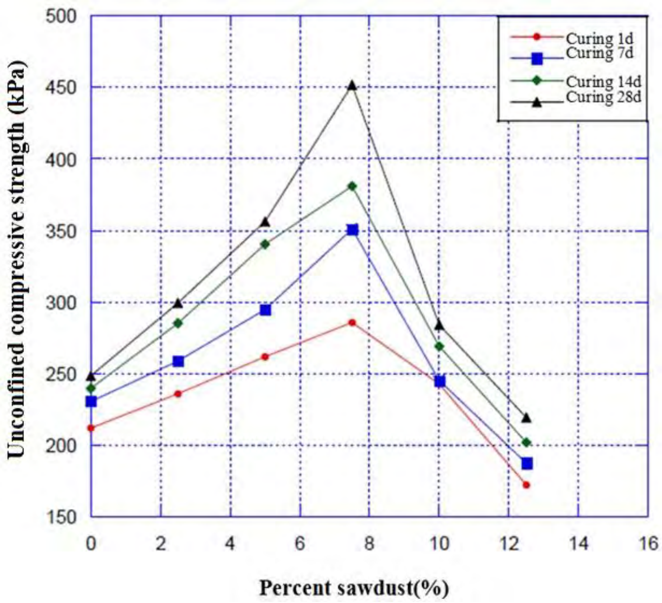

FIGURE 4
Effect of sawdust on the unconfined compressive strength

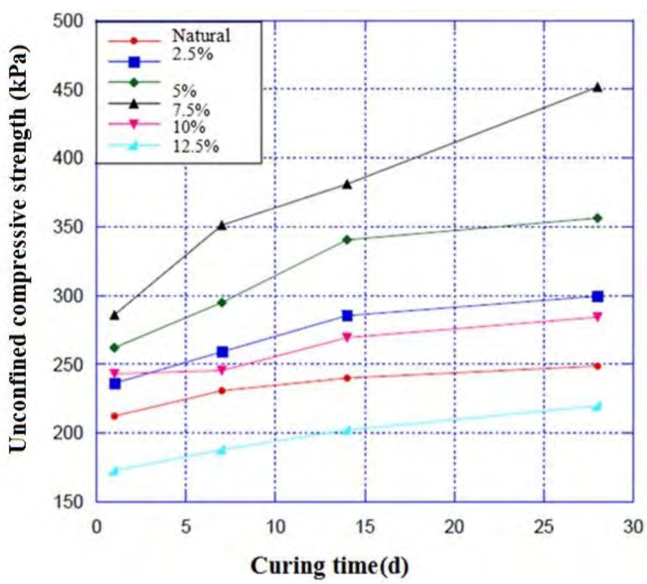

FIGURE 5
Effect of curing time on the unconfined compressive strength

The change in the unconfined compressive strength with an increase in curing time is shown in Figure 5. The strength increases rapidly at first, generally during the first 7 days of curing, then experiences a slower increase after 14 days of curing. For example, a 5% sawdust soil sample cured for 7 days develops an unconfined compressive strength of 297 kPa and sees an 15.5%-increase in the unconfined compressive strength compared with 1 day curing. And the strength of 28 days curing increases by 5.5% compared with that of 14 days curing. The possible explanations for this phenomenon are presented as follows: (1) It takes some time for the soil moisture to migrate to the sawdust particles after the mix of sawdust and expansive soil; (2) meanwhile the large amount of lignin and cellulose in the sawdust serve as surface active agents in soil-water system to generate the gel of high strength, which can improve the surface properties of soil particles, as well as to change the interaction and the bearing frame between soil particles, thereby significantly increasing the unconfined compressive strength. When the process of moisture migration and the physical and chemical reaction come to an end, the unconfined compressive strength increases slower.

Direct shear strength

Figure 6 shows the relation between the shear strength and the percent of sawdust under different vertical stress. In general, the addition of sawdust to the clayey soil increases the shear strength of the soil. The shear strength increases with the increase in the normal stress on the samples. The best ratio of the sawdust addition seems 7.5%. The increase in the shear strength is attributed to the interwoven and package structure of sawdust particles and soil particles which we mentioned above. Under the joint action of the interwoven and package structure, sawdust can play a good role in its reinforcing effect, which is not only from the friction and interlock force between the sawdust particles and soil particles, but also from the constraint of the spatial network formed by the sawdust particle in the soil.

Figures 7 and 8 show the values of cohesion and friction angle at different percentages of sawdust respectively. A general pattern is observed that the values of cohesion and friction angle develop rapidly with addition of sawdust before an optimum is reached, beyond which the values begin to decrease. When the content of sawdust is 7.5%, the cohesion

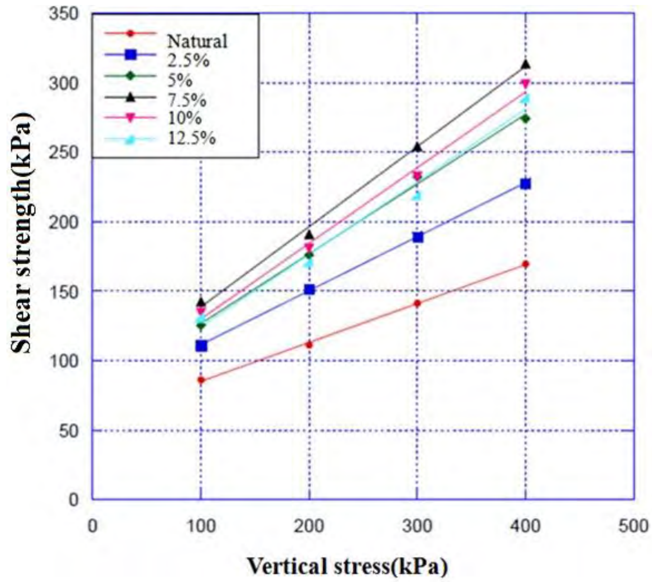

FIGURE 6
Effect of sawdust on the shear strength under different vertical normal stress

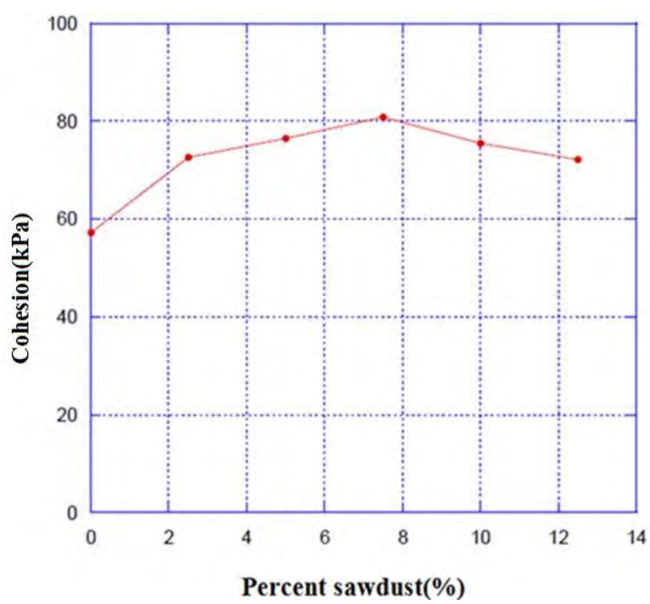

FIGURE 7
Effect of sawdust on the cohesion of the soils

and internal friction angle reach the maximum value. The change of the friction angle with sawdust content can be due to the package structure of sawdust particles and soil particles, which can prevent the movement of soil particles and increase the frictional force of the soil, that is, the friction angle becomes larger. But when the sawdust content continues to increase, sawdust improves the pore porosity ratio to provide a convenient channel for the movement of soil particles, leading to a decrease in both the friction force and the friction angle. There may be two main reasons for the change

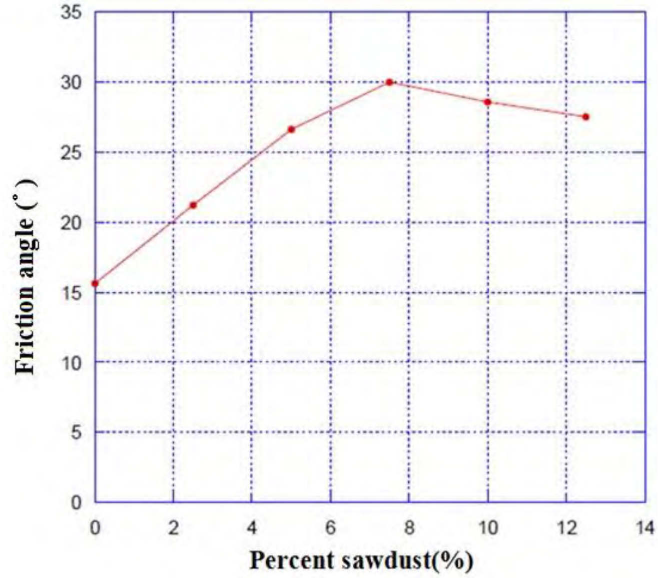

FIGURE 8
Effect of sawdust on the frictional force of the soils

of the cohesion. On the one hand, the large amount of lignin and cellulose in the sawdust serve as surface active agents in soil-water system to generate the gel of high strength, which can increase the cohesion of soil. On the other hand, due to the interwoven structure of sawdust particles and soil particles, the sawdust particles and soil particles can be well bonded together when the amount of sawdust is less. When the sample is sheared, the tensile stress is generated between the sawdust particles and soil particles which prevent soil shear failure and increase the soil cohesion. With the increase of sawdust content, however, sawdust particles overlap each other to form a weak surface that destroys the soil structure, thus reducing the original selfweight and cohesion of the soil.

Cyclic wetting-drying behavior

The effects of cyclic wetting-drying on the volumetric change and shear strength parameters of specimens have been researched in this study. Figure 9 shows relation between the volume change and the wetting-drying cycles. It can be seen that the volume of samples, both treated and untreated, decreases with increasing wetting-drying cycles. The most reduction of the volume of samples is recorded within the first 3 cycles of wetting and drying. And with the increase of wetting-drying cycles, the tendency of reduction of the volume gradually became small. It is observed that the effects of wetting-drying cycles on the volumetric change depend on the amount of sawdust in the stabilized soil samples. After the same times of wetting-drying cycle, it has been observed that the change the volume of samples decrease with increasing sawdust content. The decrease in the volume of samples is attributed to a gradual destruction of the matrix of the clay structure brought by the cyclic swelling process. And after drying, the cracks develop, so the samples show a shrinking

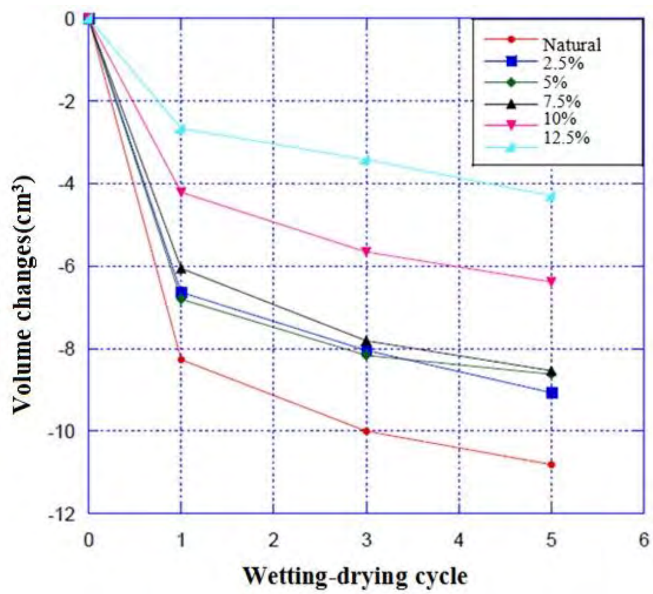

FIGURE 9
Effect of cyclic wetting-drying on the volume changes of the soils

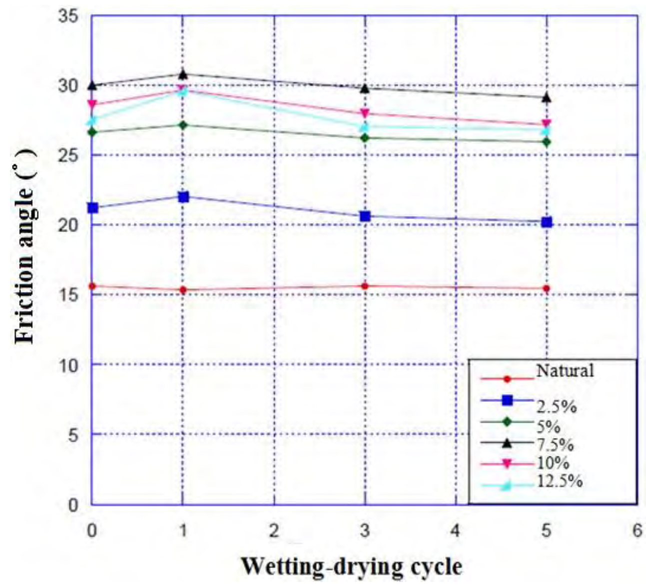

FIGURE 11
Effect of cyclic wetting-drying on the friction angle of the soil

tendency. The addition of sawdust makes the wedging effect of combined water film become weak, and the soil swell-shrink property become low, so the volume deformation decreases.

The effects of cyclic wetting-drying on the cohesion and friction angle values of soil samples are presented in Figures 10 and 11. It can be seen that the cohesion of soil decrease with increasing number of wetting-drying cycles, and the friction angle values remain almost constant. The cohesion of the sawdust treated soil is obviously higher than that of the natural soil, and with the increase of wetting-drying cycles, the increase of cohesion is more obvious. In general, when the sawdust percent is 7.5%, the values of shear strength parameters reach the maximum. It can be found in Figures 10, when the sawdust percentage is 10%, the cohesion of sample is 80.025kPa after the first time of wetting-drying cycle, which is higher than the cohesion(75.45kPa) of sample without wetting-drying cycle. The reason for this situation may be that the sample surface and internal produce many fractures under the action of wetting-drying cycles, when the shear surface and fracture surface overlap, the performance of shear strength is reduced, when the shear surface and fracture surface are perpendicular to each other, or the crack is not developed, the shear strength could show the peak value. The degree of fracture development is low after the first time of wetting-drying cycle, so there will be local data increased.

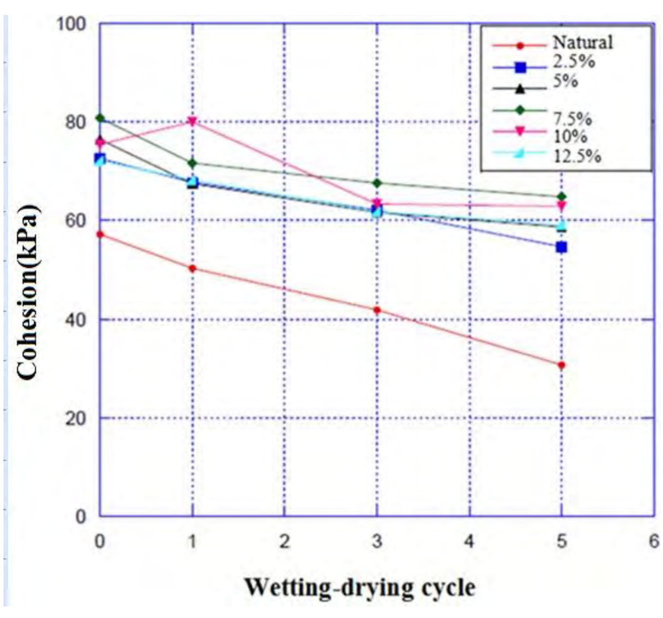

FIGURE 10
Effect of cyclic wetting-drying on the cohesion of the soils

CONCLUSIONS

Based on the experimental study of the stabilization of expansive soil using sawdust, the following conclusions can be drawn:

1. The swelling potential and swelling pressure of the samples reduce with the increase in sawdust addition, but when the adding amount is larger than 7.5%, this decreasing trend is minor.
2. The unconfined compressive strength and shear strength significantly increase after the sawdust was added in the soil, and reach the peak at 7.5% of the sawdust addition.
3. The unconfined compressive strength values increases with a longer curing period and the rate of strength gaining is initially higher and decreases after day 14.

4. The values of cohesion and friction angle increase with addition of sawdust before an optimum is reached, beyond which the values begin to decrease. When the content of sawdust is 7.5%, the cohesion and internal friction angle reach the maximum value.
5. After the cyclic wetting-drying, the samples generated irreversible volumetric deformation manifested as shrinkage. With the increasing number of wetting-drying cycles, the shrinkage deformation gradually stabilizes, and the volume deformation quantity decreases with the increasing sawdust addition.
6. The cohesion of soil decreases with increasing number of wetting-drying cycles, and the friction angle values remained almost constant. And after the cyclic wetting-drying the cohesion and friction angle of the sawdust improved expansive soil is still higher than that of natural soil. When the sawdust percent is 7.5%, the shear strength parameters reach the maximum.

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ANALYSIS OF HOUSEHOLD FOOD WASTE REDUCTION TOWARDS SUSTAINABLE FOOD WASTE MANAGEMENT IN MALAYSIA

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ABSTRACT

Food wastes generations have continued to increase in recent years in Malaysia. According to the Ministry of Housing and Local Government (MHLG), food wastes have outstripped other solid wastes generated in Malaysia, constituting more than 40 percent of the total wastes disposed in 2010. From the MHLG data, food wastes disposed from households were more than other sources. Its existence in the wastes stream can always contaminate and complicate any effort to recover and recycle other dry wastes. Furthermore, the environmental impacts are enormous, including depletion of water sources, cause climate change, and affects human health when disposed at unsanitary landfills, and as well food security. Therefore, the study aims to investigate the current status of food wastes in Malaysia towards sustainable food waste management. Purposive non-random sampling method was applied to collect primary data through structured questionnaire from 333 respondents, 257 respondents were from Selangor, a developed state, and 76 from Terengganu, an underdeveloped state. To achieve the aims and objectives of this study, a statistical analysis with Structural Equation Model (SEM) was applied. Findings showed these variables: government policies on households' food waste management, environmental knowledge, households' environmental awareness, reducing food waste generation with food waste hierarchy have significant impacts towards reduction of food waste generation to achieving sustainable food waste management at households' levels. The implication of the findings leads to the conclusion that sustainable food wastes management is not only about behavioural issues, but rather policies and regulations issues. It is suggested that government should have strong and important roles to play by formulating households' food wastes policies, and provisions of infrastructural facilities that could lead to reducing food wastes at households, and at the same time creating awareness of the negative impacts of food wastes on the natural environment and to the economy as well. This could definitely lead to change of behaviours by households towards the issues of food wastes reduction.

Keywords: Sustainable food waste management, food waste generation, food waste, households and behaviour

INTRODUCTION

Food waste is a general phenomenon in many affluent societies or countries. But the irony of it all is that while many have much to waste, there are millions out there who can't afford such to put on their tables. Global food wastes are on the increase as thousands tonnes of food wastes are dumped daily at unsanitary landfills. Of most concern to many stakeholders in this issue is the impact food wastes have on the generation of greenhouse gas emissions, methane and carbon dioxide. However, there are also growing concerns about the economic and environmental viability of existing food waste disposal systems, as well as interest in food waste as a resource input to agriculture (DSEWPaC, 2011). This wastage constitutes nuisance to the environment and as well endangers the wellbeing of those living near the unsanitary landfills which accommodate all kinds of wasted foods, most often times not properly managed (Jereme, et al., 2013).

The study by Gustavsson et al. (2011) for FAO found that each consumer in Europe and North-America wastes up to 95-115 kg/year, which is worth some $38.3 billion, while for Sub-Saharan Africa and South/Southeast Asia this figure is only 6-11 kg/year. On the other hand, Australians waste $6 billion of foods each year; these quantities of food wastes could be enough to feed the entire nation for three weeks according to the study. The Japanese threw away one-fourth of available foods in Japan ((MOE, Japan 2008). In Lagos state alone in Nigeria, Sub West Africa, wasted foods accounts for 40 percent of the available foods and estimated at $187 million annually due to improper packaging and poor transportation system (Nigeria Vanguard Friday, June 20, 2014). What this implies is that the whole efforts put in place to produce these wasted foods were all in vain, and also the energy consumption and water used with its environmental impacts, such as greenhouse gas emission. On per-capita (per consumer) basis, more foods are wasted in the industrialized world than in developing countries.

In Malaysia, the story is not different; the economic booms in the last two decades have drastically improved the living standards of the people. As a result of this, many have become affluent; as such food wastes are now an issue to the local authorities. Households and business outlets like hotels, restaurants, and resorts are left with large quantities of foods after daily business activities, such as during wedding parties, conferences, banquets and such like. Malaysians are throwing away up to 930 tonnes of unconsumed foods daily. This is equivalent to throwing away 93,000, 10kg bags of rice each day (Aruna, 2011). Therefore, it could be right to say that Malaysians do not have food shortage problem, but rather food wastes problem. This is because according to (MHLG-MOEJ Collaboration Project, 2011) the issue of treatment of food wastes generated in Malaysia could still be said to be extremely low till today, like composting or even for animal feeds. With this situation, almost all the food wastes generated in Malaysia from different sources such as households, commercial activities (e.g., restaurants, food courts and supermarkets) beverages industries are disposed of to landfills, Jereme et al. (2015), which is the traditional disposal system for long time due to the availability of vast disposal lands. This is because landfill is the most common disposal method for developing and even developed countries, due to the fact that it is simple to manage and economical as well (Khairuddin, et al. 2015). However, it is most often not properly controlled, and is always illegally occupied by thousands of low income earners who live in squatters around the areas (Ramer et al. 2015). Moreover, wastage of unconsumed foods alone in Malaysia has doubled over the past three years; this does not even include leftover foods. The unconsumed foods mostly consist of expired bread, eggs and old or rotten fruits. For example, food waste is becoming a growing trend so that almost 50% of the 31,000 tonnes of the solid wastes produced daily by Malaysians comprised organic kitchen wastes, such as leftover foods (Chuah, 2011). Figures 1 and 2 show pictures of a man taking more foods than he could consume, and edible food wastes disposed into a waste bin which has become the behaviour of many households and foods outlets.

Different studies at both local and international level have been trying to identify factors that likely influence households' food wastes behaviour, and factors to reduce it towards sustainable food waste management. This study is part of the efforts to reduce households' food waste disposal in Malaysia as food wastes are increasing daily. Its problems cut across environment, high cost of wastes disposal by local authori-

FIGURE 1. A Man Eating up a Storm

FIGURE 2. Edible Food thrown into Waste Bin

ties, methane emission and food security. Table 1 is the current municipal solid waste compositions in Malaysia with households' food waste constituting highest generation for each year. Therefore, the study focuses on households' food waste with these objectives, (1) To investigate household food wastes generation, (2) To assess households' awareness level on environmental effects of food waste, and to determine the factors affecting consumption and disposal behaviour towards food waste reduction, (3) To evaluate households' opinion regarding the food wastes reduction policy in Malaysia.

Conceptual Framework Model of Reducing Food Waste Generations towards Sustainable Food Waste Management

In this section the conceptual framework model has been developed to identity factors influencing food wastes generation behaviour at households, and the likely strategic factors to influence positive food waste reduction behaviour are discussed. These variables are; eating behaviour, cooking behaviour, lack of food waste separation and composting behaviour, and strategies to reduce food wastes. These are, environmental awareness, households' environmental knowledge, and government food waste policy towards households' wastes reduction, and food waste generation in the framework have been found to be important in this study, are based on reviewed literatures. These variables, households' environmental awareness, households' environmental knowledge, and government food waste policy towards food wastes reductions were included in the framework as their impact to reduce households' food wastes in Malaysia has not been assessed in past studies.

In this regard, in explaining the conceptual framework model, behaviours like, eating, cooking and shopping behav-

Table 1. Food waste generated in Malaysia

Estimated food waste generated in Malaysia			
	Generation rate		
Sources of food	(tonnes/day)	(tonnes/year)	percent
Households	8,745	3,192,404	38.32
Wet and night markets	5,592	2,040,929	24.50
Food courts/restaurants	5,319	1,941,608	23.35
Hotels	1,568	572,284	6.87
Food & beverages industries	854	311,564	3.41
Shopping malls	298	108,678	1.30
Hypermarkets	291	106,288	1.28
Institutions	55	26,962	0.32
Schools	45	21,808	0.30
Fast food/chain shops	25	21,808	0.26
Total	**22,793**	**8,331,589**	**100**

Source: Ministry of Housing and Local Government (MHLG) 2011

Figure 3 Conceptual framework model

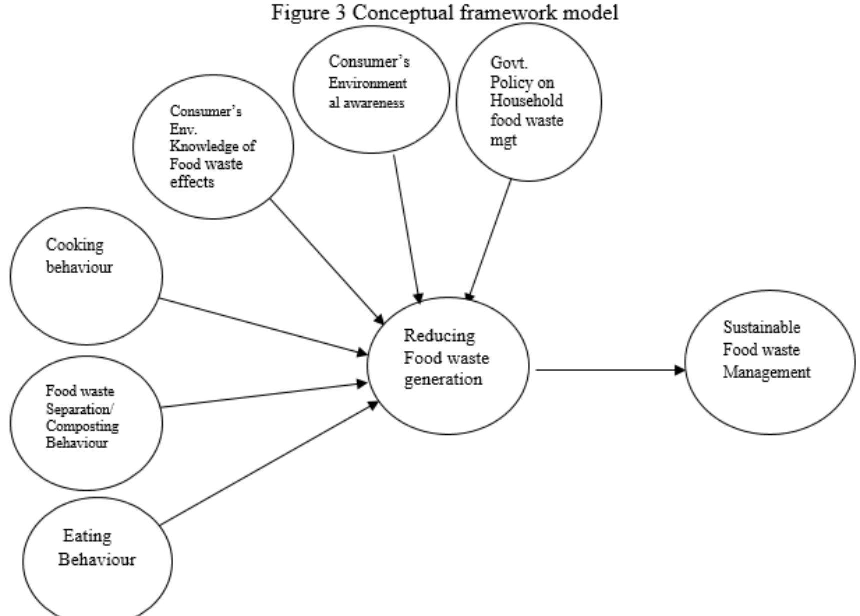

FIGURE 3.2 Conceptual Framework Model of the Study

ior and lack of food wastes separation and composting, contribute and influence food waste generation more than other sources at households (Brook, 2007; Exodus Market Research, 2007). This is because according to European Commission (2011), it is very explicit that the main causes of food wastes generation at households were due to behaviours and attitude of households. This is very evident from past studies that food waste is a household's issue that comes as a result of consumption and disposal behaviour. Households' food consumption life styles have led to high food wastes generation of edible foods wasted and unconsumed. Food consumption and disposal behaviour may be different across cultures, depending on consumption patterns which need deeper investigation with demographic factors to understand this behaviour (Stefan et al., 2013). This is because what is food in a society could become waste in a different cultural setting. Quite good number of literatures have suggested that households' efforts to control food wastes behaviours will not be possible if these predictive variables that lead to positive food waste behaviour are lacking at households: environmental awareness, households' environmental knowledge, and government food waste reduction policy (Barr, 2007; Kilbourne & Pickett, 2008: Hamilton et al. 2005). This necessitates the inclusions of these variables in this study to assess their predictive power to influence households' food waste reduction behaviour in Malaysia.

Households' that have no environmental knowledge lack environmental awareness with regards to the effects of food wastes on the environment. Studies on environmental knowledge and behaviour suggest that knowledge about the specific of waste was more closely related to practicing sustainable food waste behaviour (Oskamp et al.1991). Therefore, possession of knowledge on food waste effects may be an important variable for recycling behaviour to be exhibited. With this in mind, when individual household understands that one has significant and important role to play towards the environment, this instincts believe will always influence his or her behaviour towards positive action in their consumption behaviour. Therefore, with these facts a conceptual framework model was developed based on reviewed literature to understand the relationship of household food waste behaviour towards sustainable food waste management with these hypotheses;

1. Food waste separation and composting behaviour has significant effect towards
2. reduction of food waste generation
3. Lack of good cooking skills has effect towards increasing food waste generation
4. Environmental knowledge has significant effect on reducing food waste generation towards sustainable food waste management at households' levels.
5. Bad eating behavior has significant effect to increase food waste generation
6. Consumers' awareness of food waste effects on the environment has significant effect
7. towards reducing food waste generation leading to sustainable food waste management
8. Government Policy on food waste management will have significant effect to reduce food waste generation towards achieving sustainable food waste management
9. Reducing food waste generation through food waste hierarchy will have significant effect towards achieving sustainable food waste management

Methodology

The study was conducted in Selangor and Terengganu with 333 respondents, one respondent represented each household. 257 were from Selangor, and 76 from Terengganu applying purposive non-random sampling. This type of sampling method is used when the researcher wants to highlight specific subgroups within the population, possessing major characteristics of population of interest, such as in this case must be those within the age bracket of 18 years and above, and "must be cooking at home at least once in a day or a week." Those households who do not cook at home were excluded as they are unlikely to generate food wastes from cooking and shopping activities.

In choosing the sampling size for the study, some criteria were put into consideration, Kline (2005) considers sample sizes less than 100 not feasible if the researchers intend to use Structural Equation Model (SEM) as it is in this case. Similarly, Hoyle (1995) in his opinion recommended sample size from 100-200, while Kelloway (1998) recommends 200 observations for this type of study. Therefore, based on this justification, the sample size used is considered appropriate for this study with the application of Structural Equation Method (SEM).

Developing the Instruments

The questionnaires were structured with multiple choices anchored at the end with strongly disagree, disagree, agree and strongly agree. There were 8 constructs in this study which was developed for the model with multiple items relevant to the constructs in the study. Based on literatures, the constructs were namely, food waste separation and composting behaviour, cooking behaviour, eating behaviour, reducing food waste generation, consumers' knowledge of food waste effects, consumers' environmental awareness, government food waste policy and sustainable food waste management. Some of these items were self-developed questions and pre tested to make sure it has good reliability and validity (Stone, 1978), while some were partially adopted from existing food waste management and food consumption behaviours studies with modifications to achieve the aim and objectives of the study relevant to each specific construct.

Statistical Analysis

The data analyses for the demographic characteristics of the respondents were analyzed with SPSS version 22.0.1 Inc, Chicago, IL, 2013. From the survey, the results show 33.3% of the respondents were men, while 67.7% are women. On ethnicity level, out of these respondents the Melayu were 64.9%, Chinese 22.8%, Indians 7.2% and the rest of other respondents were 5.1%. Those who are married among the respondents were 59.2%, single 30.5% and others 3% respectively.

Results and Discussion

Cronbach Alpha values and the composite reliability of each constructs have reliable values. All the eight individual constructs in the model were assessed for construct validity and model fitness prior to being included in the overall measurement and Structural Equation Model (SEM).

Data analysis of the variables proceeded after checking of missing data. Exclude cases pairwise option was applied, which exclude the case (person) if only they are missing the data for a specified required analysis but will still be included for any other further analysis which they have the required necessary data (Pallant, 2011). However, there was no such case as all data information was adequately supplied due to the method of questionnaire administration. This is important in order to understand the characteristics of the data set (Hair et al., 1998). Therefore, the skewness and kurtosis of each variable were simultaneously analyzed to ensure that each of the variables included in the study meets the assumption of normality before SEM analyses. This was done through descriptive analysis for the independent and independent variables, (endogenous and exogenous). Following the recommendation of Kline, (2011), the statistical values of skewness was within the required threshold points of not more than -3 to +3 and kurtosis also was below -10 and +10 of acceptable range. Therefore, all the variables were within the acceptable range.

Prior to assessing with Confirmatory Factor Analysis (CFA) for each individual measurement model after data screening, Exploratory Factor Analysis (EFA) was performed. Items on attitude and behaviours from literatures that leads to household food waste generation, reduction and sustainable food wastes behaviour at households were subjected to EFA and factor analyzed with SPSS version 22 applying Principal axis Factoring prior to measurement model and Structural Equation Model (SEM). With Principal Axis Factoring all the valid items extracted were summarized into small number of reliable common factors which might explain or reveal the most important information on attitude and behaviour of food waste generation. The number of factors retained was guided by Kaiser's criterion of eigenvalues above 1 with KMO and Bartlett's Test showing sample adequacy and as well significant (Kaiser, 1960). Following eigenvalues above 1, eight common factors were adequately extracted to explain the measures and were named; reducing food waste generation, separation and composting behaviour, cooking behaviour, eating behaviour, food waste generation, consumers' knowledge of food waste effects, consumers' environmental awareness, government food waste policy and sustainable food waste management. What this implied was that the factors named were able to explain the variance like any other of the underlying item (Iacobucci 1994). In that process, measurement items with factor loadings from .30 and above according to Hair, et al (1998): Harrington (2009); Gaskin (2012) were extracted to reliably contribute to the factor and was initially included for the analysis of Confirmatory Factor Analysis (CFA) prior to the later stage of the Structural Equation Model. These common factors were further assessed in the following section in the measurement development for unidimensionality. Moreover, Raubenheimer, (2004) in Patricia de, et al., (2013) also recommended items from .25 to be acceptable factor loadings for CFA prior to SEM for exploratory study as it is in this case.

During the assessments of the measurement model fitness for the data, all constructs achieved recommended fit indexes level according to Schumacker and Lomax, (1996) IFI, TLI, CFI were all above .90, CIMN/DF was below <5.00 and RMSEA <.07. These individual measurement models assessments involved all the independent and dependable variables (exogenous and endogenous). In the exercise to achieve model fitness for the data, some items were deleted as indicated by the modification indices to improve model fitness as recommended by literatures (Harrington, 2009: Kline 2011: Zainudin, 2013). The overall results of the entire measurement models before they were included in the Structural Model to assess the significant impact of the latent variables achieved the recommended fits indexes close to .90 or above. In all, out of the forty five initial items subjected to CFA, forty were retained and five was deleted in the process of measurement refinement for the final measurement model.

Table 2. **The Overall Measurement Model Fitness Indexes for the Eight Constructs**

Model fit indices	The Overall Measurement Model Fit Indexes	
	Initial (40 Items)	Final (29 items)
(X^2/df)	1558.989 (713)	**547.914 (343)**
CMIN	2.187	**1.597**
IFI	.830	**.926**
TLI	.821	**.910**
CFI	.847	**.924**
GFI	.837	.901
AGFI	.807	.874
RMSEA	.060	**.042**

Table 2 is the overall measurement model results fit indexes.

With the overall measurement model assessed and a better fitting model achieved. The following section of the study assessed the proposed initial Structural Model (SEM) by using the retained and reliable 29 valid items. However, before the assessment of the initial proposed structural model, a comparison was made between the initial Structural Model (SEM) and the overall measurement model which of the two have a better model fit indexes good for the data and report the hypothesized paths in the structural model.

Testing the Initial Proposed Structural Model (SEM)

In this process, therefore, the hypothesized proposed Structural Equation Model was imposed on the overall measurement model to assess its significant values on the hypothesized paths. With this the researcher could make valid decisions based on their usefulness towards understanding the relationships and causal effects of cooking behaviour, eating behaviour, disposal behaviour on food waste generation and consumers' environmental knowledge, consumers' environmental awareness and government policy on reducing food waste generation. What this implies is that the full structural model was tested with all the remaining indicators and the latent variables (constructs) from the overall measurement model to assess final fitness of the proposed SEM. During this exercise, the initial results of the proposed SEM changed from the final results of the overall measurement model. The results are presented in Table 3.

The results of the initial proposed structural model show some differences with the overall results of measurement model. The joint criteria of model comparison of IFI, TLI, CFI, GFI, and AGFI were lower than the final results of the overall measurement model. However, with some re-specification as indicated by modifications indices, the final results of the structural model achieved acceptable level above .90 for all the fitness indexes, and revealed five (5) paths among the latent factors to be statistically significant. These significant paths were government food waste policy, consumers' environmental knowledge of food waste effects, consumers' environmental awareness and reducing food waste generation. The significant pathway on these latent factors reflected positive effects with these variables towards reduction of food waste generation (FWG) at households in Malaysia. Significant paths were set at $p<0.05$ and $p<.0.10$ levels respectively. The significant path coefficient indicates the level of strength of relationships between the latent constructs. When the path coefficient of latent factors is higher, it is an indication of stronger effect the casual factor has on the dependent variable in the model. Table 3 show results of the proposed SEM model and the overall measurement model compared.

After the initial assessment of the proposed SEM model, in other to improve the initial proposed SEM model to achieve a more acceptable model fitness, modification indices shows that some cross-loading items on SFWM, CEAWAR, ENKN, and COKBHV with large MI are to be deleted. In that regard, following the usual procedure, these items were removed and the SEM model was rerun. The deletion of these items resulted to a better fitting model as the X^2 difference reduced substantially. The joint criteria model indexes improved to a better acceptable level. However, one of the significant pathways of the latent factors was reduced. Table 4 is the final results of the modified proposed structural model.

After the model was re-specified to achieve acceptable fitness level for the data, the results of the modified final proposed SEM model showed slight improvement than the initial proposed SEM model. The joint criteria model comparison of IFI, TLI and CFI increased in value better than the initial proposed SEM model. Though, RMSEA decreased slightly from .045 to .047 as well the CMIN/DF but still within the level accepted to indicate good fitting structural model. The significant paths in the final SEM were four paths, less by one path from the initial proposed SEM model results, though power estimate were very close. However, the final modified SEM model seems to have a better model fits for the data, though with lower numbers of significant paths explaining the causal relationships effects towards the dependable varia-

Table 3 **Results of Tested Proposed SEM with Comparison fit indexes**

Model fitness level	The Overall Model Fitness						
	Model fit		The Model comparison				
Measurement fit	CMIN/F	RMSEA	IFI	TLI	CFI	GFI	AGFI
Acceptable fit levels	<5	<.010	Close to .90	Close to .90	Close to .90	Close to .90	>.90
Overall Measurement model results	1.597	.042	.926	.910	.924	.901	.872
Proposed Model SEM results	**1.706**	**.045**	**906**	**890**	**904**	.873	.846
Proposed Model (SEM) X^2 (df)	885.310 (519)						
Overall Measurement Model X^2 (df)	547.914 (343)						

Table 4 Final Results of Modified SEM with Comparison Fitness Indexes

Model fit level	The Overall Model Fitness						
	Model fits		The Model comparison				
Measurement fit	CMIN/DF	RMSEA	IFI	TLI	CFI	GFI	AGFI
Acceptable fit levels	<5.00	<.010	Close to .90	Close to .90	Close to .90	Close to .90	>.90
Modified Model results (SEM	1.730	.047	.915	.898	.913	.896	.868
Modified final model (SEM) X^2 (df)	557.116 (322)						

bles (endogenous). The full schematic figure of the final SEM is shown in Figure 4.

Comparison of the Initial Proposed Model (SEM) with the Final Modified Structural Model (SEM)

In examining the fitness level and model comparison of the hypothesized structural model, and as well the relationships of the latent factors between modified final models (SEM) and the initial proposed model (SEM). The joint criteria model comparison fit indexes of IFI, TLI, CLI of the modified final model (SEM) had better fitting values and also GFI and AGFI. Although, the later fits indexes were not among the model comparison fit indexes used in this study, however they improved in values than the initial proposed model (SEM). But the power explaining stronger relationship among the factors is in the final modified model (SEM) especially in ENKN and CEAWARE constructs, though with slight improvement. With that, it can be suggested that the modified final structural model (SEM) was a better fitting model than the initial proposed model in explaining the investigated phenomena and fits the data population well.

Moreover, as Hox & Bechger (2007) admonished that in SEM analysis, model fits should be seen as relatively modern approach, and models are just only approximation, therefore a perfect fit model is like making a difficult demand. Furthermore, Preacher et al., (2008) also stated that we know that no model can be literally true in all of its particulars, and can realistically fits perfectly in a population, unless the researcher is extraordinarily lucky or possesses what they called "divinely inspired theory-designing skills." However, the prob-

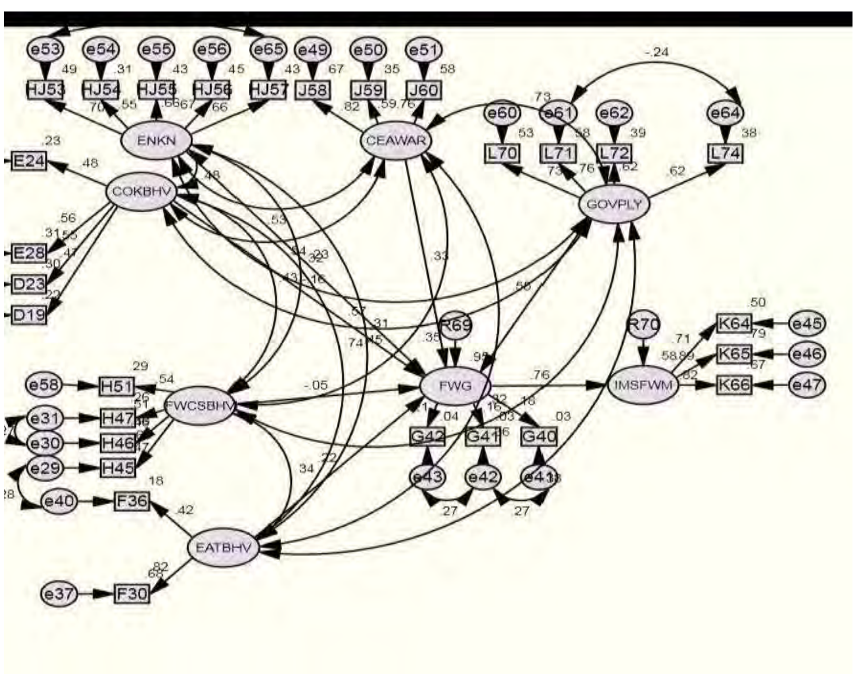

Figure 4 Final Modified Structural Model (SEM)

lem is assessing how well the model approximates the true model. This situation led to the development of an index called Root Mean Square Error of Approximation (RMSEA). Therefore, when approximation is good, it is expected that RMSEA should be small (less than.05) for the final SEM model as it is in the modified structural model.

In line with the aforementioned justification, the modified final structural model fits indexes was accepted, also based on the discussion with (Basril, Personal communication, February, 2015) an expert in Structural Equation Model who said in certain cases, it is not possible to get a perfect model fits where all the indexes will converge. At least very close to what is required can be accepted. Hence in this study out of the eight measurement indexes recommended by literatures, six have been achieved and slightly above the recommended levels, and two very close. The modified structural model therefore fits the data used and there should be no further modification or re-specification if the researcher so wish. This is because in this issue of fits indexes, researchers choose and report the one they prefer. Some only use four indexes while others more. This argument is further supported by the study of Jie Li (2005) were in her study, GFI and AGFI was .80 and the researcher decided no further modification to be done for the sake of parsimony and it was accepted in her final PhD medical program by the examination committee in Australia.

Therefore, based on the facts thus expounded, the final modified model (SEM) was adopted for the empirical better model in this study. This is because it achieved a better acceptable model fit indexes for the data and as well stronger relationships between the latent constructs. With the (X^2 chi-square difference of 322 with df=197) made it more better fitting model for the sample population than the initial proposed SEM model. Hence, lower X^2 values indicates a better fitting model, as large X^2 indicates poor model fitness (UCLA: Statistical Consulting Group, 2007: Kenny, 2014). Furthermore, with the explanatory power (R^2= 58) the modified final structural model was considered valid which is also similar to previous studies by Barr, (2007) on waste prevention behaviour, makes it the better fitting model. With all these justifications, the final modified model SEM model was accepted as adequately explaining the relationships between RFWG, ENKN, CEAWARE, GOVPLY and SFWM. The results are shown on Table 5 for the Initial proposed model SEM and final modified model (SEM).

Bold characters are main model comparison fit indices

- RFWG = Reducing Food waste generation
- COBHV = Cooking behaviour
- EATBHV = Eating behaviour
- FWCSBHV= Food waste composition and separation behaviour
- ENKN = Environmental Knowledge
- CEAWAR = Consumers' environmental awareness
- GOVPLY = Government policy on house-holds food waste management
- SFWM = Sustainable food waste management

As the final Modified Structural Model (SEM) was adopted to adequately explained the hypothesized relationships between: FWCSBHV, COKBHV, ENKN, EATBHV, CEAWARE, GOVPLY and SFWM: These significant paths

Table 5 The results of the Initial **Proposed Model (SEM)** and the **Modified Final (SEM)** Compared

Model fit level	**The Overall Model Fitness**						
	Model fits		**The Model comparison**				
Measurement fit	CMIN/DF	RMSEA	IFI	TLI	CFI	GFI	AGFI
Acceptable fit levels	<5.00	<.010	Close to .90	Close to .90	Close to .90	Close to .90	>.90
Initial Model results (SEM)	**1.706**	**.045**	**906**	**890**	**904**	.873	.846
Initial model (SEM) X^2 (df)	885.310 (519)						
Final Modified SEM results	**1.730**	**.047**	**.915**	**.898**	**.913**	.896	.868
Final Modified (SEM) model X^2 (df)	557.116 (322)						

Table 6 Results of the hypothesis

Hypothesis	**Paths in SEM model**	**The final modified proposed SEM model**				**Results**
		Standardized (ß)	**S.E**	**C.R.**	**P**	
H1	FWCSBHV → RFWG	-.012	.020	-.589	.556	Not significant
H2	COKBHV → RFWG	-.057	.078	-.736	.452	Not significant
H3	ENKN → RFWG	. 067	.035	1.930	**.054**	**Significant**
H4	EATBHV → RFWG	.057	.050	1.142	.254	Not significant
H5	CEAWAR → RFWG	.095	.051	1.850	**.064**	**Significant**
H6	GOVPLY → RFWG	.167	. 066	2.464	**.014**	**Significant**
H7	RFWG → SFWM	2.59	. 868	2.980	**.003**	**Significant**

The results of significance levels were supported at = p ≤0.5 and p ≤ .010

and their non-significant paths are shown in Table 6 to achieve the objectives of the study laid out in the introductory part of this study. Therefore, the results of the hypothesized paths in the final modified structural model are thus presented in details in Table 6 below. From the results, all the significant paths between factors were supported at 0.05 and 0.10 significant levels respectively.

CONCLUSION

From the findings, government policies on households' food waste management, environmental awareness and environmental knowledge have shown significant impacts on household food wastes reduction behaviours. These results are further justified as policies such as pay-as-you-throw-away in Athens and Sweden have prompted households to change their behaviours towards household waste in general. Though, this is not a call to increase waste disposal rates for households considering the current economic situations in Malaysia, and again the income disparities between these countries where this type of policy has brought down quantities of food wastes at homes and wastes in general. The implication of these findings is that government strict and strong food waste policies could change the behaviours and perceptions of households to see the issue of food waste to be unacceptable behaviour. For example, German citizens were made to understand that although the money spent to purchase foods wasted are theirs, the "resources to produce foods belongs to the people." For that reason, wasting food attracts penalties even though they are the richest economy in Europe. This has reduced food wastage at households and in the public eateries.

On the other hand, South Korea and Taiwan have also achieved significant results in food wastes reduction due to strict government policies on household food wastes. Though, facilities to motivate towards positive behaviour should be provided for households with regard to separate bins for food wastes and dry wastes. Policies that suit local environment should be considered in this regards. It can be concluded perhaps that food waste management is not just only a behavioural issue among households, but policies and regulation issues. With these findings, food waste management ceases to be a sector specific issue at this stage and becomes a governance issues. It is important that Selangor and Terengganu take leadership roles towards reducing problems, building solutions and responsible sustainable methodologies to achieve sustainable food waste management in the long run. The local authorities should try as much as possible to develop food waste management programs that will focus on minimizing barriers to implement sustainable food waste. This could lead to positive behaviour to reduce households' food waste.

Finally, although it is not feasible to have a hundred percent prevention of food waste at households as claimed by some researchers like Salhofer et al. (2007), it could be minimized. This is because there are some reasons whereby households are not to be held responsible for some edible food wastes disposed by their households Stefan (2011), having said that, efforts being put in place by the Ministry of Housing and Local Government (MHLG) and National Solid Waste Department (NSWD) to reduce food wastes generation in Malaysia through collaborations with MOE Japan should be commended. Even though at this moment it is only channeled towards "macro food wastes generators," such as hotels and food industries. It is expected that this will be extended to households as well. Households being the single and biggest contributor in waste management sector with regards to the total amount of food wastes generated annually in any food wastes study. More households' food waste oriented reductions measures should be put into place to enable people change their perception and behaviour on food wastes, and the need to do so could probably make a difference in the efforts to reduce food wastes generation in Malaysia. While that is being expected, increasing awareness through enlightenment campaign via the mass media, educating the people to the environmental impacts of food wastes to the economy, cost of waste management, its impacts on food security, coupled with availabilities of recycling facilities and making wasting of food to be seen as socially unacceptable behaviour, could minimize food waste generation and disposal at households. Therefore, it is hope that in the near future, Selangor and Terengganu will become the role model for other states on sustainable food waste management at households' levels in Malaysia.

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