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Full Length Research Paper

Effective solid waste management: A solution to the menace of marine litter in coastal communities of Lagos State, Nigeria

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Effective management of solid wastes is a goal that is yet to be achieved in many countries, even developed ones. In attempt to carry out a study on effective waste management system as a solution to the menace marine litters posed on coastal communities, three coastal areas in Lagos State Nigeria which are known for fishing, recreation, housing, and other various coastal activities were selected. Three groups of research questions were formulated based on the problem perception and impacts, actors and level of governance, and strategy and instrument; and each question was examined, and specific strategy was developed for necessary data gathering. This study was based on the observational findings and interviews conducted for various actors; and conclusion and recommendations were based on the evaluation of the research questions. While a clear cut of marine littering resulting from ineffective solid waste management was the case at Makoko and Ebute-metta, the dividend of relatively effective solid waste management system with multi-actor approach was seen clearly at Victoria Island bar beach, as this location was found to be relatively clean, thus reducing the chances of litters escaping into the marine system. Generally, the major impacts identified are aesthetics impairment, health issues, and economic downscale. Based on the studied sites, the framework for requisite actions to address the problem of marine littering in an effective and sustainable manner is documented herein.

Key words: Solid waste, waste management, marine litter, Makoko, Ebute-metta, Victoria Island, multi-actor approach, pollution, coastal community.

INTRODUCTION

Human health and environmental quality are undergoing continuous degradation by the increasing amount of wastes being produced (UNCED, 1992; Osibanjo, 2001). Solid waste is a major public health and environmental

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concern in urban and coastal areas worldwide; the situations in Africa, part of Asia and Latin America in particular are severe (UNEP, 2005). The total volume of marine litter collected in 2008 beach cleanup worldwide was estimated at 3,402 tons (ICC, 2009). In Africa, increasing urbanisation, rising standards of living and rapid industrial growth have resulted in increased solid waste generation by households, commercial institutions and industrial activities. Coastal litter, also referred to as marine litter or debris, is any item that appears on beaches, or at sea as a result of anthropogenic activities causing environmental quality deterioration (Storrier and McGlashan, 2006). Littering has been attributed to, inter alia, poor solid waste management practices, lack of infrastructure, indiscriminate human activities and behaviours, and an inadequate understanding on the part of public on the potential consequences of their actions (UNEP, 2009). Marine litter is an environmental, economic, health and aesthetic problem. It threatens marine and coastal biological diversity in productive coastal areas (UNEP, 2005).

An insight into Nigeria's population data is necessary to fully understand that increasing population poses a major obstacle to effective solid waste management (Solomon, 2009). As a result of beach user behavior, urbanization, shipping, fishing and residential activities, solid wastes of anthropogenic sources have polluted virtually all the lagoons and creeks in Lagos (Ajao et al., 1996; Nubi et al., 2008). According to the Ocean Conservancy International Beach Cleanup report of 2009, shoreline and recreational activities resulting in waste materials like plastics bags, food wrappers and beverage drinks constitute nearly 88% of waste volumes collected annually in Nigeria (ICC, 2009). Litter from smoking related activities and composition involving dumping activities along the coastline, as well as medical and personal hygiene constitute the remaining 12%. Anthropogenic causes of flooding in Lagos has been attributed to ineffective waste disposal system that encourages littering which eventually leads to flooding (Folorunsho and Awosika, 2001). The resultant effect of the population growth on littering is evident, as the volume of waste generated continues to increase at a rate beyond the ability of the responsible agencies to improve on resources needed to handle the problem of solid waste management. Beside the increase in population, Nigeria suffers from lack of continuity in implementation of government policies, financial and operational constraints, inadequately formulated policies and poor attitude of citizens towards waste management. Waste collection and management is handled either by the state environmental agencies or private companies or both. Most often high and medium socio-economic class urban and coastal areas get better services than low socio-economic class areas mainly due to willingness of the former group to pay for services which are facilitated by proper planning in these areas, thereby making monitoring and enforcement less difficult. This paper consequently provides an overview of the current state of solid waste management in the coastal areas of Lagos, Nigeria, and the causes of marine litter in these areas. It identifies key stakeholders in solid waste management (SWM) in Lagos, their perceptions and interests towards effective solid waste management system, and also makes available recommendations for improvement.

METHODOLOGY

Study area

Makoko, Ebute-metta and Victoria Island (Figure 1) were selected as the case studies for this research because they are located at the tributaries of Lagos lagoon, and are both known for commercial and residential activities. Makoko and Ebute-metta areas are known to accommodate the low-income class people while Victoria island accommodate the rich and middle class people. In the latter area, marine litter is not as prominent as Makoko and Ebute-metta and waste management within this area seems to be more effective. Understanding the perception of various individuals with different backgrounds in similar location will help to ascertain if effective solid waste management can be a solution to the menace of marine litter.

Nature and source of data

Extensive literature search, interviews and personal observation and administering of questionnaire were employed. Interviews were conducted for key officials who are responsible for solid waste management, institutional organizations, research bodies, governmental authorities at central and municipal levels who are concerned with coastal litter management which includes the Lagos State Ministry of Environment, the Lagos State Environmental Protection Agency (LASEPA) and Lagos State Waste Management Authority (LAWMA), and also the coastal communities. Pre-structured interview questionnaires were used (see appendix); and these help to give precise answers to questions for better analysis. However, the interviewees were at liberty to explain and answer the questions in their own way.

Data collection instruments

Combination of three primary data collection instruments was used for this study. These include face-to-face interviews (an open style of interviewing with a high degree of pre-structured questions, observational scheme, and search method). The use of a combined instrument ensured appropriate data collection with desired details and accuracy.

Sample frame

The target group consisted of relevant stakeholders based on theoretical framework which underscores the need for multi-actor character in policy management, and as a result a predetermined list of institutions like governmental authorities at central and municipal levels, research bodies dealing with coastal litter and solid waste management, and also the coastal dwellers formed the sample frame. The coastal dwellers sampled were residents of Ebute-metta, Makoko (Igbeyinadun and Apollo), and Victoria Island bar beach. In Table 1, a list is presented of the organizations from

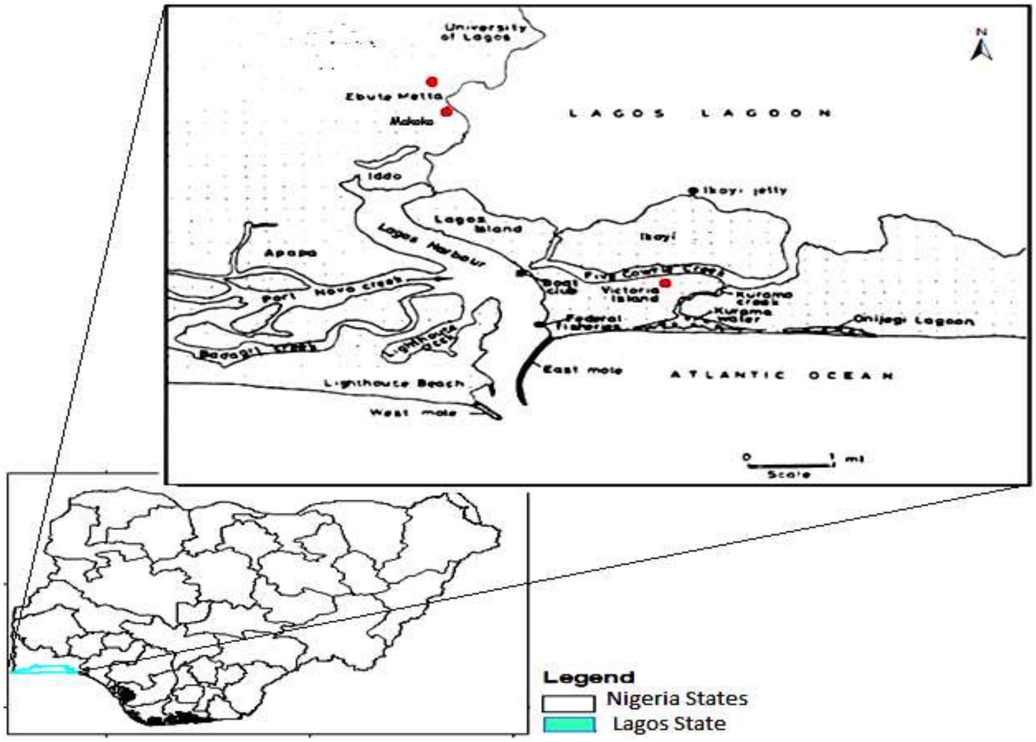

Figure 1: Map of Lagos showing the study locations (in red dots)

Table 1. Organisations/Respondents interviewed.

Name	Organization type	No. of interviewee
Federal Ministry of Environment (FMEnv.)	Government	2
Lagos state Ministry of Environment (LAMENV)	Government	2
Lagos State Waste Management Authority (LAWMA)	Government	2
Nigerian Maritime Administration and Safety Agency (NIMASA)	Government	2
Nigerian Institute of Oceanography and Marine Research (NIOMR)	Research Institute	2
Coastal dwellers in Makoko	Residents	10
Municipal authority for Makoko	Government	2
Coastal dwellers in Ebute-metta	Residents	10
Municipal authority for Ebute-metta	Government	2
Coastal dwellers in Victoria Island	Residents	10
Municipal authority for Victoria Island	Government	2

which employees were interviewed (two person per actor for the governmental organisation and ten respondents per coastal community).

RESULTS AND DISCUSSION

Observational report

Makoko is a large coastal area comprising many communities. Governed by Yaba local government of Lagos State, the major occupation of the residing people is fishing (Plate 1). The communities visited were Igbeyinadun and Apollo. These two communities are the closest to the Lagos lagoon, and their choice was influenced by this proximity. At Makoko, there was no observable waste management system in place as wastes were seen dispersed all over the sites visited (Plate 1). There were no observable road networks within the communities at Makoko. The few accesses seen were bad, and have been encroached by the dispersed wastes.

Plate 1. Fishing activities (left) and open waste dumpsite (right) at Makoko.

Plate 2. Lumbering activities (left) and open waste dumpsite (right) at Ebute-metta.

Ebute-metta is a coastal area that also shares boundaries with the Lagos lagoon. This area is located beside Makoko and also governed by Yaba local government of Lagos State. Apart from the area being used as residential zone, the major commercial activity in this area is sawmilling (Plate 2). Also at Ebute-metta, there was no observable waste management system in place as wastes were seen dispersed all over the sites visited (Plate 2). Conversely, there are relatively better road networks at Ebute-metta compared with Makoko.

Bar beach in Victoria Island is a coastal zone predominantly occupied by recreational, religious, and commercial activities (Plate 3). Horseback riding, sun tanning, and picnics are part of the observed activities. There is a waste management system in place at the Victoria Island bar beach, as the whole place was found to be in a tidy state (Plate 3).

Interview report

Problem perception and impacts

Ninety percent of the respondents at Victoria Island perceived marine littering as an environmental and economic problem, because it impairs the aesthetics of the beach thereby reducing the number of tourists visiting the beach. They are also of the opinion that other recreational and commercial activities would be adversely affected. Although from respondents and observation, the area does not have waste management or littering as a major problem, but the beaches experience littering from land based sources during public holidays when there is high inflow of people on picnic. The major impact of litters on the beaches to the businessmen on the beach is the economic impacts; when people would leave a particular beach for other beaches, making them loose customers and revenue.

Eighty percent of the respondents in Makoko and Ebute-Metta area did not strongly perceive marine littering as an environmental or health problem, they rather perceived it more as an economic problem, because it affects their fishing and dredging activities due to clogging. The respondents identified lack of awareness as the main contributory factor to the menace posed by marine littering on the community. In addition to lack of awareness, defective waste management system such as inadequate collection facilities, poor legislation, and

Plate 3. Recreation (left) commercial (middle), and religious (right) activities at Victoria Island bar beach.

enforcements are also contributory factors. According to the respondents, ineffective solid waste management in Makoko and Ebute-Metta makes the area filthy and unsightly; causing injuries to people, reducing revenue from fishing, and having adverse effects on the children. Secondary problems such as localised flooding are claimed to be caused by litters and waste that block the waterways and drains after heavy rainfall (see appendix).

Actors and level of governance

The information gathered from all residents of Victoria Island is that everybody litters. This is evident due to huge municipal waste generated on daily basis in this area. However, more of the littering is associated with children, low income earners (local inhabitant), and people on picnics who visit the beaches for recreation. The actors handling the waste generated in this area are the state government, local government, non-governmental organizations, private sectors and general public (beach users). From the respondents in Victoria Island, the key actor responsible for their waste management is LAWMA, an institution under the state government.

The information gathered from all residents of Makoko and Ebute-metta is that everybody litters because they do not have an effective waste management system in place, most of the littering is associated with artisanal-fishermen, coastal residents, and local dredgers and since the area is waterlogged with many depressions, they resorted to using their wastes as materials for landfills and landscaping. They believe it is the state government duty to make their vicinity clean by providing them an effective solid waste management system. The actors identified as key to solving the littering menace in this area are the state and local governments, non-governmental organizations, and private sectors (mainly manufacturers). According to the respondents in this area, LAWMA is the authority responsible for managing the solid waste, but they have not been effective with no facility in place for waste collection (see appendix).

Strategy, instruments, and resources

According to respondents, LAWMA and other private contractors are the authority responsible for managing their solid waste. A mixture of strategies, instruments and resources were utilized to achieve the national goal of a clean and healthy environment involving proper solid waste management in Lagos. In Victoria Island, the financing mode used is the user charges, where residents pay for waste collection and disposal. The respondents felt that the waste management (collection and disposal) by LAWMA is fairly satisfactory. Rendering their quota to combat marine littering through waste management, residents participate in the Environment Sanitation Day that was inaugurated by the state government whereby last Saturday of each month is set aside for people to clean their homes and their surroundings. The monitoring of the exercise is usually undertaken by the State Environmental Sanitation Task Forces. Mobile Courts are put in place to issue appropriate sanctions to those who flout the environmental sanitation laws and regulations. Despite the fact that various actors consider litter and littering as major problems in most coastal area, it was discovered that there is no separate policy to address marine littering as a problem, but rather marine littering management is considered as an integral part of solid waste management. It was also gathered from the respondents that the resident's motivations to litter reduction is mainly to have a good and clean environment, and this has been achievable with activities such as paying someone to clean their vicinity, and providing small working tools for the hired labour. The basic caution for coastal littering within this community is ‘‘self regulation’’, a situation whereby fellow resident insist their neighbours clean their environs.

In Makoko and Ebute-metta, residents of these areas have not started paying for waste collection and disposal

Table 2. Summary of the interview report

Stakeholders	Problem perception and impacts	Actors and level of governance	Strategy and instrument
Bar-beach (Victoria Island)	(i) Environmental and economic problem (ii) Aesthetics impairment, Health issues, economic impacts	(i) Litter generation -children, low income earners (local inhabitant),picnickers (ii) Litter reduction – LAWMA	(i) Financing mode (users charge), Environmental sanitation day. (ii) No specific policy for litter
Makoko and Ebute- metta	(i) More economic than environmental and health problem (ii) Injuries to people, reduce revenue from fishing, adverse effect on children, flooding	(i) Litter generation – artisanal fishermen, coastal residents, local dredgers (ii) Litter reduction – LAWMA	(i) No financing mode (users charge), Environmental sanitation day (ii) No policy
Governmental organisation	(i) Environmental problem	(i) Litter generation – artisanal fishermen, coastal residents, picnickers (ii) Litter reduction – LAWMA	(i) Financing mode (users charge), Environmental sanitation day (ii) No specific policy for litter but for SWM

basically because there is no facility or program in place. The respondents were of the opinion that LAWMA has forgotten them, and left alone to tackle their waste problems. To combat the problems of solid waste dispersal, and prevent marine littering, residents of this area also participate in the Environment Sanitation Day, inaugurated by the state government. In spite of resident's perception towards marine littering, solid wastes are still being used to landfill, and cart pushers are paid to empty wastes collected from other areas into waterlogged and depressed zones within the community. They are not aware of any policy that addresses littering and still very myopic to dangers associated with it. Moreover, they have little knowledge on solid waste management policy. Respondent's motivation to tackle marine littering is to have a good and clean environment, increase yields on fishing, and prevent damage to ships and canoes. Also, monthly meetings of youths and elders within the community are often organised to discuss issues on development. There are no penalties for marine littering within this community, as residents are even encouraged to use their solid waste to landfill (see appendix).

In Table 2, a summary is provided on the actors and level of governance, the problem perception and impacts, and the various strategy and instrument in place.

Collaboration among agencies

The governmental organizations perceived solid waste and marine littering as an environmental, health, social and economic issue. It was established that the main actor involved in waste management and marine litter prevention is LAWMA; and the latter also accepted this responsibility. Collaborations were identified among various stakeholders, and at various levels. Figure 2 illustrates the collaboration between various stakeholders on matters of SWM and marine litter.

The respondent for the Ministry of the Environment pointed out that there is collaboration between FMEnv and other stakeholders which resulted in the creation of the national committees for Agenda 21, Coastal erosion and integrated coastal zone management. The collaboration is largely mutual and was initiated by the Federal Government. The LAWMA respondent also indicated some level of collaboration between herself and the private sector such as the PSP (Private Sector Partnership) for waste collection, the press for constant public enlightenment, Manufacturer Association of Nigeria (MAN) to help minimize wastes from industrial sources and ensuring member's compliance to FMEnv guidelines and regulations, and NGOs to ensure effective campaign and dissemination of information. Conversely, the respondent for NIOMR pointed out that there is little or no collaboration between the institute and other stakeholders involved in marine littering. The little collaboration that exists is not with the main stakeholder that is responsible for marine littering cases in Lagos State, LAWMA. The respondent also pointed out that NIOMR only study the marine environment, and make findings available to the public. Except for the FMEvn and the Nigerian Navy that exchange information with NIOMR on marine studies, other stakeholders operate in isolation. The reason most times is as a result of contest for supremacy, particularly when there is difference in opinions, and a division is trying to encroach into other's responsibilities. Collaboration between governmental organizations is scarce, but few that exist do not involve subsidies (schemes) but are present so that each organization can achieve its mandate. Economic incentives such as stationeries, products of companies, field materials, and sometimes cash are sometimes available to some governmental organizations by private

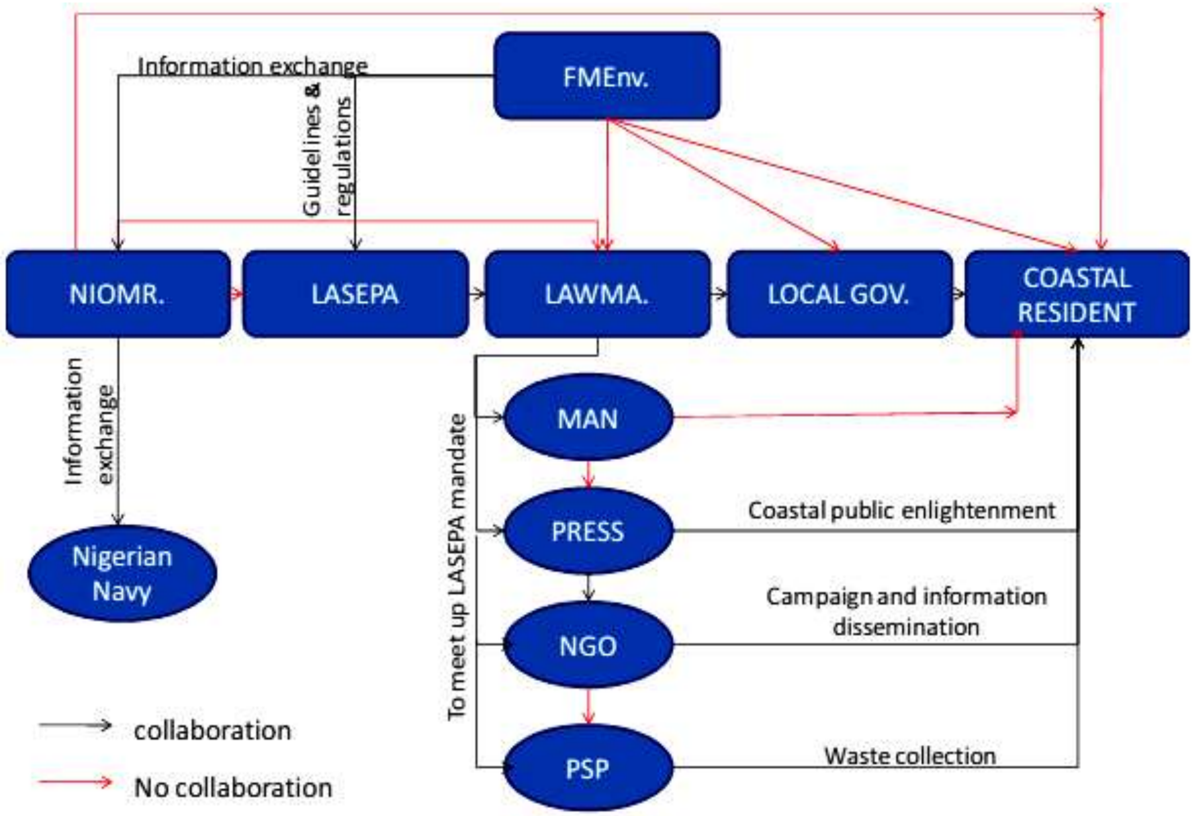

Figure 2: Collaboration between stakeholders on matters of SWM and marine litter.

sector to implement their corporate social responsibility.

The major source of marine litter in Makoko and Ebute-metta is the solid waste generated within these communities. Though the residents claimed that tidal waves do bring litters from other coastal communities or land based sources, but it was clear that greater percentage is from within the community based on the huge solid wastes that were found dispersed throughout the community. In line with the work of Folorunsho and Awosika (2001), during high tides at the study sites, there is an influx of coastal waters into the coastal communities which fill up all the depressions and landfill areas, creating a situation that could be termed as coastal flooding. The dispersed solid wastes in these communities are therefore left floating, and are transported into the middle of the lagoon during low tide, as the water movement is reversed. Fishing and dredging activities by the residents of these communities are also factors to be considered. The fishing traps of fishermen (Plate 4) trap both the fishes and the free flowing litters escaping from shores of the coastal communities and also from other sources, thereby concentrating the litters, and making the marine environment unsightly and unproductive.

Dredging activities re-suspend materials that could have natural decay in the bottom sediment; thereby turning them to nuisance, a case of marine littering.

Taking a critical look at the situation at these communities, one could easily conclude that they have been neglected, or that LAWMA, whose responsibility is to manage their waste had given up on them. Inaccessibility (bad road networks) is another problem facing these communities; and this has created a bottleneck in the activities of LAWMA in this area. The interview report revealed that collaboration among actors that are responsible for the proper management of the coastal areas in Lagos State is very weak. This is not in accordance with Bressers contextual theory on sustainable development (Bressers, 2004), Mazmanian and Kraft's epochs of environmental policy (Mazmanian and Kraft, 1999), and Bressers and Kuks's governance model (Bressers and Kuks, 2003).

Due to effective cleaning practice that is operational at the beach and the surrounding communities, the high level of cleanliness observed at the Victoria Island bar beach is expected. The activity of LAWMA that takes care of the collection and disposal of solid wastes in this area, the type of governmental establishment (FMEnv, NIOMR, Nigerian Navy) located in this area, and the calibre of people living in this area are also contributory in ensuring a high level of hygiene in this area. The Federal Ministry of Environment outstation and the Naval Base located at the Victoria Island bar beach area maintain

Plate 4. Makoko coastal community showing the fish traps of fishermen, and the litters hanging on them.

high profiles in keeping the environment clean. Many research works had been carried out as well by NIOMR on different aspects of marine debris, and some are still ongoing. This multi-actor approach of management at this location, albeit not collaborative (thus inconsonance with Bressers and Kuks governance model (2003) that emphasizes collaboration within actors) is instrumental to its relatively clean state. According to Isaac et al. (2005), tourist density also contributes to the small amount of solid wastes observed during weekends (Saturdays and Sundays) when the beach is put into full use (Plate 5).

Plate 5. State of the environment at Victoria Island bar beach after the weekend activities.

Conclusion

Within the scope of this study, effective solid waste management has been identified as a solution to the menace marine litter poses on coastal community. A clear-cut case of marine littering resulting from ineffective solid waste management was the case at Makoko and Ebute-metta. The solid wastes generated by these coastal communities escaped to the surface of the lagoon system during high and low tides systems. Factors responsible for marine littering observed at Makoko and Ebute-metta are:

(1) lack of integrated coastal zone management (ICZM) or marine spatial planning (MSP);
(2) ineffective solid waste management system;
(3) poor road networks which prevent accessibility;
(4) lack of awareness of the danger posed by marine littering;
(5) the perceptions of the coastal dwellers towards marine littering.

Of the aforemention listed causes, ineffective solid waste management is critical and requiring urgent attention.

Conversely, the dividend of relatively effective solid waste management system with multi-actor approach is seen clearly at Victoria Island bar beach. Except for weekends when the visitor's density is higher than during the week, the beach and the surrounding communities were found clean and tidy. The contributory factors are:

(6) excellent awareness of the danger posed by marine littering;
(7) environmentally sound solid waste management system;
(8) the perception of the coastal dwellers towards marine littering;
(9) relatively sound ICZM;
(10) good road networks that allow accessibility;
(11) a multi-actor (though not collaborative) approach of ensuring sound solid waste management within the coastal communities.

Overall, effective solid waste management is among the environmental subjects of major concern in maintaining the quality of the earth's environment and especially in achieving sustainable development. This however, must go beyond the mere safe disposal or recovery of wastes that are generated, and seek to address the root cause of the problem by attempting to change unsustainable patterns of production and consumption. This implies the application of the integrated life cycle management concept, which presents a unique opportunity to reconcile development with environmental protection. The following recommendations are key towards achieving effective and sustainable waste management system:

(1) It is anticipated that if the government uses a participatory approach especially with the coastal dwellers, that is, the fishermen and residents, a substantial result can be achieved, which will be source-based. Also, the implementation of a review waste management policy at grassroots levels by involving NGOs, communities, business enterprises and traditional social institutions.
(2) Collaborative multi-actor approach in tackling the problem of solid waste should be encouraged as this will prevent replication of duties and responsibilities among actors. LAWMA should collaborate more with Manufacturers Association of Nigeria (MAN) and also the General public to tack the problem of waste within the coastal zone; this can be done by encouraging individual people and commercial sectors to get involved in litter/solid waste management business which include collection, sorting, and recycling.
(3) Perception/Awareness: Educational campaign on litter reduction strategy is highly recommended. This awareness campaign should be targeted at all actors/ stakeholders by teaching them the mechanisms of controlling litter at the source, introducing alternative disposal mechanisms and also the negative effects of littering.
(4) Involvement of all actors such as representatives of MAN, FMEnv, LAWMA, research institutes, coastal residents, local governments, and PSPs in policy development and decision-making so as to encourage acceptance and ownership, thus improving policy effectiveness.
(5) Adequate monitoring, feedback to actors in waste management on the basis of monitoring data and trends, and evaluation of the effectiveness of the policy to support future planning should be embraced. Studies and surveys should be conducted to aid proper planning and optimise the use of scarce resources.
(6) Budget of sufficient financial resources to tackle waste and litter problems. This can be achieved by levying some manufacturing companies especially nylon and plastics companies, sponsorship from international/ national companies, levy from individuals and companies that prohibit waste management laws. Also, the Federal Government should budget for solid waste management in the annual budget.
(7) Although LAWMA has started the involvement of public private partnership (PPP) with solid waste collection, more suchlike involvement should be encouraged in all aspect of waste management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Data collection strategies

The central question of this work is "What is the present situation in the coastal areas of study i.e. Ebute-metta, Makoko, and Victoria Island bar beach, concerning marine litters, solid waste management, and means of improvement?"Sub questions were:

1. Actors and level of governance

- Who are the main stakeholders involved in solid waste management and marine litter?
- What resources do actors have to reduce litter?
- Is there any collaboration between the various actors?

Sources		Accessing
Individual people	Coastal dwellers	Face-to-face group interview
	Municipal authorities	Face-to-face individual interview
	Government informant	Face-to-face individual interview

2. Problem perception

- What are the stakeholders' perceptions about solid waste management and coastal littering?
- How do coastal dwellers perceive litter as a problem and what are their motivations and activities to reduce litter?

Sources		Accessing
Individual people	Coastal dwellers	Face-to-face individual interview
Situation	SWM and marine littering situation	Observation

3. Strategy and instrument

- What are the present strategies used in waste management within the coastal area and how effective are the functional element of the SWM system?
- Which authority is in-charge of managing the waste/litter in the coastal area and what is its main policy strategy?
- Which recommendations and strategy can be given to improve the current situation?

Sources		Accessing
Individual people	Coastal dwellers, Municipal authorities, government informant	face-to-face interview
Situation	SWM and marine littering situation	observation
Documents	files from ministries, municipality	content analysis
Media	web-sites, internet, newspapers	content analysis

4. Impact

What are the main sources and impacts of marine litters in the coastal communities?

Sources		Accessing
Individual people	Coastal dwellers, Municipal authorities, government informant	Face-to-face interview
Situation	SWM and marine littering situation	Observation
Documents	Files from ministries, municipality	Content analysis
Media	Web-sites, internet, newspapers	Content analysis

INTERVIEW QUESTIONS FOR GOVERNMENTAL ORGANISATION

Information obtained shall be exclusively used for Academic and planning purposes only

Please fill in the table below:

Sex Male ☐ Female ☐

Location …………………………………………

Part A: <u>Actors, level of governance and problem perception</u>

1. What is your organisations role and experience on marine litter and solid waste?
2. What is your perception about solid waste management and coastal littering?
3. Who are the main stakeholders involved in SWM[1]?
4. Who are the main stakeholders involved in marine litter generation and reduction? Is there any collaboration between the various actors?
5. From your experience, how do you perceive marine litter? Do you consider it a problem?
6. Is there any law governing the management of waste to reduce coastal littering?

<u>Part B: Strategy, instruments, and resources</u>

7. Which authority is in-charge of managing the waste/litter in the coastal area? And what is the main policy strategy?
8. What are your motivations, activities and what resources (financial assets, skills, knowledge, and support) do you have available to handle the litter and Solid waste problem?
9. What kind of SWM system is present in the coastal areas and how do you control waste generation?
10. Is there a monitoring system that ensures that waste is properly collected and transported to designated disposal sites in order to discourage littering?
11. What are the actions taking against persons who improperly dispose litters?

<u>Part C: Impacts</u>

12. What are the sources and types of marine litter?
13. What are the main impacts of marine litters on the coastal communities?

<u>Part D: Evaluation</u>

14. What suggestions can you provide to improve waste management /coastal littering reduction?

- More involvement of private business partners or local communities?
- Conducting of educational activities and specific targeted campaigns?
- Economic incentives for manufacturers and small monetary rewards for coastal dwellers?
- Provision of more trash bins in public areas?
- Increase penalties and fines?

15. Which barriers do your organization/stakeholders experience with regard to a successful litter reduction and SWM?
16. Is there any activity you do to reduce the amount of waste that is generated/ discarded?
17. What can be done/recommendations to improve the situation of marine littering?
18. What can be done/recommendations to improve the SWM in the coastal areas?

INTERVIEW QUESTIONS FOR COASTAL RESIDENTS

Information obtained shall be exclusively used for Academic and planning purposes only

Please fill in the table below:

Sex Male ☐ female ☐

Location …………………………………………

---

[1]Solid Waste Management

Part A: Actors, level of governance and problem perception

1. Why do you have litter/ waste around your vicinity? What is your perception about solid waste management and coastal littering? Do you consider it a problem?
2. Who do you think are the main actors[2] causing marine litter?
3. Who in your opinion are the most affected by impacts of coastal littering? Fishermen, resident, others specify…………..

Part B: Strategy, instruments, and resources

4. Who do you think/ which authority is responsible for managing your solid waste? And what is the main strategy? Taxes, penalties, collecting facilities, PSP, safe disposal, treatment, other………….
5. Is there any law governing the management of waste to reduce coastal littering?
6. Do you pay for the waste collection? If yes how effective is the waste collection and SWM within your vicinity?
7. What are the penalties for coastal littering/waste within your community (**What is your opinion about the effectiveness of the penalties)**

o Monetary fine
o Imprisonment
o Other *Specify*:

8. What are the main barriers you have experienced in dealing with coastal littering and with regard to a successful SWM?
9. Is there any community participation to reduce litter and waste around you? If yes what measures have you/your community taken in order to respond to littering/solid waste problem?
10. What are your motivations, activities and what resources do you have to reduce this marine litter? Resources-financial, skills, monthly sanitations, other………..

Part C impacts

11. What are the sources and types of marine litter?
12. What are the impacts that coastal littering has caused?

Ruins Aesthetics of the area ☐
Injuries to people ☐
Environmental threat to society ☐
Lack of accessibility to facilities, beaches, ☐
Threat to particular sea species ☐

13. Do you believe that litter is causing any problems to you? If yes what happened
14. Wounds ☐ Diseases ☐ discomfort ☐ economic ☐

Part D: Evaluation

15. What do you consider the most pressing problem regarding MSWM[3] in the coastal areas and why?

Collection ☐ transport ☐ disposal ☐ others ☐…………………..

16. What suggestions can you provide to improve waste management /coastal littering reduction?

- More involvement of private business partners or local communities?
- Conducting of educational activities and specific targeted campaigns?
- Economic incentives for manufacturers and small monetary rewards for coastal dwellers?
- Provision of more trash bins in public areas?
- Increase penalties and fines?
- Other

Thank you for responding positively to this interview. Your assistance and cooperation are greatly appreciated!

[2] Stakeholders: Different actors involved in litter generation.
[3] Municipal Solid Waste Management

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Full Length Research Paper

Design, realization of a fixed bed downdraft gasifier and conduction of preliminary gasification tests with balanites aegyptiaca hulls, rice husk and charcoal

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This work is focused on the design and testing of a co-current fixed bed gasifier with two air injections. The electric power of the gasifier was set at 10 kW. The design is based on experimental data relating to specific gas production rate, engine power efficiencies, biomass flow rate, pyrolysis and reduction time etc. The gasification tests were conducted with rice husk, hulls of balanites aegyptiaca and charcoal. The realized gasifier has a diameter of the grid and a total height of 14 and 87 cm, respectively. A mass of 6.7, 17.9 and 10.8 kg were respectively gasified for rice husk, hulls of balanites aegyptiaca and charcoal. The highest temperatures (968°C in the oxidation zone) were obtained during charcoal gasification with a reaction time of 244 min. the temperature of 625°C in the oxidation zone and a reaction time of 114 min were obtained for the gasification of the hulls of balanites.

Key words: Gasification, design, rice husk, balanites aegyptiaca hulls, charcoal.

INTRODUCTION

The socio-economic context of the African countries is characterized by a strong demography and low per capita income, particularly for the countries of the West African Economic and Monetary Union (UEMOA). The UEMOA countries must ensure a strong economic growth in order to achieve a sustainable development of their populations. The achievement of such economic growth requires the increase of productivity particularly in the primary or even secondary sector. It is in this context that access to modern energy services such as electricity is

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essential because it helps to promote access to resources (water ...) necessary for the development of all sectors of the economy. Indeed, the rate of access to electricity in rural and urban areas of the UEMOA area is very low. In addition to weak economic growth, the lack of access to modern energy services such as electricity results in the predominance of traditional biomass which accounts for almost 80% of primary energy supply compared to 15% for hydrocarbons and only 5% for electricity (UEMOA, 2006). This is reflected by the deforestation aggravation, hence the need to find sustainable alternative sources and to modernize the biomass use as energy. Many efforts have to be made by African countries in this field. Indeed, biofuel generates 4% of electricity in Europe against the zero in Africa in 2017 (IEA, 2018). In such a context, the energy recovered from agriculture residues can make a significant contribution to improve the access to modern energy services. In addition to agricultural residues, forestry residues are recommended by Long et al. (2013) to increase the biomass potential to achieve a secure raw material supply for biomass energy conversion technology like gasification. Gasification is the production of a gaseous fuel from a solid fuel. The gas produced during the gasification can be used for heat and power production.

The development of this technology in the UEMOA zone requires on one hand a fully control of the techniques of design and realization of gasifiers and on the other hand an improvement of the performances of the process. The major difficulty related to the control of the process of gasification of biomass is related to the presence of tars in the gas. Indeed, the gas is generally produced with a high content of tar and dust. Gas treatment is needed before most applications, especially in an internal combustion engine. For these types of applications oriented towards electric and power production scrubbing and filtering of the gas are essentials to avoid embedding in the engine pipes. The additional cost of gas cleaning involves the increase of the production cost per kilowatt-hour (kWh) as well as the investment cost. The gasification technology still needs to be improved in order to compete in the energy market (Anjireddy and Sastry, 2011). It should be noted that the co-current type fixed-bed gasifier produces the least tar compared to other types of gasifiers, (Milne et al., 1998). This justifies the choice of this type of gasifier for the present study. It should also be noted that the design of a gasifier plays a crucial role in the efficiency of gasification, the gas heating value and the tars formation (Cao et al., 2006). For example, the injection of secondary air at the level of the biomass feed can lead to a reduction up to 88.7% in mass of total tars content (Pan et al., 1999); hence the importance of providing a secondary air supply on the gasifier. The objective of the work is to design, build and test a co-current type fixed bed gasifier equipped with a secondary air supply. Agricultural and forestry residues such as rice husk and balanites aegyptiaca hulls were tested. The gasification of wood charcoal was also tested during the works.

MATERIALS AND METHODS

Design method

The gasifier is composed of a drying zone, a pyrolysis zone, oxidation zone and a reduction zone (Figure 1). A throat has also been provided in the oxidation zone to allow better thermal cracking of the tars. To dimension the Imbert gasifier, we can proceed as follows:

(1) Set the nominal electrical power required (P_e) and the gasifying agent;
(2) Choose the type of fuel (wood, rice husk, charcoal…), the gas lower heating value (LHV) and the efficiency of the electric conversion of the gas by the engine (r_m);
(3) Determine the appropriate parameters for sizing the gasifier using mathematical formulas, interpolation or experimental data.

The appropriate parameters for the design of the Imbert generator are: the throat diameter (d_{gr}) located above the reduction zone, the tuyeres diameter (d_r), the diameter of the charging zone (drying and pyrolysis) (d_c), the diameter of the nozzles (d_n), the height of the charging zone (H_c), the height of the inclination zone (H_i), the height of the reduction zone (H_r), the position of the tuyeres (h_{a1}), the inclination angle of the throat (α).

Choice of gasifier data

Choice of electric power and gasifying agent

The thermal power of the gasifier is of the order of 30 kW. This will meet the needs of low mechanical power (P_e) of the order of 10 kW. The use of air as a gasifying agent is inexpensive and the produced gas has a low LHV (varying between 3 and 5 MJ/Nm^3) but sufficient for the electrical and thermal production. Thus, air was chosen as a gasifying agent for this study.

Choice of biomass, LHVof the gas and electrical efficiency of gasification

The gasifier is intended to be fed by a wide range of biomass, particularly agroforestry residues (rice husk and hulls of egyptiacabalanites). The HHV of the gas depends on the nature of the biomass used. A low HHV of the gas must be chosen for the gasifier sizing thus the targeted electrical power can be achieved even though the biomass produced gas has a very low calorific content. A gas HHV of 3 MJ/Nm^3 was considered in this study. The electrical efficiency, which represents the ratio of the electric power to the thermal power of the biomass, depends on the performance of the device. Electrical efficiencies ranging from 25 to 27% have been reported in the literature (Henriksen et al., 2006, Mukunda et al., 1994). The electrical efficiency of 25% was considered in this study.

Determination of appropriate parameters

Gas flow

The determination of the gas flow d_g(m^3/s) (Equation 1) makes it

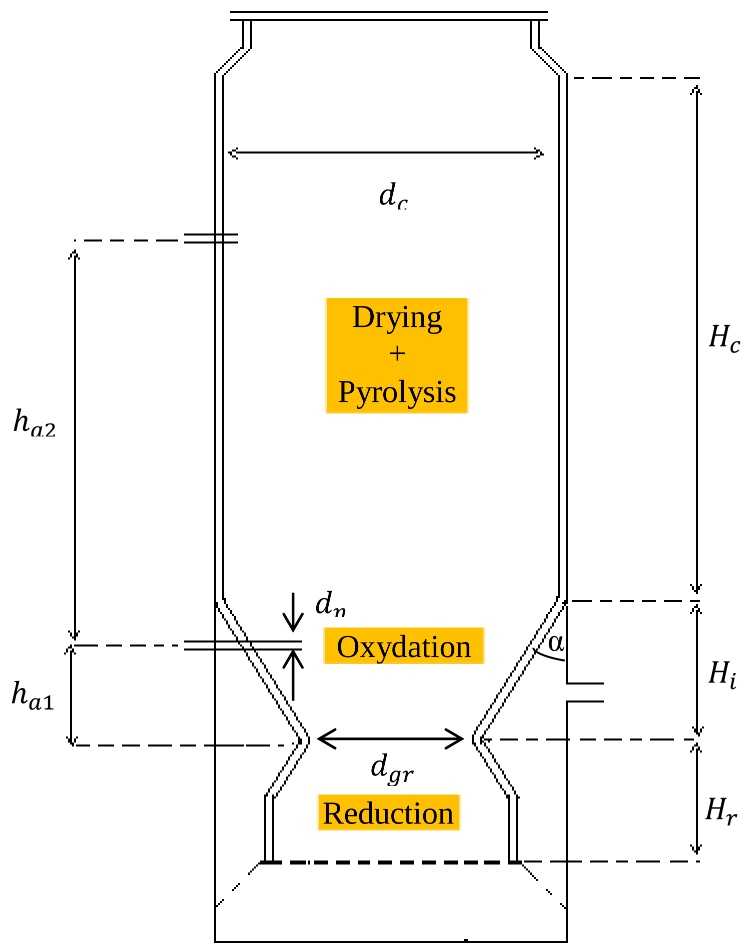

Figure 1. The different zones of the gasification and the basic dimensions of the gasifier.

possible to calculate the specific gas production rate, p_s.

$$d_g = P_e / r_m \times LHV_{gaz} \quad (1)$$

r_m: Engine efficiency; LHV_{gaz} : Lower heating value of the gas (3-5 MJ/Nm^3).

Throat diameter

The throat diameter is determined from experimental data of the specific gas production rate. The specific production, p_s ($m^3.cm^{-2}h^{-1}$) and the throat surface are given by Equation 2. The throat diameter, $d_{gr}(cm)$, is deduced from Equation 2 according to Equation 3.

$$p_s = 3600\, d_g / S_{gr} \quad (2)$$

$$d_{gr} = 2\sqrt{S_{gr}/\pi} \quad (3)$$

The throat load also called the specific gasification rate, p_b(Equation 4), can be used instead of the specific production. p_b represents the fuel consumed per hour per cm^2 of the throat. The fuel mass can be estimated from the amount of the produced gas. Considering one kilogram of biomass produces around 2.4 to 2.5 m^3 of gas, the fuel load per hour or the biomass consumption rate is given by Equation 5.

$$p_b = p_s / 2{,}4 \quad (4)$$

$$m_b = d_g / 2{,}4 \quad (5)$$

Tuyeres position and nozzles diameter

The position of the air tuyeres is obtained by the ratio, a_1, between the position of the air inlets and the throat diameter in accordance with equation 6 (Swedish Academy of Engineering Sciences, 1979).

$$h_{a1} = a_1 d_{gr} \quad (6)$$

The diameter of the nozzles is also obtained based on the diameter of the grid (Swedish Academy of Engineering Sciences, 1979).

Diameter of the pyrolysis zone and the height of the inclination zone

The diameter of the pyrolysis zone is of the order of 4 to 2 times the diameter of the throat (Swedish Academy of Engineering Sciences, 1979). Thus for this study, the diameter of the pyrolysis zone, d_p, is 3.5 times the diameter of the throat (Equation 7).

$$d_c = 3.5\, d_{gr} \tag{7}$$

The height of the inclination zone (H_i) is given as a function of the angle of inclination or throat angle (α) through the Equation 8:

$$H_i = \tan\alpha \times \left(d_c - d_{gr}\right)/2 \tag{8}$$

The recommended value of angle α is in the range of 45° to 60° (Venselaar, 1982).

Height of the pyrolysis and reduction zone

The following simplifying assumptions can be made for determining the heights of the pyrolysis and reduction zone. The calculation of heights was based on the estimation of the fuel flow velocity and the time of pyrolysis and reduction (Reed and Levie, 1984). The flow velocity of the loaded combustible is given by equation 9 (Reed and Levie, 1984).

$$v_b = m_b/(S \times d_c \times \rho_{bulk}) \tag{9}$$

ρ_{vrac} the bulk density of the combustible load, S is the cross-sectional area of the pyrolysis zone. The pyrolysis time (equation 10) is determined by the ratio of the sum of the heat required for pyrolysis and the evaporation of water by the heat transfer flux of this zone (Reed and Levie, 1984).

$$t_p = \left(\left(h_p + \tau_h \times h_e\right) \times V_p \times \rho_{bulk}\right)/\left(q \times S_p\right) \tag{10}$$

The terms h_p, h_e, τ_h, V_p, q and S_p respectively correspond to the heat required for the pyrolysis, the heat of the steam, the moisture content, the volume of the fuel particle, the heat transfer flux in this zone and the total lateral surface of the fuel particle. The time of charcoal reduction can be taken as 100 s regardless of the type of biomass (Reed and Levie, 1984). The heights of the pyrolysis and reduction zone will be given by Equations 11 and 12.

$$H_p = t_p \times v_b \tag{11}$$

$$H_r = t_r \times v_b \tag{12}$$

The height of the drying zone (Equation 13) located above the pyrolysis zone has been estimated to contain the hourly fuel load (m_b).

$$H_s = m_b/\rho_{bulk} \times S \tag{13}$$

The height of the charging zone (drying and pyrolysis zone) is given by the sum of the height of the pyrolysis zone and the drying zone (Equation 14).

$$H_c = H_s + H_p$$

Gasification tests

Preliminary tests were carried out with the realized gasifier. Charcoal, rice husks and balanites hulls were used for the gasification tests (Figure 2).The biomass is weighed with an electronic balance of precision 5 g before filling progressively the gasifier. Four type K thermocouples were placed along the gas generator. A temperature recorder of the type Testo 176 T4 was used for temperature recording every 10 s. The process of gasification is done by introducing nearly one kilogram of biomass into the gasifier. Then about two hundred grams of charcoal are ignited and then introduced into the gasifier. Subsequently, the gasifier is filled and closed. Gas production begins once the flame ignites at the flare. The end of the gasification is indicated by the extinction of the flame and then the temperature drops at the gasifier bottom.

RESULTS AND DISCUSSION

The gasifier dimensions

The data used are summarized in Table 1. The typical value of the specific gas production rate (p_s) is 0.9 $\mathrm{m^3.cm^{-2}h^{-1}}$ for an Imbert-type gasifier (Brandini, 1983). Thus the value of 0.9 $\mathrm{m^3.cm^{-2}h^{-1}}$ was considered in this study. The height, h_{a2}, between the primary and secondary air tuyeres has been estimated so that the secondary air tuyeres will be placed at the fuel bed top. The dimensions considered for the gasifier realization are different from those estimated in order to take into account the technical capacity and the dimension of the available materials. The used values for the gasifier realization and theoretical estimated values are summarised in Table 2. The gasifier is shorter, but has a slightly larger reactive zone than the gasifier designed on the basis of calculations. The image of the gasifier is shown in Figure 3.

Results of gasification tests

The evolution of the temperature within the gasifier according to the time for each type of biomass used is given in Figure 4. Temperature rapid increase is observed during the gasification of agricultural residues (balanites hulls and rice husks) which is due to the rapid combustion at the primary air inlet at the beginning of the gasification trials. The temperatures dropped significantly after the reactor was closed during the gasification of raw agricultural residues. Thus, the oxidation front situated at the hottest point of the reactor stabilizes near the primary air inlet (at T_3) in the case of balanites hulls and charcoal. Gas production, which is indicated by gas ignition at the flare, occurs rapidly (less than 5 min after reactor closure) in the case of balanites hulls.

Figure 2. Biomass used for the gasification tests; (A) Charcoal, (B) *Balanites aegyptiaca* hulls, (C) rice husk.

Table 1. Data taken into account for the estimation of reactor dimensions.

Data	Values	Reference
Electric power (kW)	10	Estimation
Electicity efficiency	0.25	Estimation
LHV of the gas (MJ/Nm^3)	3.0	Estimation
$p_s(m^3.cm^{-2}h^{-1})$	0.9	Estimation
Biomass bulk density(kg/m3)	300	Estimation
Hp (J/kg)	2081000	Reed et Levie, 1984
he (J/kg)	3654000	Reed et Levie, 1984
Moisture content (%)	20	Estimée
q (W/m^2)	20000	Reed et Levie, 1984
Biomass particle size (m)	0.02	Estimation
Throat angle (α)	55°	Estimation

Table 2. Estimated and used dimensions of the reactor.

Characteristics	Estimated dimensions	Dimensions of the realized gasifier
Volume flow rate of the gas, $\boldsymbol{d_g}$(m^3/h)	40.0	-
Biomass consumption, $\boldsymbol{m_b}$(kg/h)	16.7	-
Throat diameter, $\boldsymbol{d_{gr}}$(cm)	7.5	14
Ratio, $\boldsymbol{a_1}$	1.2	-
Tuyeres diameter, $\boldsymbol{d_r}$(mm)	10	35
Position of the primary air tuyeres, $\boldsymbol{h_{a1}}$(cm)	9	27
Position of the secondary air tuyeres, $\boldsymbol{h_{a2}}$(cm)	100	50
Tuyeres number	5	3
Biomass flow velocity (cm/s)	0.11	-
Pyrolysis time (s)	131.5	-
Diameter of the pyrolysis zone, $\boldsymbol{d_c}$ (cm)	26.3	30
Height of the reduction zone, $\boldsymbol{H_r}$ (cm)	10.8	17
Height of the inclination zone, $\boldsymbol{H_i}$ (cm)	13.4	20
Height of the pyrolysis zone, $\boldsymbol{H_p}$ (cm)	14.1	-
Height of the drying zone, $\boldsymbol{H_s}$ (cm)	102.0	-
Height of the charging zone, $\boldsymbol{H_c}$ (cm)	116.1	50
Total height of the reactor (cm)	140.3	87

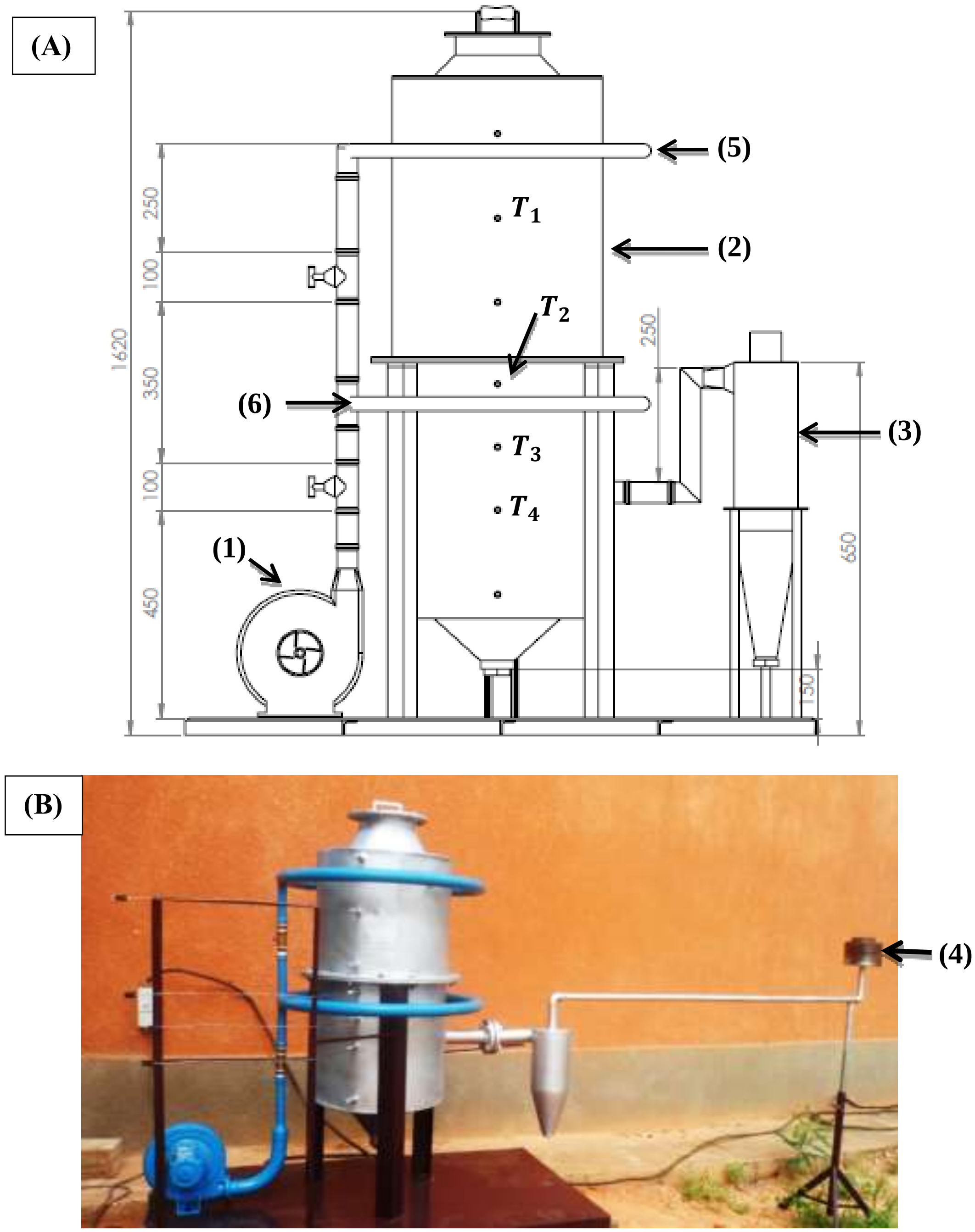

Figure 3. Schematic diagram (A), and Image of the gasifier (B). Position of the thermocouples and the different components of the device are represented: (1): Blower; (2): Reactor; (3) Cyclone; (4): Flare; (5): Secondary air tuyeres; (6): Primary air tuyeres.

Contrarily to the gasification of balanites hulls and charcoal, the front of the oxidation stabilized at the bottom of the reactor (at the level of T_4) during the gasification of the rice husk. Thus, the absence of a reduction zone at the bottom of the oxidation front has led to the absence of flame at the flare. A flowing problem of the rice husk inside the reactor was observed after the gasification test. Indeed, the rice husk remains blocked in the upper part of the reactor (pyrolysis zone).Thus, the temperatures drop after burning the rice husk at the gasifier bottom. As a result, an agitator system is needed for future improvement of the gasifier. The biomass agitation system at the top of the reactor will force the rice husk to flow downward inside the gasifier.

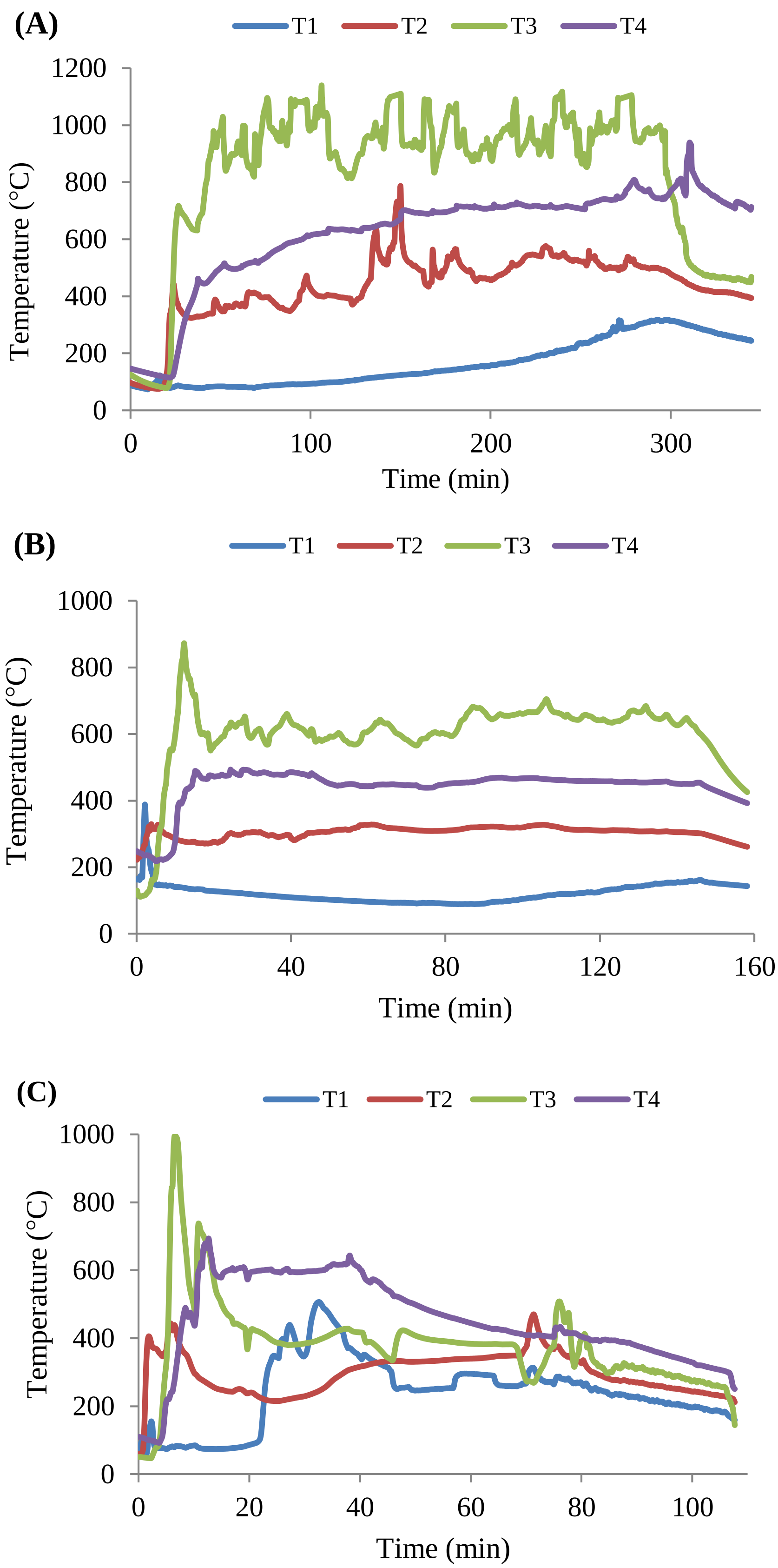

Figure 4. Temperatures in function of time during gasification tests, (A) case of charcoal; (B) case of balanites hulls; (C) case of the rice husk.

Table 3. Average temperatures, reaction durations and hourly and specific consumption during gasification tests.

Combustible type	Charcoal	Rice husk	Balanites hulls
T_1averagein drying zone (°C)	154	282	109
T_2average in pyrolysis zone (°C)	473	291	309
T_3average in oxidation zone (°C)	968	408	625
T_4average in reduction zone(°C)	664	547	462
Consume combustible (kg)	10.8	6.7	17.9
Mass of the residues (kg)	1.9	-	1.8
Gasification duration (min)	244	54	114
Biomass consumption rate (m_b en kg/h)	2.2	4.8	7.2
Specific gasification rate ($\mathrm{kg.m^{-2}h^{-1}}$)	143	313	438

The average temperatures, reaction durations, biomass consumptions and specifics gasification rate obtained during the gasification trials were summarized in Table 3. The results show a high average temperatures and unconverted carbon (residues) and low biomass consumption rate obtained for charcoal gasification comparatively to the raw biomass gasification. Similar results were achieved by other authors (Harouna et al., 2018). The lower reactivity of charcoal comparatively to raw biomass is the principal cause of this fact. More investigations are needed to increase the combustible consumption by improving the air flow per example in order to increase the output power of the gasifier while it is mainly fuelled with charcoal. The injection of steam and air mixture may also help to improve the gasification process (He et al., 2012; Lv et al., 2004). This issue will be addressed during the future study for improving the gasification system designed and realized in the present work.

Furthermore, the biomass consumptions rate obtained are under the estimated consumption of 16.7 kg/h (Table 2). This explains the low specific consumptions obtained especially during the gasification of charcoals for which a specific consumption of 143 $\mathrm{kg.m^{-2}h^{-1}}$ was obtained. Indeed, for this type of reactor a minimum specific consumption of 509 $\mathrm{kg.m^{-2}h^{-1}}$ has been reported by Kaupp and Goss (1981). The low biomass consumption and the specific consumption is probably due to a low airflow, hence the need to review the blower power and the gasifier's air supply system by increasing the number of air inlets from 3 to 5 at least in the oxidation zone.

Conclusion

A co-current type fixed bed gasifier has been designed, constructed and tested in the present study. The mechanical power of 10 kW was targeted which led to an estimated biomass consumption of 16.7 kg/h and a throat diameter of 7.5 cm. The produced gasifier has a larger reactive zone than the gasifier designed with a throat diameter of 14 cm. However, a low biomass consumption of 2.2, 4.8 and 7.2 was obtained during the gasification of charcoal, rice husks and balanites hulls respectively. This is due to a low air flow hence the need to increase the power of the blower and increase the number of air inlets from 3 to 5 at the oxidation zone of the gasifier. A flowing problem of biomass was observed after the gasification test of the rice husk. This did not allow the production of gas during the gasification of the rice husk hence the need to design and install an agitator system of biomass in the upper part of the gasifier.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Shared household septic tank: A case study of Fiapre in the Brong Ahafo Region of Ghana

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This study investigated the feasibility of utilizing composite septic tank to reduce cost, save space and prevent faecal related diseases. Survey research methodology was adopted based on people's experience with septic tank, water use, soil properties, land space, user numbers and user satisfaction. The study also provides procedure in the design of a two-compartment septic tank with soil absorption field for three composite houses of thirty residents. Calculation utilizing Brazilian code was employed in the sizing of a two-compartment septic tank, which considers the tank in four zones; the scum zone, the sedimentation zone, the sludge digestion zone and the sludge storage zone. It was found that majority of the residents in the study area connected with septic tanks are not only willing to share composite septic tanks but are also financially capable of constructing and maintaining it. Shared septic tank coupled with suitable conditions is cost effective for households.

Key words: Shared septic tank, households, sanitation, septic tank design, cost effective.

INTRODUCTION

Sanitation systems are systems designed to collect, store, process or treat and dispose human waste and other forms of waste back to nature in a safe way avoiding excreta-related diseases and pollution to the environment (Ahmad, 2015). Providing sanitation to people requires a system approach rather than only focusing on the toilet or wastewater treatment plant itself. The experience of the user, excreta and wastewater collection methods, transportation or conveyance of waste treatment and reuse or disposal all need to be thoroughly considered (Duncan, 2004). The main objective of sanitation systems is to protect and promote human health by providing a clean environment and breaking the cycle of disease (WHO, 2015). Effective sanitation systems provide barriers between excreta and humans in such a way as to break the disease transmission cycle, for example in the case of faecal-borne diseases.

Water resources are under increasing pressure. Continuing population growth, urbanization, rapid industrialization as well as expanding and intensifying food production all put pressure on water resources (UN,

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2015). Most houses are built with access to running water as a priority. Access to running water raises the need of sewerage disposal systems to dispose waste water safely to the environment, minimizing the risk of excreta-related diseases and pollution to the environment.

In most developing countries across the world, most people rely on the septic tank systems for sewerage treatment and disposal because of the relatively low cost as compared to conventional network sewerage system. The septic tank is a water tight chamber constructed beneath the earth surface, designed to receive and treat household sewerage (black water and grey water/ just black water) so that the effluents discharged from the tank to the environment have little or no chance of causing excreta-related diseases or pollution to the environment as well as factory nuisance (Carr, 2001).

According to WHO standards, septic tanks should not be used in areas with high water tables or areas with groundwater as the main source of drinking water and in soils with low permeability. Septic tanks must be emptied periodically at least every three years and the solids disposed of hygienically (Vaughan , 2013). This is usually done with a vacuum tanker. Septic tanks allow safe disposal of waste water particularly in rural areas where it might otherwise go directly into rivers. Therefore, in a typical situation like Fiapre community, where onplot latrines dominate and their contents are basically blackwater, septic tank is the commonest form of wastewater treatment system to be used in dealing with the treatment of the faecal waste (GSS, 2000). Septic tanks have advantages of little maintenance, isolation and partial treatment of excreta, little odor or few problems and the possibility of subsequent sewerage system (Reed, 2011).

Septic tanks or their disposal systems must be installed to ensure minimum clearance distances from:

1. The highest ground water level,
2. Water supplies such as bores, creeks, and dams,
3. Buildings and boundaries,
4. Subsoil and open drainage channels.

They should not be located where vehicles will drive over them. The weight of a vehicle may damage system components and compact the surrounding soil which reduces its ability to absorb effluent (WAPHD, 2014). Drainage characteristics of soils are of importance in both sizing and sitting of drainage receptacles. In poor draining soils, such as clay, bigger drainage receptacles are needed to increase the area of soil into which the effluent can be absorbed (WAPHD, 2014). In contrast, some coarse sands can be so free draining they provide little ability to filter out pollutants. In these cases, it may be desirable to surround the sides and base of drains with loam or other fine-grained soil (WAPHD, 2014). In areas with either shallow groundwater where only a thin layer of free draining topsoil overlies less absorbent soils, the drainage receptacles may need to be installed fully or partially above the natural surface. This is to allow effluent to be dispersed into and be absorbed by surrounding soils (WAPHD, 2014) as shown in Figures 1 and 2.

The main aim of this research was to design a septic tank for 3 composite houses of 30 residents. In order to achieve this aim the following objectives shall be considered;

1. Propose an alternative model option to existing domestic septic tanks.
2. Design a two compartments septic tank based on calculations with a soil absorption field for the proposed design.

METHODOLOGY

This research adopted a mixed methodology coming from qualitative means through structured questionnaire and quantitative study through calculations of design parameters. The calculations of the design parameters were based on the information received from the respondents through the structured questionnaire.

The study area

Fiapre is a suburb of Sunyani, the regional capital of the Brong Ahafo Region of Ghana. It is about 10 km from Sunyani. It shares boundary with Sunyani to the north, Nsoatre to the south, Odumase to the west and Baakoniaba to the east within the Sunyani west District (SMA, 2010). Fiapre is an urban community constituting 10.19% of Sunyani West district's population (SMA, 2010).

The use of septic tank has not been encouraging in Fiapre. This is due to relatively high cost of construction for many households. The selection of the study area was made after taking into consideration the following factors:

1. Availability of water,
2. Relatively poor sanitation situation,
3. Relatively low-level use of septic tanks,
4. Location and topology of the area,
5. Proximity advantage for the study.

The target population for this study consists of residents of Fiapre who use latrines that are connected to septic tanks. Sample size for this study was 100 households.

Data collection

Information gathered for the study was mainly primary and secondary. The primary data were information gathered from the field through the administration of a structured questionnaire. This was complemented with secondary data through a comprehensive review of journal articles and trusted publications from other sources.

For this study, questionnaires were used to get and understand people's ideas and opinions on the design and use of septic tanks. The daily toilet facility usage as well as the source of water used by residents in the study area was surveyed to ascertain the rate of filling and emptying of the septic tanks. As a main tool in qualitative research, interviews were conducted to ascertain users' willingness and acceptability of the shared septic tank concept. The qualitative interview is a very good way of accessing people's perceptions,

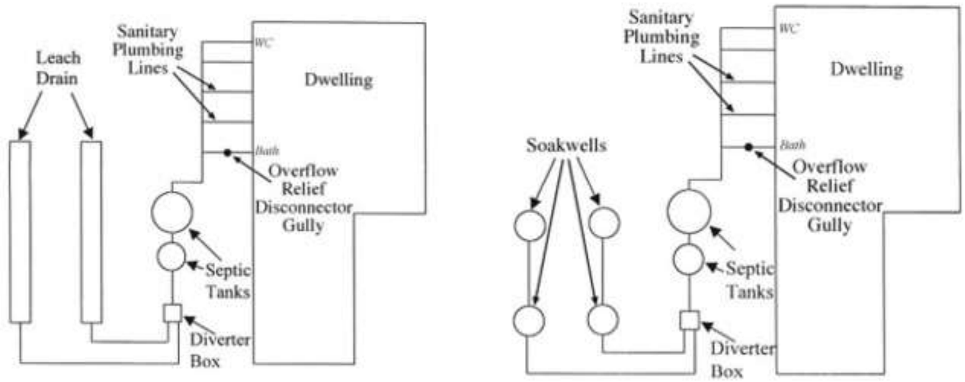

Figure 1. A septic tank and leach drain system (L) and soakaway system (WAPHD, 2014).

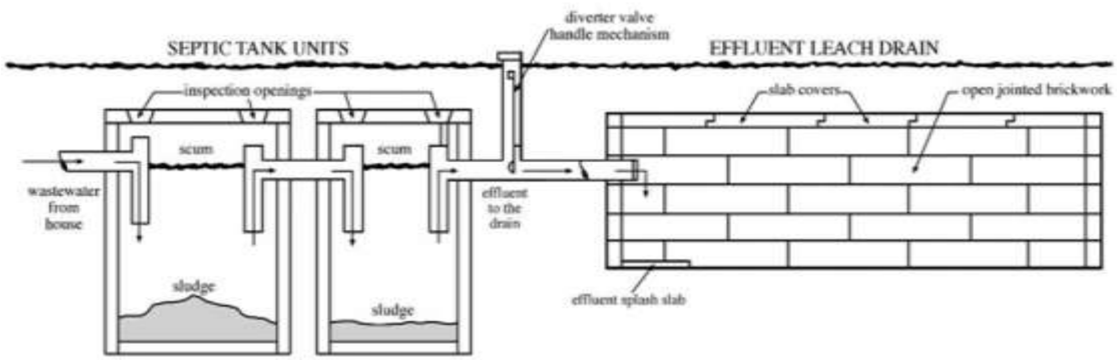

Figure 2. The side view section of a septic tank with one leach drain (WAPHD, 2014).

meanings, and definitions of situations and constructions of reality (Punch, 2006). Sampling method was used to study just a section of the population at a particular place at a point in time (Miles et al., 1994). Since Fiapre is quite populated, not everyone with a septic tank was included in this exercise, though the questionnaire was administered to a sizable number of the population. Data collected from the sampled number were treated as data for the whole of Fiapre community with septic tanks. Random sampling was employed for this activity, giving each one an equal probability of being selected for the data collection.

Shared septic tank design and assumptions

The total number of people to use this shared tank is estimated as thirty (30) persons comprising three households. Calculations were used to determine the volume of the tank required to receive and treat wastewater coming from these three households. The calculations were based on the user population, wastewater flow per capita per day, sewage generation and sludge accumulation rate. Also, the capacity indications for septic tanks for residential households and typical dislodging periods for septic tanks according to size of households as seen in Tables 1 and 2 respectively were also taken into consideration. Assumptions were made on the wastewater flow rate. Here it was assumed that 85% of the water consumed by an individual comes out as waste whiles the rest of the water is absorbed by the body.

Data analysis

Data collected from the administering of questionnaires was analyzed using statistical package for social science (SPSS), data analyses software. The carefully recorded information was inputted in SPSS to generate pictorial results of the analyses, including tables, and charts to visualize the data.

RESULTS AND DISCUSSION

Water usage points

Septic tanks are designed based on the volume of wastewater produced. Knowing the water usage points connected to the system will help to estimate the amount of wastewater that could enter the tank. From Figure 3 the results obtained from the survey shows that 93% of the houses surveyed had only their toilet facilities connected to the septic tank. The remaining 7 houses had both their bathroom and their toilets connected to the septic tank. The challenge here is that households with both bathroom and toilet connected to the septic tank will contribute more towards the filling rate of the septic tank. Therefore, in a situation of shared septic tank facility, an

Table 1. The minimum septic tank capacities for residential houses. (LRD, 2016).

Tank Size (gals)	Household size (Number of people)									
	1	2	3	4	5	6	7	8	9	10
500	5.8	2.6	1.5	1.0	0.7	0.4	0.3	0.2	0.1	-
750	9.2	4.2	2.6	1.8	1.3	1.0	0.7	0.6	0.4	0.3
1000	12.4	5.9	3.7	2.6	2.0	1.5	1.2	1.0	0.8	0.7
1250		7.5	4.8	3.4	2.6	2.0	1.7	1.4	1.2	1.0
1500		9.1	5.9	4.2	3.3	2.6	2.1	1.8	1.5	1.3
1750			6.9	5.0	3.9	3.1	2.6	2.2	1.9	1.6
2000			8.0	5.9	4.5	3.7	3.1	2.6	2.2	2.0
2250				6.7	5.2	4.2	3.5	3.0	2.6	2.3
2500					5.9	4.8	4.0	4.0	3.0	2.6

Table 2. Dislodging periods of septic tanks in years according to size and household (LRD, 2016).

Bedrooms (Number)	House size (square feet)	Tank capacity [without water-saving devices] (galons)	Tank capacity [with water saving devices] (gallons)
1 or 2	Less than 1500	750	750
3	Less than 2500	1000	750
4	Less than 3500	1250	1000
5	Less than 4500	1250	1250
6	Less than 5500	1315	1250

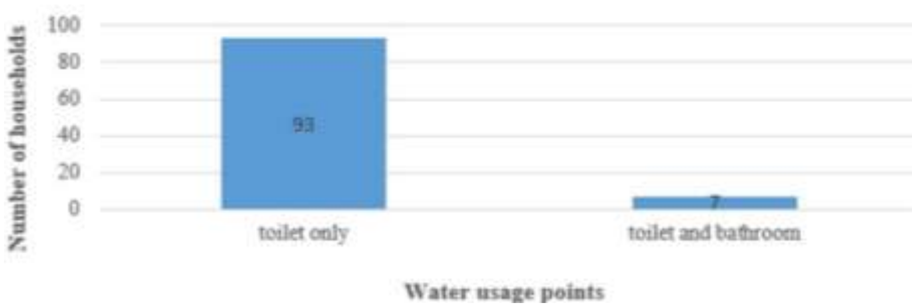

Figure 3. Water points connected to the septic tank in the household.

arrangement or agreement should be reached where proportional payment based on rate of usage will be made. Households were therefore asked if they would agree with such arrangement. Overwhelming majority of the households (about 96%), said they would agree to the proportional payment based on rate of usage in terms of what (toilet and or bath) is connected to the shared septic tank.

Toilet facility usage

The results showed that individuals in 60 out of the 100 houses surveyed, use their toilet facility twice in a day whiles the remaining 40 houses use their toilet facility once in a day as shown in Figure 4. The significance of this is to determine how often the system is used. This will help to know the rate of usage and filling rate of the septic tank. Households interviewed reported that they would not mind sharing septic tank facilities irrespective of how many times a household uses the toilet facility since it is impossible to record how often one uses a toilet facility in a day.

Water source

The results from (Figure 5) the survey showed that 78 out

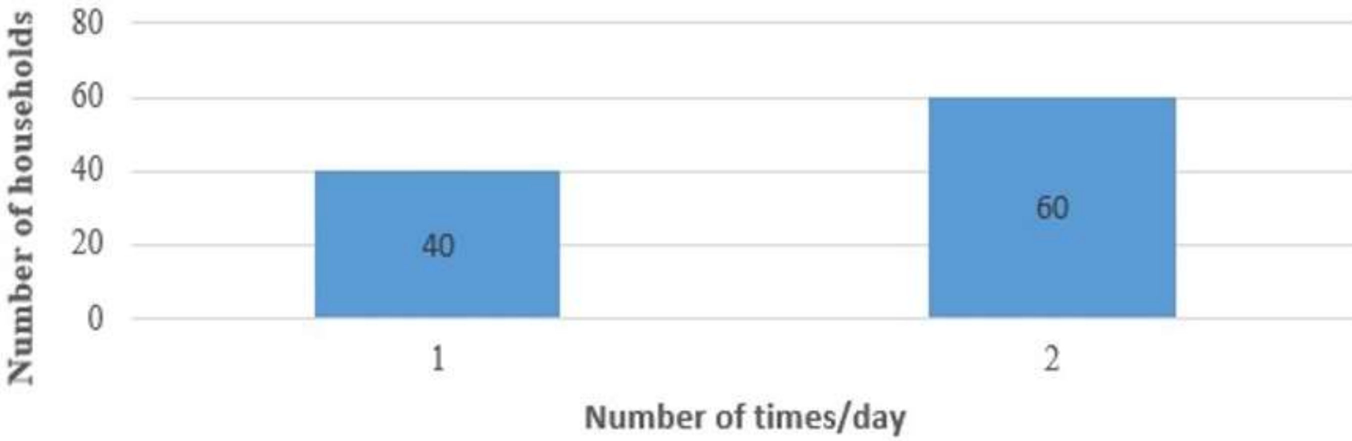

Figure 4. Toilet facility usage for each individual per day in the houses surveyed.

of the 100 houses surveyed are connected to a stand pipe system. 15 houses out of the remaining 22 use wells with pumps, while the remaining 7 use wells without pumps. Septic tanks are wet onsite sanitation systems which need water to function properly. This survey helps us to know the availability of water in the area which, in turn, helps to determine whether or not the area is suitable for septic tank installation. From this survey, it was found out that water is available to flush toilets and so water availability will not constrain the use of shared septic tank facility.

Major forms of occupation of residents

Figure 6 shows that residents in 45 out of the 100 houses surveyed are self-employed, 19 houses had residents who work in private sectors and 32 houses with residents work for the government sector. This implies that all the households interviewed are working, therefore there is the means for supporting the shared facility financially.

Willingness and acceptance of shared septic tanks

From the survey conducted, 84% of respondents were very happy with the shared septic tank facility if the average cost per household was cheaper than a household owning and maintaining own septic tank. However, 16% were either sceptical or unhappy about such facility. Some of the concerns raised included lack of cooperation from other households, non-compliance to payment rules and arrangement and difficulty in revenue collection towards emptying and maintenance especially when it becomes necessary to connect a distribution box to a drain field to evenly distribute the effluents coming from the tank to the soil (Awuah, 2012).

Septic tank design calculations and cost implications

Overall design capacity

The overall design volume under the Brazilian septic tank code is the sum of the volume of the four zones described by the approach (Ahmad, 2015). The four zones under the Brazilian septic tank code include:

1. The scum layer
2. The sedimentation zone
3. The sludge digestion zone
4. The sludge storage zone

$$V_T = V_{sc} + V_h + V_d + V_{sl} \quad (1)$$

Where, V_T is the total volume of the tank; V_{sc} is the volume of scum storage zone; V_h is the volume of the sedimentation zone; V_d is the volume of the digestion zone and V_{sl} is the volume of the sludge zone.

The sedimentation zone

In the septic tank the velocity of the black water is reduced greatly and allows the heavy particles (faecal matter) to settle when gravity works on it. The rate at which the faecal matter and other settleable solids settle in the tank is dependent on the number of users of the facility (Ahmad, 2015). The formula for finding the volume of the sedimentation zone is given as:

$$V_h = 10^{-3} \times P \times Q \times t_h \quad (2)$$

P is the user population, Q is the wastewater flow per

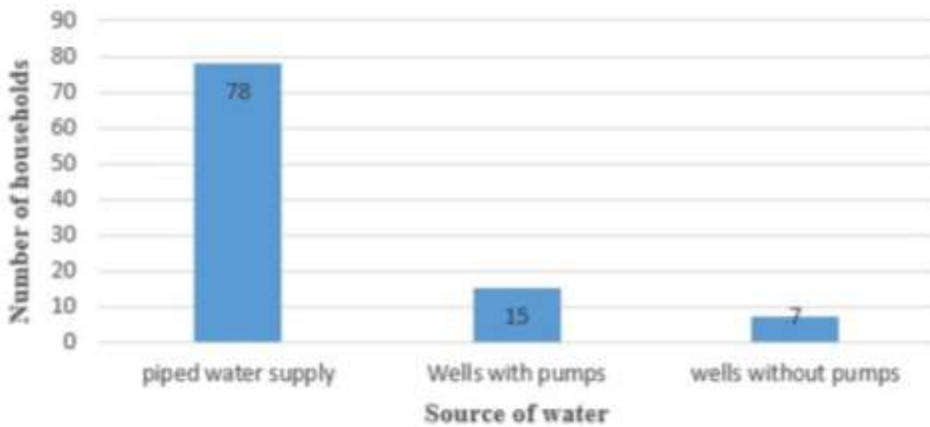

Figure 5. Sources of water for the houses surveyed.

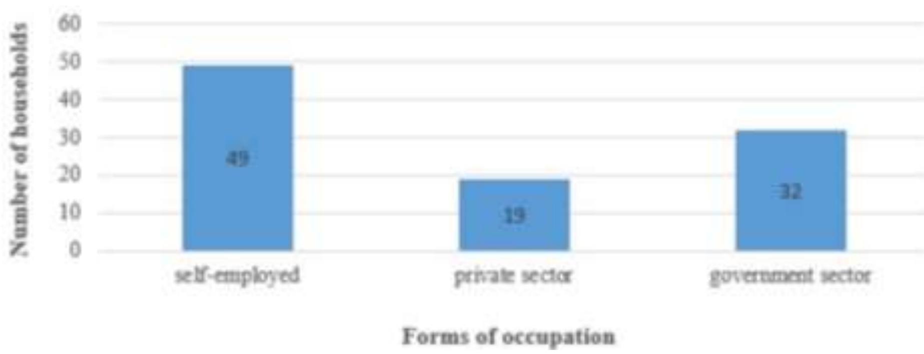

Figure 6. Major forms of occupation for residents in the houses surveyed.

person in litres/day and t_h is the minimum mean hydraulic retention time in days.

$t_h = 1.5 - 0.3\log(PQ)$

$P = 30$ people

Average water consumption rate is 20 lpcd (CWSA, 2010)

$$Q = \frac{85}{100}(20\ \text{lpcd}) = 17\ \text{lpcd}$$
$t_h = 1.5 - 0.3\log(30 \times 17) = 0.6877$ days
$V_h = 10^{-3} \times 30 \times 17 \times 0.6877 = 0.35\text{m}^3$

Sludge digestion zone

$$V_d = 0.5 \times 10^{-3} \times P \times t_d \quad (3)$$

t_d is the time for anaerobic digestion.

The time, t_d needed for the digestion of sludge in the tank is dependent on temperature (Ahmad, 2015).

$t_d = 30(1.035)^{35-T}$, T is the temperature in degrees Celsius
$t_d = 30(1.035)^{35-20} = 50.261$ days
$V_d = 0.5 \times 10^{-3} \times 30 \times 50.261 = 0.75\text{m}^3$.

Digested sludge storage zone

The sludge storage volume, V_{sl}:

$$V_{Sl} = C \times P \times N \quad (4)$$

Where, C is the digested sludge accumulation rate, P is the number of users and N is the desludging period of the tank.
The volume of the sludge storage zone is dependent on two factors (Ahmad, 2015):

1. The digested sludge accumulation rate,
2. The desludging period of the tank,

For N<5, C =0.06 m^3/person/year, For N>5, C=0.04 m^3/person/year.

With N=3 years, C=0.06 m^3/person/year,

The volume for the digested sludge storage zone is given as:

$V_{sl} = 0.06 \times 30 \times 3 = 5.40\text{m}^3$.

Scum layer

It is the fatty, greasy or oily part that settles on top of the clear water space in the septic tank. The scum layer because of its greasy nature is less dense than water, the reason it floats on the clear water space area. The floating scum layer accumulates at approximately 30-40% of the rate at which the sludge accumulates (Ahmad, 2015).

The formula for the scum layer is therefore given as:

$$V_{sc} = 0.4 \times V_{sl} \quad (5)$$

$$V_{sc} = 0.4 \times 5.4 = 2.16\ \text{m}^3$$

Overall tank volume

$V_T = V_{sc} + V_h + V_d + V_{sl}$

V_{sc} = 2.16 m3, V_h = 0.35 m^3,Vd = 0.75 m^3, V_{sl} =5.40 m^3

$V_T = 2.16 + 0.35 + 0.75 + 5.40 = 8.66\text{m}^3 \sim 9.0\text{m}^3$

Dimensions of the septic tank

Assumptions made:

Tank depth of 2.3 m
Tank width of W meters
Total tank length of 3W
1st compartment length is $\frac{2}{3}$ of the overall tank length
2nd compartment length is $\frac{1}{3}$ of the overall tank length
V_T = 1st compartment volume + 2nd compartment volume
1st compartment volume = 2W × W × 2.3 = 4.6W^2
2nd compartment volume =W × W × 2.3 = 2.3W^2
$V_T = 4.6W^2 + 2.3W^2 = 6.9W^2$

Equating the two volumes,

$9.0\ \text{m}^3 = 6.9W^2$

$W^2 = \frac{9.0}{6.9} = 1.30$

$W = \sqrt{1.30} = 1.14\ \text{m} \sim 1.2\ \text{m}$

Tank depth = 2.3 m
Total Tank length = 3 × 1.2 = 3.6 m
Tank width = 1.2 m
1st compartment length = $\frac{2}{3} \times 3.6\text{m}$ = 2.4 m
2nd compartment length = $\frac{1}{3} \times 3.6\text{m}$ = 1.2 m

Design of the soil absorption field

The parameters for the design include:

The number of users = 30 persons, the infiltration rate of porous silty loam soil = $20\text{l}/\text{m}^2\text{day}$
The daily wastewater flow (lpcd) = 17 lpcd

The trench sidewall infiltration area is given as:

$$\frac{\text{Effluent flow, l/day}}{\text{Infiltration rate, }\frac{\text{l}}{\text{m}^2}\text{day}}$$

Effluent flow = 17 lpcd × 30 persons = 510 l/day
Infiltration rate = $\frac{20\text{l}}{\text{m}^2\text{day}}$, for porous silty loam soil (SMA, 2010).

The trench sidewall infiltration area = $\frac{510\text{l/day}}{20\text{l/m}^2\text{day}}$ = 25.5 m^2

The absorption trench should have a bed depth of 0.46 to 0.76 m deep (Schultheis, 2017).
Using an average trench depth of 0.6 m

The total trench length = $\frac{1}{2}\left(\frac{25.5}{0.6}\right) = 21.25$ m (Yukon, 2017)

Assuming 3 uniform trenches each trench length $= \frac{21.25}{3} = 7.1$ m.
Assuming the total width of the trenches is Y

Total trench sidewall infiltration area=7.1 m × Y
$25.5\text{m}^2 = 7.1\text{Y}$
$\text{Y} = \frac{25.5\text{m}^2}{7.1\text{m}} = 3.59\text{m}$
Width for a trench $= \frac{3.59\text{ m}}{3} = 1.2$ m
Area for a trench = 7.1 × 1.2 = 8.5 m

Design calculations

The calculations show the total tank volume and the overall tank length which was calculated based on the user population, given to be 30 and the per capita wastewater flow, 17 lpcd which is 85% of the water consumed. The average water consumption rate was found to be 20 lpcd (CWSA, 2010). A fraction of the water

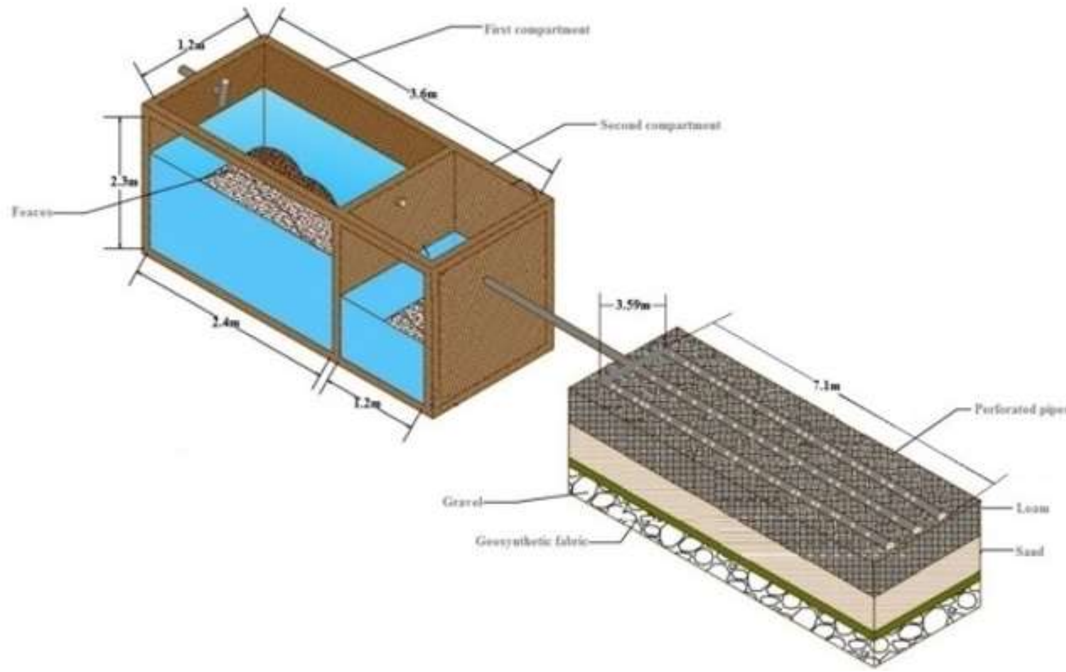

Figure 7. AutoCAD drawing showing the septic tank and drain field.

consumed comes out as wastewater while the rest is assimilated by the body. The return factor is usually 80 - 90% of the water consumed (Mara, 2004). The total volume and length of the tank was calculated to be approximately 9.0 m^3 and 3.6 m respectively.

The first compartment length which is $\frac{2}{3}$ of the total length was calculated to be 2.4 m and the second compartment length which is $\frac{1}{3}$ of the overall tank length was calculated to be 1.2 m. This is illustrated in Figure 7.

Cost implications

From the survey, the average volume size for the septic tank was $6m^3$. At the time of the survey, this could cost about 3,000 Ghana (GH) Cedis. The exchange rate of Ghana cedis to the United States (US) dollar at the time was 4 GH Cedis: 1 US dollar. By extrapolation, the shared septic tank of 9 m^3 could cost 1.5 times the existing average septic tank in the community. This could therefore cost 4,500 GH cedis. Sharing this cost among three household will amount to each household paying 1500 GH Cedis, which is half the cost of average single septic tank (3000 GH cedis) found in the community. Thus, households will save quite significant amount for constructing a shared facility. More studies and work need to be done regarding the filling rate and emptying frequency of the shared facility as this study did not cover that.

CONCLUSIONS AND RECOMMENDATIONS

Conditions suitable for shared septic tank facility in the study area included availability of water, suitable soil conditions for drain fields, positive user's employment status, and user's willingness for the shared facility. A shared septic tank volume calculated is approximately 9.0 m^3, based on the user population of 30 people, waste water flow rate of 17 lpcd (85% of water consumed, that is 20 lpcd) and a minimum desludging interval of 3 years. This volume is enough to handle the wastewater for 3 households in the Fiapre community. Also, the shared septic tank facility was comparatively less expensive to a household and therefore very appealing to be patronized.

The following recommendations are made to improve the project and for the sustainability of the shared septic tank facility;

1. The addition of soil absorption field or a drainage field to the septic tank system should be considered as it offers better treatment solution to the effluent from the tank.
2. Pipes used for the connections should be of good quality and buried in the ground and should not be exposed to avoid breakages of the pipes.
3. The septic tanks should be dislodged regularly.
4. Less fat or grease should be allowed into the system.
5. The alternating drain field system must be properly used.

6. Only human wastes should be allowed into the septic tank.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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