

INTEGRATING ANALYTICAL HIERARCHY PROCESS AND LIFE CYCLE ASSESSMENT TECHNIQUES FOR REDUCING THE ENVIRONMENTAL IMPACTS OF MUNICIPAL SOLID WASTE DISPOSAL

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ABSTRACT

Increase in solid waste had been due to improvements in public life style and services delivery systems. While curtailing waste generations rates and reduction of impacts had been contending issues in developed countries. However, unfavourable economic status, inadequate institutional structure, legislative inadequacy, technical and operational constraints are the problems in developing countries. In Nigeria, the most critical environmental challenges are contamination of land and public environment on one hand and limitation of waste disposal facilities because waste dumping is the primary means of disposal. Campaigns and regulations for the implementation of waste reduction programmes via the implementation of 3Rs were also not complied by the populace. For these reasons, effective techniques and management policies need to be exploited and recommended. The adoptions of the packages for control measures in the reduction of impacts created by waste needs a holistic evaluation. Considering stakeholder's opinions and contributions towards tackling the effects created by waste are vital ingredients towards this target. This paper presents effects of the environmental impacts using analytical hierarchy process (AHP) and life cycle assessment (LCA). Results show that 13, 33, 28 percents in terms of public preferential perception for Landfilling, incineration and composting respectively were observed. While the cumulative effects of global warming potential among others ranges from 256, 54 and 90 (kg CO₂-Eq) for the same Landfilling, incineration and composting respectively. It is further observed that, the use of the integrated techniques could guide research on where to look for improvements that can significantly reduce environmental damage.

Keywords: environmental impacts, Landfilling, Incineration, Composting, lifecycle assessment, analytical hierarchy process

1 INTRODUCTION

Municipal solid waste disposal had always been a major burden of most nations because improvements in Technology and services delivery have promoted the increase in population sizes and simultaneous generation of waste. More alarmingly, the twenty first century experiences rapid population increase especially in the developing countries. Mostly, city growth rates exceed 4% per annum [1, 2] and more than 90% of collected wastes end up into the landfill without pretreatment in these countries [3]. As noted in some reports, an average of 20 to 40 percents of municipal revenues spent to manage waste are not enough to handle the problems thereof [1]. While this is the case in these countries, less than 30% of city population get adequate and regular refuse removal [4, 5]. Further constraints such as unfavorable economic status, inadequate institutional structure, legislative inadequacy, technical and operational constraints have added to the problem in most developing countries [6]. Nigeria, the population has been increasing at a rate that is so alarming. As this trend is likely to continue; and by the year 2020, the quantity of MSW to be generated is expected to rise to uncontrollable tonnes. Consequently, management of municipal solid waste will continue to be one of Nigeria's most critical environmental challenges because open dumping is the primary means of disposal [7]. The resources for construction of landfill for most cities of the country are yet a major

contending problem along this juncture [7]. The problems of environmental pollution caused by disposal of solid waste were reported in many townships in the country [7, 6] This is linked to several factors, such as inability of the local authorities to collect all the wastes, lack of adequate financial resources, lack of skills, improper disposal facilities, and improper organizational structure of the authority responsible to manage the waste as well as inadequacy of proper and accurate data upon which waste disposal facilities could be properly put up [4, 8]. In addition, cases of illegal dumping of all categories of wastes were reported and this further strains authority's budgets to collect and dispose properly [4, 9]. The campaigns and regulations for the implementation of the 3Rs were not complied by the populace as well [10]. Waste composition is also highly heterogeneous and can contain a lot of pollutants [11] whereby single technique of treatment/management is not enough. For these and other reasons, new effective and sustainable techniques and management policies need to be exploited and recommended. The adoptions of these packages of control measures for the reduction of impacts created by wastes need a holistic evaluation. Considering stakeholder's opinions and contributions towards tackling the effects created by waste and knowing the impacts thereof will be one positive approach. However, researchers and waste management authorities are confronted with challenges of interdisciplinary dimension in identifying which impacts are of most critical environmental and health concerns, and how and where to put more efforts and emphasis to control for waste management [12]. Since it appears difficult to adequately dispose waste by single means (such as landfilling alone or recycling or composting alone), adopting multicriteria and life cycle assessment will serve as a vital integrated tools. When both methodologies (AHP and LCA) are put together it will be possible to interact with stakeholders so that guided life cycle analysis is conducted on MSW disposals deemed important by them. In the literature reviewed, there are few instances where LCA and AHP were integrated to assess environmental impacts [13]. In Nigeria, both concepts are still fresh and based on our investigation; there are no instances where these concepts (AHP and LCA) are put together to assess impacts of municipal solid waste disposal. It is therefore worthwhile to bring together these methods so that bases in stakeholder views on solid waste disposal might be established and decisions on disposal alternatives based on impacts bound to be created thereof are adequately pointed out. It will then enable researcher's advice authorities on the most sustainable way of waste disposal. It is worthy to state that the report of the research will serve as guide in identifying, evaluating and pointing out waste disposal impacts for future planning and management with a view of exploiting opportunities in waste to benefit practices in the country. This is one of the contributions of the paper. Figure 1 shows the framework demonstrating procedure on how the two techniques can be integrated in putting up a sustainable solid waste disposal alternative/s.

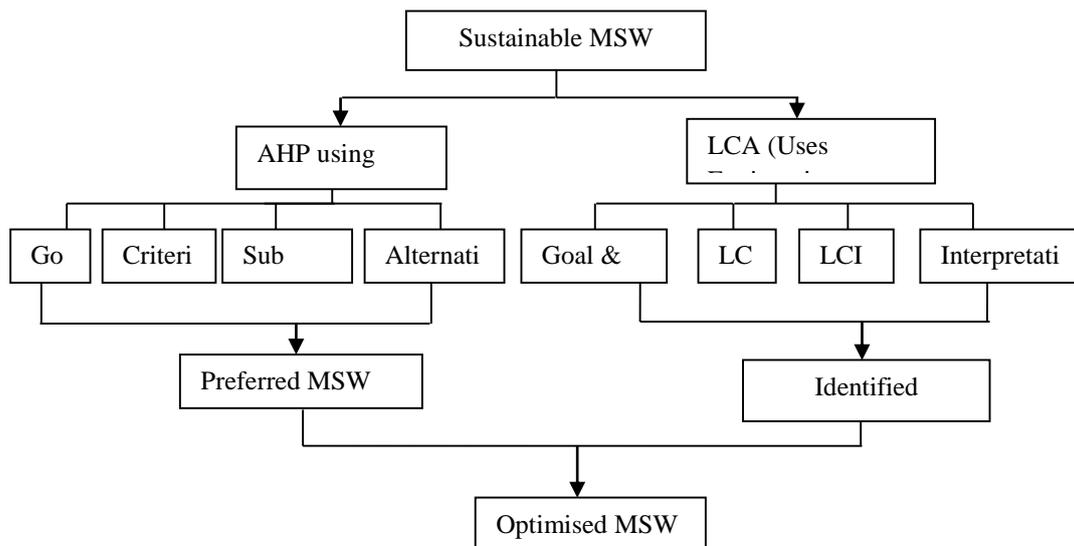


Figure 1 Framework of integrating AHP and LCA for Optimised MSW disposal

Key: MCDA: Multi-criteria decision analysis; LCI: Life cycle inventory; LCIA: Life cycle inventory analysis

On the left hand side of the figure, AHP technique according [14], consist of the following multicriteria hierarchical steps: (1) structuring a problem with a model that shows the problem's key elements and their relationships, (2) eliciting judgments that reflect knowledge, feelings, or emotions of stakeholders, (3) representing these judgments with meaningful numbers, (4) using these numbers to calculate the priorities of the elements of the hierarchy, (5) synthesizing these results to determine an overall outcome, and (6) analyzing sensitivity to changes in judgment. The hierarchy is in such a way that the primary factor (main criteria) is decomposed into subcriteria with feedback alternatives at the bottom of the hierarchy. The factors are treated as cluster or groups in the model asbest described by [15]. While on the right hand side, the assessment method of LCA is based on ISO 14040 and 14044, 2016 series and consists of goal and scope, inventory, impact assessment and interpretation as pointed out by [1].

2 METHODOLOGY

2.1 Data collection

Data were obtained from two sources: Initially, Questionnaires were used to obtain the views of solid waste stakeholders, namely, waste collectors, environmental health workers and local authority officials. Their views and perceptions were assessed and synthesized using analytical hierarchy process (Table 1). Secondly, three solid waste treatment options were proposed, namely, Landfilling, Incineration and Composting. Information for incineration assumes complete combustion of municipal solid waste in the data base. Likewise, mechanical biological treatment (MBT) facility was used for composting facility in the data base as well. GaBi software was used to access and process an inbuilt data for waste treatment of various countries including Nigeria. Inputs for solid waste were extracted and processed by the GaBi software. The working principle remains the same as reported in [1] earlier. The result so obtained from the assessment is presented for different environmental impact categories such as global warming potential GWP, Acidification potential AP, Photochemical ozone depletion potential PODP and Eutrophication potential EP (Table 1). The result so obtained is discussed below.

2.2 GaBi operational mechanism

With features refined through experience on thousands of PE consulting projects, GaBi supports every stage of an LCA, from data collection and organization to presentation of results and stakeholder engagement. GaBi automatically tracks all material, energy, and emissions flows, as well as defined monetary values, working time and social issues, giving instant performance accounting in dozens of environmental impact categories [18]. With a modular and parameterized architecture, GaBi allows rapid modeling even of complex processes and different production options. This architecture also makes it easy to add other data such as economic cost or social impact information to a model, making GaBi a holistic life cycle analysis tool. The GaBi software is complemented by the most comprehensive, up-to-date Life Cycle Inventory database available. With over 4,500 Life Cycle Inventory datasets based on primary data collection during the institute's global work with companies, associations and public bodies. GaBi Databases span most industries. The operational principles are reported in [18].

3 RESULTS AND DISCUSSION

3.1 Combined Assessments for Landfill, Incineration and Composting

Table 1 above presents the combined effects of integrating AHP and LCA. In AHP, the preferences of the stakeholders are in favour of landfilling, composting and incineration in descending order. This implies acceptability of incineration and composting to landfilling. This claim is further substantiated by the results of the proportions shown for environmental impacts in LCA. Landfill has most pollutants; 90, 60, 60 and 46 percents for global warming, acidification, photochemical creation potential and Eutrophication potentials respectively. Composting contributes 2, 40, 21 and 27 percents of these impacts. Finally, incineration contributes 8, 0, 19 and 27 percents for the impacts categories respectively. Landfill was found to be the most polluting MSW disposal system in both assessments (Figures 2 and 3). While preferences of the stakeholders in AHP indicated that landfill was the least (with 13% to 33%, and 28% for Landfilling incineration and composting respectively). The assessment with LCA reveals that impacts from the landfill account for 90% in terms of global warming potential.

The LCA also coincided with the view of the stakeholders that incineration is one of the best disposal options because the option in this assessment contributes only 8% to global warming environmental impact potential compared to 90% landfilling. Composting as can be seen contributes least (2%) in terms of global warming potential.

Table 1. Combined impacts of AHP and LCA

AHP	Landfilling	Incineration	Composting
Preferences (%)	13	33	28
LCA (Environmental Impacts intensity in percentage)			
GWP	90	8	2
AP	60	0	40
POCP	60	19	21
EP	46	27	27

Figure 2 shows the graphical representation of the results of GWP for the three MSW disposal plans assessed.

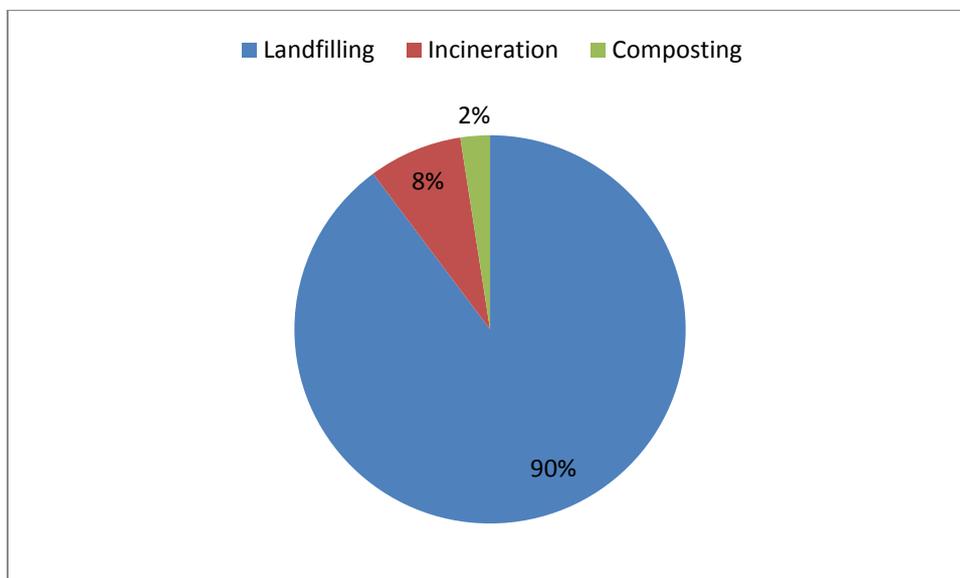


Figure 2. GWP (CO₂ eq) for the three MSW disposal scenarios assessed

This problem in the study area can be averted if gas collection and utilization is incorporated in dump sites when properly managed. Assumed higher concentrations of CO₂, NO₂, N₂O are responsible for the higher environmental impacts in the landfills/dumpsides. MBT composter emits some amount of particles as assumed because of the sorting activities observed to be releasing a lot of dust since air scrubbers are not provided in the MBT plant. Odour gases such as ammonia are one of the typical characteristic of composting operation. Thus the reason for the gaseous quantities in the current composting plant. Incineration and composting are however better because of two reasons: (I) Lesser emission of pollutants, (II) Energy recovery [17]. Incineration is more beneficial here because of the additional electrical energy production assumed for dump side operations [16]. Environmental impact for each scenarios are hereby presented in Table below.

3.2 Influence of AP in the LCA of the MSW Disposal Scenarios

Although the impacts for acidification are not as high as was the case with global warming potential, those detected in the result can be ascribed proportions as shown in Figure 3. Landfill again contributes 60% to his impact category, MBT composting accounts for 40%, while contribution by the incineration process is insignificant. This could be because of the application of the gas cleaning system in the assumed data base.

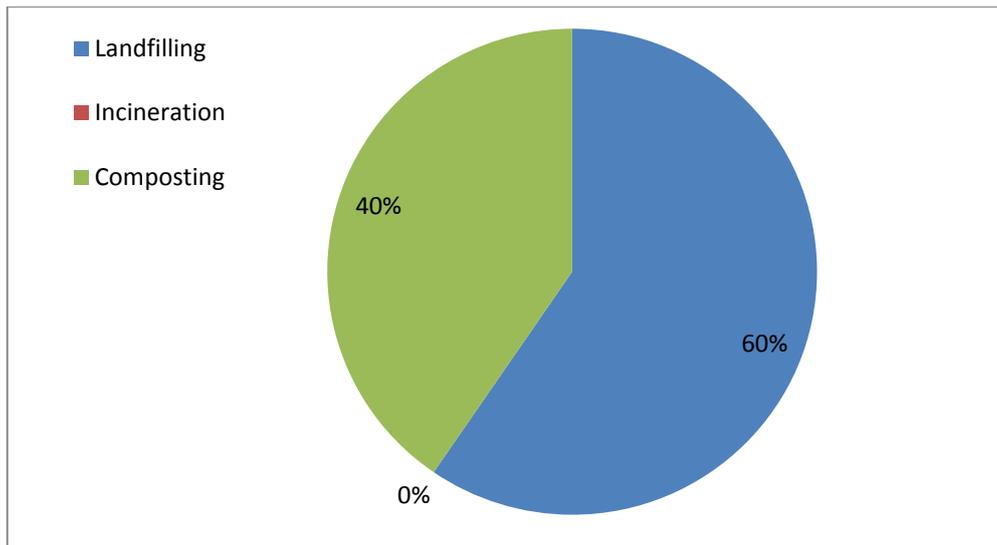


Figure 3. Influence of AP in the LCA

3.3 Implication of POCP in the LCA

For this impact category, landfill again has the highest burden to the environment; MBT has lesser, while incineration has the least in the proportions of 60%, 21% and 19% respectively (Figure 4). We can see that incineration is the best disposal option since it has least impacts followed by the composting.

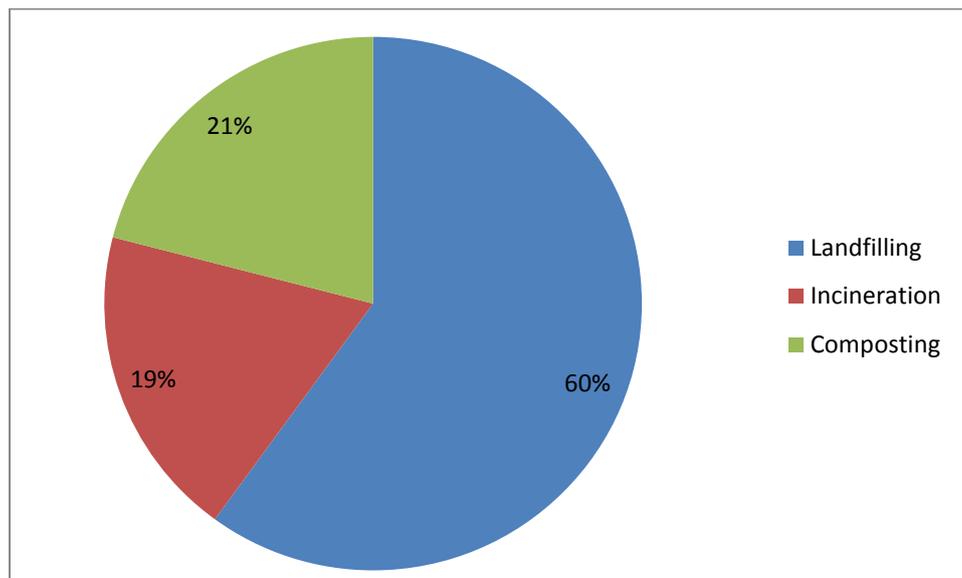


Figure 4. POCP impacts on the 3 MSW disposal scenarios (kg NMVOC)

3.4 Implications of Nitrogen Enrichment in the LCA of the Disposal Alternatives

Landfill is still the major contributor to Eutrophication (46%) with the remaining disposal scenarios 27% each (Figure 5). The concentration of the impacts in the landfill is due to presence of nitrogen based or sulfur based compounds in the leachate which are not treated. Leachates are not produced in incineration as well as in the composting (aerobic composting of the present case). However, sulfur based compounds are found in composting as well as in flue gas cleaning equipments and some aspects of combustion in the process; thus yielding those amounts of EP impacts as depicted in the Figure.

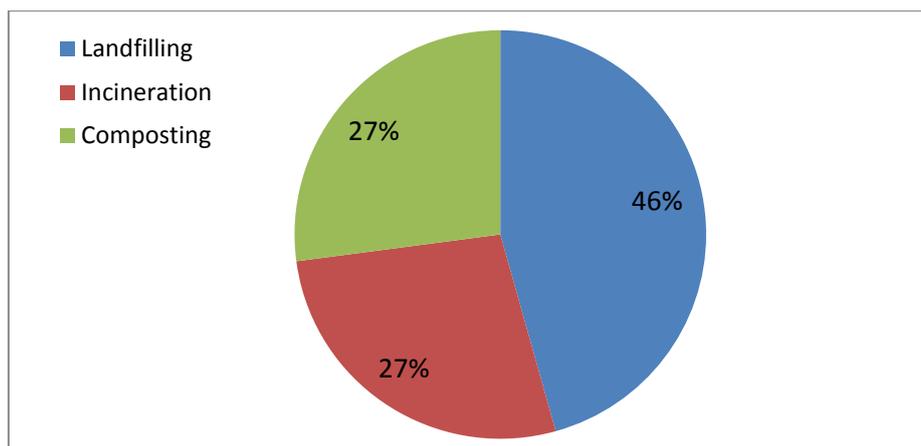


Figure 5. Concentration of EP based impacts in the scenarios (moles of N or S)

Figure 6 shows normalized/cumulative values for the total environmental impacts assessed in the landfilling, incineration and composting scenarios. Landfill contributes the highest environmental impacts; and thus should not continue to be the only MSW disposal means in the study area. In composting, the environmental impacts are reduced (by 36% of that of landfilling). Incineration has the least total environmental impacts (only 1/4th of that of landfilling). This then shows that incineration and composting are the most environmentally less impacting means of MSW disposal in the area of study. It further indicates that landfill should be strongly complemented side by side with the two disposal means similar to some findings by [16,17].

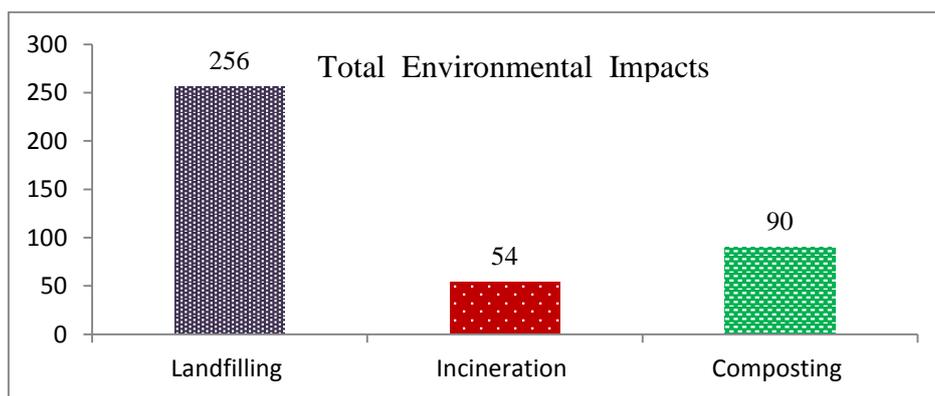


Figure 7. Total Environmental Impacts for the Three Scenarios Assessed

4 CONCLUSIONS

Assessment of environmental impacts with three MSW disposal alternatives (landfilling, composting and incineration) reveals that incineration and composting are most preferred. Proportions of these values are demonstrated in LCA conducted on the three of the disposal alternatives (landfilling, incineration and MBT-Composting). Results show that landfilling generates more environmental impacts in terms of GWP, AP, POCP and EP. Incineration and MBT-Composting are more environmentally friendly because they generate far less environmental impacts for the impacts categories assessed. By proportions it is observed that incineration and MBT composting are both favourable to the environment. Landfill is thereby confirmed to be generating a lot of burdens to the environment. It should be noted that these improvements often involve trade-offs, in some cases saving raw materials may be of higher priority than saving energy obtained from the raw materials. The opposite may be true in other cases. The ultimate decision depends on the need of the situation on ground.

REFERENCES

1. Othman, S.N., Zainon Noor, Z., Abba, A.H., Yusuf, R.O. and Abu Hassan, M.A. (2013). Review on life cycle assessment of integrated solid waste management in some Asian countries. *Journal of Cleaner Production*, vol.41, pp. 251-262.
2. Zerbock Olar, 2003. Urban Solid Waste Management: Waste Reduction in Developing Nations. *M.S. programme School of Forest Resources & Environmental Science Master's International Program Michigan Technological University* www.cee.mtu.edu/peacecorps, pp. 1-23.
3. Abd Kadir, S. A. S., Yin, C.-Y., Rosli Sulaiman, M., Chen, X. and El-Harbawi, M. (2013). Incineration of municipal solid waste in Malaysia: Salient issues, policies and waste-to-energy initiatives. *Renewable and Sustainable Energy Reviews*, vol.24, pp. 181-186
4. Ahmad Halilu Abba, Zainura Zainon Noor, Rafiu O. Yusuf, Mohd Fadhil M.D. Din, Mohd Ariffin Abu Hassan, (2013). Assessing environmental impacts of municipal solid waste of Johor by analytical hierarchy process. *Resources, Conservation and Recycling*, vol. 73, pp. 188– 196.
5. Senkoro, H. (2003). Solid Waste Management in Africa: A WHO / AFRO Perspective, Paper 1, *Presented in Dares Salaam at the CWG Workshop*.
6. Imam, A., Mohammed, B., Wilson, D.C. and Cheeseman, C. R. (2008). Solid waste management in Abuja, Nigeria. *Waste Management*, vol. 28, no. 2, pp. 468-472.
7. Abba, A. H., Babagana, U. M., Atiku A. A., Burmamu, B. R (2019). Evaluation of Energy Potentials from Municipal Solid Waste: A Case Study of Yola, Nigeria. *FUTY Journal of the Environment*, vol. 13, no. 1, pp 36-45.
8. Lee, G. B. (2007). Solid Waste Management: Issues and Challenges in Asia. The Asian Productivity Organization, 1-2-10 Hirakawacho, Chiyoda-ku, Tokyo 102-0093, Japan: APO, Environmental Management Centre, Mumbai, *India Asian Productivity Organization, 2007 ISBN: 92-833-7058-9, 339p*.
9. Amber, I., Daniel, K.M. and Nicholas, G. (2012). Municipal Waste in Nigeria Generation Characteristics and Energy Potential of Solid Waste. *Asian Journal of Engineering, Sciences & Technology*, vol. 2, no. 2, pp.84-88.
10. Ahmad Halilu Abba, Zainura Zainon Nur, Nasir Idris Medugu and Adati Ayuba Kadafa (2018). Overview of Solid Waste Disposal: Applicability of Analytical Hierarchy Process and Life Cycle Assessment as Planning Guide in Johor, Malaysia. *Savanna: A Journal of the Environmental and Social Sciences*, vol. 24, no. 3, pp. 107-120.
11. Damgaard, A. and Christensen, T.H. (2010). Implementation of life cycle assessment models in solid waste management. Kgs. Lyngby, Denmark: Technical University of Denmark (DTU). Downloaded from orbit.dtu.dk on: Dec 19, 2017, pp. 1-83.
12. De Feo, G. and De Gisi, S. (2010). Public Opinion and Awareness Towards MSW and Separate Collection Programmes: A Sociological Procedure for Selecting Areas and Citizens with a Low Level of Knowledge. *Waste Management*, vol. 30, no. 6, pp. 958-976.
13. Contreras, F., Hanaki, K., Aramaki, T. and Connors, S. (2008). Application of Analytical Hierarchy Process to Analyze Stakeholders Preferences for Municipal Solid Waste Management Plans, Boston, USA. *Resources, Conservation and Recycling*, vol. 52, no. 7, pp. 979-991.
14. Saaty, T.L. (1994). How to Make a Decision: The Analytic Hierarchy Process. *Interfaces*, vol. 24, no. 6, pp. 19-43.
15. Blair, A.R., Mandelker, G.N., Saaty, T.L. and Whitaker, R. (2010). Forecasting the Resurgence of the U.S. Economy in 2010: An Expert Judgment Approach. *Socio-Economic Planning Sciences*, vol. 44, no. 3, pp. 114-121.

16. Abba, A.H. (2014). Assessment of municipal solid waste disposal options using analytical hierarchy process and life cycle analysis. *Unpublished PhD thesis submitted to Universiti Teknologi Malaysia for the award of PhD degree*, 315p.
17. McDougall, F. R., White, P. R., Franke, M. and Hindle, P. (2001). *Integrated Solid Waste Management: A Life Cycle Inventory*. (second ed.) 2121 State Avenue, Ames, Iowa 50014-8300, USA, Tel: +1 515 292 0140: Blackwell Science Ltd, a Blackwell Publishing Company, 532p.
18. Gabi Paper Clip Tutorial (2011). Handbook for Life Cycle Assessment (LCA) Using the GaBi Software. PE INTERNATIONAL, *Hauptstraße 111-115 70771 Leinfelden-Echterdingen, Germany*, 74p.