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Current situation of solid waste management in East African countries and the proposal for sustainable management

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Effects of unsustainable solid waste management are found all around the world but it is worse in developing and under developed countries like East African Community (EAC) countries. A big proportion of their solid waste is not properly managed. This paper highlighted the situation of solid wastes management in EAC countries and compared with other countries. More than 62.5% of generated solid waste in EAC is organic, 19.6% of papers and plastics, 3% of glasses while other kind of waste occupies 14.9%. Waste management (WM) system in developing countries is dominated by insanitary landfill which cover more than 59% of the total collected SW, between 13 and 33% is openly dumped, a negligible quantity is recycled while between 6 and 26% is inappropriately thrown. Only less than 50% of the total generated solid waste (SW) in developing countries is collected and this is the same case in EAC. Sanitary landfill, sustainable composting, waste to energy (WTE) and other recycling system can change waste from unwanted materials to important products. Almost all generated wastes in developed and highly developing countries are collected, with high generation site sorting and sustainably treated and managed. Some countries achieved zero landfilling while others have sanitary landfills. The final destination of each kind of waste in developed countries determine collection mean and improve the quality of raw materials for recycling companies. Value of sorted waste to the recycling companies improves the interest of generation site sorting and maximization collection.

Key words: Solid waste management, East African Community (EAC), waste collection system, future waste management, level of income, waste prioritization, sustainable solid waste management.

INTRODUCTION

Solid waste is one of the big problems all around the world and it becomes even worse in developing and under-developed countries (Scheinberg et al., 2011). This situation is mainly found in many cities of these countries where the main cause is the rapid urbanization, improper city planning and lack of prioritization of SWM by many governments (Aparcana, 2017). East African Community (EAC) is a regional inter-governmental organization of 6 partner states: The Republic of Burundi, Kenya, Rwanda, South Sudan, the United Republic of Tanzania, and the

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Republic of Uganda as shown in Figure 1 (Turner, 2017). All these countries are classified in developing and under-developed countries based on their income levels (UNCTAD, 2018). Living conditions, economy and many other factors affecting characteristics of generated solid waste are similar in EAC. So, the composition of solid wastes generated in these countries is very similar.

In general, the important and basic ways of solid waste management is the control of its generation (reduce waste as much as possible), improved collection system and transportation to the treatment sites (Mbiba, 2014). Smartness of these steps based on waste characteristics and generation rate of community makes treatment easier and quicker (Matsumoto, 2011; Lederer et al., 2017). Like other developing and under-developed countries, a big proportion of EAC solid waste is organic which can be composted easily (Lederer et al., 2017; Das et al., 2019). Studies on composting of organic wastes have been conducted in many countries and it has been concluded as a good alternative on solid waste management especially in developing countries (Couth and Trois, 2012a, b).

For instance, Clean Development Mechanism (CDM) by composting in Uganda started in 2007 and its results are impressive. An experimental study of compost application on beans yield have been done in 8 different sites in Uganda and showed an important increase of yield in terms of quantity and quality. This trial increased the will of farmers on buy and use of compost. However, the quality of produced compost is still critical due to poor sorting, and consequently affects market (Alemiga, 2017). Smart collection and sorting are the key ways of improving waste transportation as big quantity (organic) can be composted at source of generation (Loan et al., 2019). These also result on improving the quality of compost and price reduction which has been found to be a barrier to farmers (Oteng-Ababio et al., 2013; Mbiba, 2014; Isugi and Niu, 2016; Lederer et al., 2017). In contrast, almost all solid wastes generated in EAC are either insanitary landfilled, openly dumped or thrown in inappropriate places, only a negligible quantity is recycled or composted (Okumu-Okot, 2012; Guerrero et al., 2013; Mbiba, 2014; Lederer et al., 2017). In this review paper, different solid waste management systems, sustainable and non-sustainable, challenges and ways to improvement based on experience of developed and highly developing countries will be highlighted. Both sustainable and non-sustainable management in EAC countries will be compared with other developing countries in Africa and with some countries of other continents. The journey of developed and highly developing countries to sustainable waste management will be also reviewed to find the gap between these countries and EAC. At the end of this paper, the best ways to improve solid waste management (SWM) in EAC will be suggested. Suggestion will be based on countries with good history in waste management, EAC economy, and the characteristics of generated waste as well.

METHODOLOGY

Study area

This review was conducted on EAC countries in comparison with other countries. Figure 1 illustrates the map of all 6 EAC countries. This is a home of 177.2 million populations with a density of 80.6 persons/km^2 and a population growth rate of 2.9%. In 2018, the overall EAC real GDP growth rate excluding Burundi grew to 6.5% from 5.9% in 2017 with the highest growth rate of 8.6% from 6.2 for Rwanda while Tanzania, Uganda and Kenya recorded 7 from 7.2, 6.3 from 5.1 and 6.1 from 5.1%, respectively. Report of EAC in 2015 projected population urbanization to increase from 39% in 2014 to 70% in 2050.

Document review

Available published papers, governmental and NGOs reports on SW in EAC were reviewed and used as source of information. Due to scarce publications on EAC waste management, some information has been collected from available papers and compared with other countries with similar living standard. These helped to have some relevant information of SW from generation to final management. These information were compared with highly developing and developed countries to understand their ways to sustainable waste management, difficulties faced, current situation and their future projection. Review was based on the current information and it is divided into four main categories: (1) SW management in EAC countries; (2) solid waste management in other developing countries in Africa and other continents; and (3) SWM in developed and highly developing countries (4) some important innovation that EAC can learn from developed countries. Developed and highly developing countries were chosen according to their sustainable waste management, their route to current situation and their future projection, while other developing countries were chosen based on their past and current situation of SWM, economic status and the characteristics of generated waste.

RESULTS AND DISCUSSION

General characteristics of solid waste in EAC countries

Characteristics of solid wastes generated by a community depend on many factors. These can be due to working conditions, living standard, life style, income level and so on as shown in Table 1 (Marshall and Farahbakhsh, 2013). The characterization of solid waste in EAC's cities showed that a big proportion is organic waste (Okumu-Okot, 2012; Mbiba, 2014).

It is clear that change in living standard affects the characteristics of solid waste generated by a community. From Table 1, it can be seen that a big change appears on organic waste with a difference in percentage of 36 from low to high income community followed by papers with a difference of 26 while other compositions do not show a big change. This means that income level has a high influence on the quantity of organic waste available

Figure 1. EAC map.

Table 1. Worldwide impact of income level on solid waste composition

Income level	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)
Low income	64	5	8	3	3	17
Lower middle income	59	9	12	3	2	15
Upper middle income	54	14	11	5	3	13
High income	28	31	11	7	6	17

in the total solid waste generated by community. Linkage between income level and composition of waste generated by communities (Henry et al., 2006; Oteng-Ababio et al., 2013; Farley et al., 2019) as well as the findings of Mbiba (2014) conclude that as big proportion of EAC's people is found in low and low middle-income level, thus a big proportion of their wastes is organic. It means that a big proportion is decomposable which can be composted easily.

However, poor sorting and collection is a barrier for composting as well as recycling of other wastes like plastics, metals, electronics and so on (Isugi and Niu, 2016). Improved sorting and collection are the basic keys to sustainable waste management by increasing the quantity and quality of waste to be composted or recycled and consequently improve the quality of the end products of recycling. From literature it has been concluded that almost 62.5% of all EAC solid wastes are organic as shown in Table 2; some are easily decomposable which can be composted others are slowly decomposable which can be sanitary landfilled (Oyoo et al., 2014). So, based on today's EAC economy and the cost of some sustainable WM, they are suggested to reinforce sanitary landfill and composting as their main solid waste management system. The remaining 19.6% is plastics and papers, 3% glasses and 14.9% of other kinds of waste can be directly recycled (like metals, paper, plastics, etc.), incinerated and so on.

Research showed that a big proportion of EAC solid wastes are unsustainably landfilled or dumped, another proportion is thrown in inappropriate places while only a very small proportion is recycled (Mbiba, 2014; Aparcana, 2017; Lederer et al., 2017). The main difference between EAC landfills and developed as well as highly developing countries (like China) is sustainability which consider the treatment of landfill leachate and gases (Das et al., 2019; Mishra et al., 2019). Sanitary landfill reduces the risk of leachate ground water pollution as well as atmospheric air pollution. In developed and highly developing countries, composted wastes are characterized by improved generation site sorting which results on increasing the quality of compost produced (Matsumoto, 2011; Farley et al., 2019; Knickmeyer, 2019). Not only these methods but nowadays worldwide environmental researchers are interested on waste to energy through incineration, biological fermentation of organic waste for biofuel production and so on. All these treatment methods show a great contribution in solid waste management because it increases the quantity of wastes treated and the quality of their end products (Weimer et al., 2015; Jankowska et al., 2017; Abdallah et al., 2019).

The dominance of organic waste in EAC can be explained by their industrialization. Look back to the economy, EAC countries are not industrialized. Their

Table 2. Characteristics of solid waste generated in East African major cities.

Waste composition (%)	Dar es Salaam/Tanzania	Moshi/Tanzania	Kampala/Uganda	Kigali/Rwanda	Jinja/Uganda	Lira/Uganda	Nairobi/Kenya
Bio-waste	71	65	77.2	68	78.6	68.7	65
Paper	9	9	8.3	9	8	5.5	6
Plastic	9	9	9.5	5	7.9	6.8	12
Glass	4	3	1.3	-	0.7	1.9	2
Metal	3	2	0.3	2	0.5	2.2	1
Others	4	12	3.4	15	4.3	14.9	14

food processing industries are very few; thus, a big quantity of food consumed is fresh and results in generation of high quantity of organic waste compared to developed countries where a big quantity of their food is pre-processed and generated few organic waste. The reduction of organic waste in developed countries occurs with the increase in paper and plastic waste as shown in Table 1; this is due to the use of papers and plastics for food packaging. While the data in Table 2 show high level of organic waste in some EAC cities, low paper and plastic waste generation can also be explained by low food packaging habit. However, plastic waste shows a big change in some cities comparatively to papers; this is due to restriction of use of plastic as bags and packaging in some countries (Kabera and Nishimwe, 2019). Metals and glasses which are usually found in construction sites need further research to know the reason of change (Isugi and Niu, 2016; Han et al., 2018; Kwori, 2019). Based on worldwide situation of SW, it can be predicted that the quantity of waste will continue to decrease. This must be carefully considered and as the level of income is increasing, the budget of solid waste management must also be increased to improve the current waste management system as well as introducing new sustainable systems (Owusu et al., 2012; Oteng-Ababio et al., 2013).

Solid waste management and control in EAC

SWM is a multistep system and the results of the next step are in function of the previous one. This means that a good management of solid waste must start from its generation to their final disposal or treatment (Kassim and Ali, 2006; Katusiimeh et al., 2012; Oteng-Ababio et al., 2013; Knickmeyer, 2019). As shown earlier, a big proportion of generated SW in EAC is unsustainably managed. This is mainly due to their low income, poor living standards, lack of SWM prioritization by governments, inadequate knowledge on SWM and the effects of its improper management and so on (Das et al., 2019).

Waste generation, collection and transportation

The first step to sustainable SWM is generation control. This is a basic way of WM; it directly reduces the quantity of waste to be generated by a community through maximizing consumption (Matsumoto, 2011; Knickmeyer, 2019; Loan et al., 2019). After generation, waste must be collected; almost all collected solid waste in developing and under developed countries are poorly sorted. Note that the quantity of waste collected is usually less than half of the total waste generated. These wastes are finally transported to landfills, dumped or composting sites while another proportion is thrown to the streets, water bodies and so on (Oyoo et al., 2014). Among all these solid waste management systems, only landfilling and composting can be considered as sustainable and require a careful sorting (Farley et al., 2019). In contrast, almost all EAC landfill are not sanitary; these are only holes used for waste disposal usually open, without compaction or leachate recycling (Komakech et al., 2014; Ephantus et al., 2015; Scarlat et al., 2015). Sustainable Sorting must focus on waste characteristics carefully decomposable and non-decomposable, hazardous and non-hazardous. The best collection system makes further treatment easier because each kind of wastes is treated based characteristics. In EAC and many other African cities, collection system is very poor because it is mostly done without wastes characterization, this cause many difficulties during treatment and increase the cost of sorting (Oteng-Ababio et al., 2013). SW collection system in EAC's countries is considered as informal. This system is mainly done in three steps as follow: community collection, from community collection to transfer point and from transfer point to final disposal. Frequency of

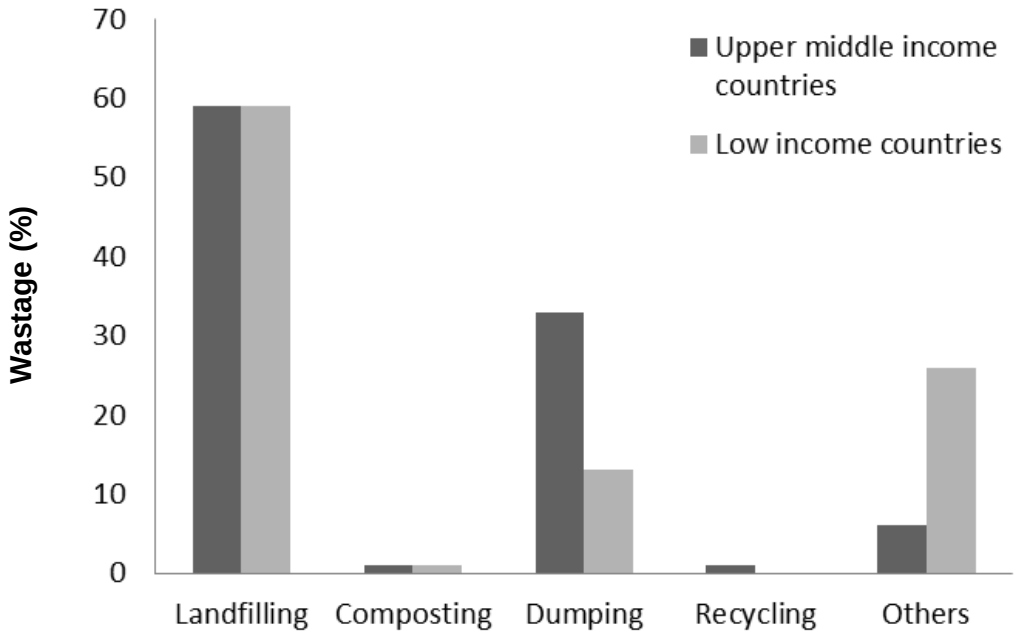

Figure 2. Upper middle-income and low-income countries waste treatment methods.

collection is mainly based on income level of community; the higher the income of community the more the frequency of waste collection and transportation and vice versa (Okumu-Okot, 2012; Sandhu et al., 2017). For instance, in Rwanda, collection is by house to house using different means of collection but the common one is by using plastic bags. Waste is transported to treatment site by companies in charge of waste transportation. The day of waste transportation, plastic bags deposed to the streets are picked by waste transportation companies and transported to the treatment site (Isugi and Niu, 2016; Elias et al., 2017).

In all EAC countries, waste from markets are collected to the nearest transfer points with or without sorting and further transported to disposal site. These cause serious problems because some wastes remain at the street or transfer point. Sometimes waste decomposition start in collection bags or at transfer point due low frequency of transportation, insufficient trucks, quality of roads and so on. These cause bad smell and produce some liquid (like leachate) which result in environmental pollution and cause diseases to the nearest population. Waste transportation has a big contribution on the final treatment. In EAC; transportation is done using open or closed trucks; densely populated cities (urbans) have more trucks than less populated cities. Unsorted or poorly sorted wastes are transported to the disposal sites by trucks and sorting is usually done at treatment site. This affects the efficiency of sorting, cost of treatment through the increase of sorting fees, overloading of trucks and directly affects the efficiency of waste treatment (Kassim and Ali, 2006; Katusiimeh et al., 2012; Okumu-Okot, 2012). Unsustainable solid waste sorting and collection also affect the quality of treatment end products and decrease landfill service life (Mbuligwe, 2002; Lederer et al., 2017).

Waste treatment and recycling

In general, there are different types of solid waste treatment and recycling; a community chooses their favorite based on different factors such as incomes level, types or characteristics of wastes, the main purpose of waste treatment and so on. The common methods of solid waste treatment in high income countries are sanitary landfill, thermal treatment, wastes to energy and so on. Contrary, lower and lower middle-income countries' (like EAC) wastes are unsustainably treated (Bhada-Tata, 2012; Owusu et al., 2012; Mishra et al., 2019). Literature reveals that in low income countries, 59% of their wastes are landfilled, 13% dumped, 1% composted, 0% recycled and 26% unclear. While in upper middle-income 59% of their wastes are landfilled, 33% dumped, 1% composted, 1% recycled, while the remaining 6% are unclear as shown in Figure 2.

All these treatment methods are common in under-developed and developing countries (Mishra et al., 2019). A big proportion of their solid waste is unsustainably treated and result in environmental pollution (Owusuet et al., 2012). From Figure 2, it is clear that a big proportion of solid wastes in these countries are landfilled. A big difference is found only on unclear method, this means that apart from known methods of waste treatment and

Figure 3. Unclear method of solid waste treatment.

disposal there is another proportion of waste which is thrown in inappropriate places. Unclear waste disposal in low and upper-middle income countries are at a percentage of 26 and 6%, respectively. These wastes are improperly managed, either directly deposed in water bodies, to the streets and roads, or to agricultural land as shown in Figure 3 (Mireri et al., 2007). Comparison shows that dumping increased from 13% in low income to 33% in upper-middle income countries. This is not sustainable but explains the relationship between income level and waste management method. In many communities of upper-middle income countries, the level of waste collection is higher than in low income countries; but due to financial issues, inadequate knowledge on SW and lack of SWM prioritization; collected wastes are not properly treated or managed but dumped a bit far from communities or market (Kasmiro Gasim, 2019; Yusuf et al., 2019).

Solid waste management difficulties in EAC

Solid waste treatment and management in EAC countries face many challenges which affect its sustainability. These challenges can be classified based on social, economic and climatic factors (Han et al., 2018). Family size is directly proportional to the daily quantity of wastes generated and composition depends on their economic status, living conditions and so on. In many developing countries (like EAC), cities are densely populated and characterized by poor planning. These affect either directly or indirectly management of solid waste generated; due to improper, insufficient or even total absence of waste management and treatment infrastructures compared to the population of communities they have to serve (Aparcana, 2017; Knickmeyer, 2019). Population growth, size and living standard must be factors to consider during decision of solid waste management. EAC leaders and environmental decision makers must carefully take into consideration rural to urban migration as well as waste generation rate. These facilitate decision making of SWM infrastructure size, numbers, location as well as waste transportation means for sustainable management.

Level of knowledge on waste management is also another factor to be considered. Many people do not have adequate knowledge about solid waste and their impact on life or environment in general. People do not consider their contribution, but they think that every responsibility is that of governments, local leaders or private companies in charge of waste management (Mbuligwe, 2002). The awareness of some local leaders and private companies are also critical. Some are interested in waste management, others are not or are targeting quick income. So, governments, NGOs, experienced private sectors, experienced local leaders and environmentalist must collaborate to organize more training to all level of people to raise their knowledge on solid waste management and improve their contribution in this issue. Culture also challenges the implementation of solid waste treatment and management. Many people think that waste have to be thrown in land for decomposition and become fertilizer or thrown into nearest water bodies and so on (Mireri et al., 2007). This is the culture of many people in developing countries. In many EAC cities, people use to throw waste in rivers during night or when it rains. Primarily for hiding their waste to reduce collection and transportation fees, secondarily because it is their long term behavior and thirdly due to poor collection and transportation mean. Usually people do not accept changes at the same levels; so, trainings on impact of improper SWM and people's contribution on sustainable waste management must be prioritized (Okumu-Okot, 2012; Marshall and Farahbakhsh, 2013; Aparcana, 2017).

Economy is another challenge on SWM especially in EAC. SWM requires a high investment while direct profit in term of money is low. In EAC, landfilling and composting are considered as their main solid waste

management and treatment system. However, due to low investment in this sector most of their landfills are not sanitary, their wastes are not or poorly sorted and the quality of compost is very poor. Low investment does not have effects on the final disposal only but to all steps of waste management. For instance, in many EAC cities the frequency of waste transportation depends on the income of the population. The more the income of communities, the more the frequency of waste transportation (Kirama and Mayo, 2016). This causes a big problem of pollution in low income regions and becomes worse when it is privatized (Sandhu et al., 2017). So, governments must invest more and elaborate clear rules and regulations of solid waste management and create a good working environment especially for private companies. The budget of waste treatment and management depends on the economy of each country; the lower the economy, the lower the budget and vice versa (Han et al., 2018; Das et al., 2019). However, no matter the low investment but good plan from waste generation to the final disposal or treatment can increase the quantity of waste to be managed by EAC communities. These can be achieved through minimizing waste generation as much as possible, improved sorting and collection, wastes recycling and reuse (composting, waste to energy), sanitary landfill and so on. In turn, some money will be gained from this improved waste management to support the budget.

Climatic condition is a factor which mostly affects the quality of roads especially during the rainy season. This directly affects the frequency and the time of waste collection point emptying and transportation. Survey conducted showed that waste disposal areas in many EAC cities are not connected to good roads which cause many difficulties during transportation (Henry et al., 2006). To overcome this, on-site waste treatment must be prioritized focusing on quickly decomposable waste (organic) by composting and other waste can be transported to another treatment place when conditions of roads are good. Administrative factors where some authorities do not prioritize solid waste management and treatment is also another concern (Henry et al., 2006; Okumu-Okot, 2012). All these highlighted challenges will be solved by prioritization of solid waste by authorities and down step by step to local people through trainings and increase their knowledge on the impacts of solid waste, role of waste treatment and their contribution on this issue.

Common EAC solid wastes management and treatment systems (landfill, composting and open dumping)

Like many developing countries, the common SWM system in EAC countries is poor or insanitary landfilling, poor composting and open dumping (Alemiga, 2017; Idowu et al., 2019). In these three management systems, only landfilling and composting can be considered as sustainable. However, they are not, this is due to non-engineered landfills which results on environmental pollution through landfill leachate and gases or incompletely decomposed compost which is usually characterized by some indecomposable materials due to poor sorting.

Landfill

In EAC countries and many other developing countries, many landfills are considered as non-sustainable due to many factors which are usually ignored during landfill site selection, construction, unprofessionalism, lack prioritization of SWM and so on (Owusu et al., 2012). Sanitary landfilling does not only consider waste disposal but also further treatment of landfill leachate and gases from waste decomposition (Idowu et al., 2019; Mishra et al., 2019). In many developing countries (including EAC), more than 59% of all collected solid wastes are landfilled but among all available landfill in EAC only very few are engineered. This results in indirect environmental pollution through underground water pollution by leachate infiltration and air pollution by landfill gases (Isugi and Niu, 2016). Landfilled wastes in EAC are not poorly sorted before disposal; these wastes are composed of organic and inorganic waste. Landfilling of almost all collected wastes as well as unplanned or unexpected waste generation rate result in disturbance of landfill life cycle. Maximization of on-site waste generation sorting increase the quantity of waste to be composted or recycled thus the remaining quantity can be landfilled and consequently reduce the risk of landfill life cycle disturbance (Aparcana, 2017). Based on big proportion of waste which is still dumped or thrown in water bodies, uncollected waste and a big number of insanitary landfill (Henry et al., 2006; Guerrero et al., 2013) efforts are needed in onsite sorting, collection and increase number of sanitary landfills. It has been concluded that there is a direct correlation between sustainable waste sorting and collection and the quantity of waste recycled rather than landfilling (Ferraris et al., 2013).

Composting

Composting is a process which converts biodegradable material such as garden or kitchen waste into a stable material that can be used as a soil improver. This can be considered as the priority option of SWM especially in EAC where about 62.5% of all generated solid wastes are biodegradable (Okumu-Okot, 2012; Oyoo et al., 2014). This is not the only factor which favors the selection of compost as SWM option in EAC, but also agriculture which is their first economic activity. So, composting must be improved as a way of solid waste

management and treatment and also as a source of compost for farmers. In EAC and many other developing countries, some composting plant are available but still very few which cover not more than 1% of the total collected solid waste. The low quality of compost produced in EAC affects its market and reduces the interest of investors in composting. So, to improve the quantity of waste to be composted, sustainable on-site sorting needs to be reinforced and prioritized thus improving the quality of compost produced (Couth and Trois, 2012a, b; Isugi and Niu, 2016; Lederer et al., 2017). Sustainable composting increases the quantity of solid wastes treated in developing countries as a big proportion of all generated solid waste can be easily composted even at the place of generation (Loan et al., 2019). This reduces the problem of overloading of wastes transportation trucks and increases the quality and quantity of waste to be recycled (Couth and Trois, 2012a). The use of compost by EAC farmers is a solution to unaffordability of inorganic fertilizers due to high cost which result on low yield in quality and quantity (Isugi and Niu, 2016; Potdar et al., 2016; Lederer et al., 2017).

Open dumping

Open dumping is not considered as a sustainable SWM due to its impact on environment. However, due to different reasons, open dumping is common and occupies the second position of waste disposal mean in upper-middle income countries and the third in low income countries. Wastes are collected from communities, markets and other generation sites without sorting then transported and deposed at a selected open air place. Research showed that in upper-middle and low-income countries, between 13 and 33% of all collected solid waste are dumped (Owusu et al., 2012; Farley et al., 2019). This is the same situation in all EAC countries which are also classified in this category of incomes. Review showed that from low to upper-middle income countries, dumped wastes increased from 13 to 33% while unknown management decreased from 26 to 6% of all collected SW (Bhada-Tata, 2012). This shows that, despite its effect, open dumping is legally accepted in these countries and can divert a big proportion of unknown management to dump (Waweru and Kanda, 2012; Kasmiro Gasim, 2019). However, open dumping causes a serious problem of environmental pollution; either directly or indirectly. This becomes worse to the population around these dumping sites due to runoff into water bodies, bad odors, attracting flies and breeds, soil pollution, reduction of soil infiltration rate and so on (Mireri et al., 2007; Okumu-Okot, 2012). As open dumping is not sustainable, waste to energy, sanitary landfill and composting must be prioritized to reduce secondary pollution from dumping and produce important products from these wastes. Insanitary landfill, incomplete composting and open dumping are serious problems in all EAC countries.

These cause pollution to the surrounding environment; the effects can be either direct or indirect and the routes of exposure differ accordingly. This pollution also affects different activities of EAC people like agriculture which is their first economic activity (Mireri et al., 2007; Oyoo et al., 2014). Improper solid waste management affects agricultural yield through soil and water pollution, this can be caused by landfill leachate and gases, indecomposable waste (like plastics, and metals) and long-time decomposable wastes which affect soil infiltration rate and so on (Mireri et al., 2007). Open dumping also attracts flies, breeds and other disease vectors which cause health problems to the surrounding population, pests and diseases to crops, and so on (Okumu-Okot, 2012). So, as population is growing quickly and directly proportional to solid waste generated, this waste must be prioritized by all governments, NGOs and people as well for protecting environment.

SWM in other developing countries

The situation of solid waste management in other developing countries across the world is not far away from that of EAC. The characteristics and management of SW differ according to the economy of each country and the quantity of waste managed increase with increase in economy. The composition of SW in developing countries can differ from one country to another but in general organic waste dominate all over the world while other composition can differ according to different reasons (Das et al., 2019; Perteghella et al., 2020). A case study in 8 least developed countries in Asia (Afghanistan, Bangladesh, Bhutan, Cambodia, Laos PDR, Maldives, Myanmar and Nepal) showed that the composition of their solid waste is dominated by organic waste. The level of organic waste varies according to the country but in general it ranges between 30 and 70%. Plastics and papers also fluctuate according to population living condition with a very big change on plastics waste which is usually caused by measures of each country for their rules of restricting the use of plastic bags, but in general the range is between 10 and 50% (Glawe et al., 2005; Vazquez et al., 2020). These compositions fall in the same range with EAC countries.

Many developing countries have been reported to have a big number of population who rely on money from waste picking at disposal sites. This is considered as the common method of waste sorting in these countries. Collected wastes are transported by companies and deposited at selected places, usually open-air dumping or insanitary landfill as shown in Table 3. Waste pickers, usually women and children sort these wastes at deposition site, not for sustainable waste management but for selecting waste which can be sold to the recycling

Table 3. Comparative summary of SWM between EAC and other countries.

Economic status	Country	Waste composition (%)				Waste Management system (%)				References
		Organic	Papers and plastics	Glasses	Others	Landfill	Composting, recycling and Incineration	Open dumps	Others	
Developed and highly developing countries	Germany	30	37	10	23	0	100	0	0	Mühle et al. (2010) and Pomberger et al. (2017)
	UK	38	25	7	27	57	39.7	0	0	Patrick (1985); Mühle et al. (2010), and Wang et al. (2020)
	Belgium	35	38	5	22	0	100	0	0	Gentil (2013), Pomberger et al. (2017), and Sharma and Jain (2020)
	China	58.8	20.5	5	15.7	63.7	36.3	0	0	Liu et al. (2017) and Duan et al. (2020)
	India	51	17	-	32	93*	7	0	0	Malav et al. (2020)
	Italy	35	30	6	29	34	66	0	0	Ferraris et al. (2013), Pomberger et al. (2017), and Ripa et al. (2017)
Developing countries	Bangladesh	74.5	12.6	0.8	12.1	86.5*	13.5	0	0	Shams et al. (2017), Islam and Moniruzzaman (2019), and Alam and Qiao (2020)
	Algeria	64.6	26.4	2.8	6.2	0.2	2	96.8	1	Guermoud et al. (2009), Naïma et al. (2012), and Scarlat et al. (2015)
	Cameroon	70	16	4	10		5	95	0	Scarlat et al. (2015) and Sotamenou et al. (2019)
	Niger	57	35	2	6	64*	4	-	32	Oumarou (2015) and Scarlat et al. (2015)
	Thailand	65	27	-	8		11	-	-	Tuprakay et al. (2014)
	Bulgaria	64.3	16.5	4.4	15.8	74	26	0	0	Barata (2003), Inglezakis et al. (2012), and Pomberger et al. (2017)
EAC countries	Kenya	65	18	2	15	75*	9	16	-	Henry et al. (2006), Gakungu et al. (2012), Waweru and Kanda (2012), Mugo et al. (2015), and Palfreman (2015)
	Uganda	75	15	1	9	41*	8	51	-	Komakech et al. (2014) and Yusuf et al. (2019)
	Rwanda	68	14	-	17	79*	10	11	0	Isugi and Niu (2016) and Kabera and Nishimwe (2019)
	Tanzania	68	18	4	8	60*	10	30	-	Sharma and Jain (2020)
	S. Sudan	35.5	33	4.5	27	-	-	100	-	Cowling (2013), Kasmiro Gasim (2019), and Mohamed and Elhassan (2019)

companies (Ahmed and Ali, 2004; McBean et al., 2005). These people are vulnerable due to improper protection from risks which can be caused by hazardous waste. Note that almost all facilities and infrastructure for waste management are found in capital cities and secondary cities while there is no single waste management infrastructure in rural areas. The frequency of waste transportation varies from capital cities to secondary cities; high frequency in capital cities is supported by big investment which results in having many trucks and good roads while secondary cities invest less and their roads are not good enough (Al-Khatib et al., 2007; Olay-Romero et al., 2020). No matter the investment or waste transportation facilities, but a big proportion of waste is disposed in insanitary landfill or in open dump. Review shows that landfilling is leading all systems of waste management in developing countries. This is dominated by insanitary landfills with poor site selection and planning which results in ground water and air pollution. The lifecycle of these landfills is usually unpredictable due to unplanned increase of waste generation, disposal of all kind of waste without sorting, lack of compaction as well as rapid population growth.

Open dumping which is ranked the second receiver of collected wastes in developing countries is not environmentally friendly but it can be legal or illegal. It is legally accepted when in charge of waste management agree with leaders to select a specific places of waste disposal. It is also classified as illegal when it is chosen by people themselves (Al-Khatib et al., 2007, 2010; Kasmiro Gasim, 2019). Landfills and open dumps

cover almost all waste in developing countries with a small quantity recycled. Note that although the quantity of sanitary landfilled or recycled waste increase with economic growth of the country while dumped quantity decrease; almost all cities in developing countries face the challenges of inadequate or insufficient waste management and transportation facilities (Ahmed and Ali, 2004; Scarlat et al., 2015; Turcott Cervantes et al., 2021). It is also important to know that, not all generated wastes are collected, but there is another big proportion which are not collected. In some cities, collected wastes are even less than half of total generated waste, for instance in Kabul, Afghanistan only 23% is collected. Uncollected wastes are either openly burned, thrown in water bodies, streets, forests or farms which expose population to health problems (Glawe et al., 2005; Sotamenou et al., 2019). Organic waste composting and other waste recycling are also available in some cities; however, these are very rare due to lack prioritization of these sustainable methods by governments.

SWM in developed and highly developing countries

Many criteria are considered for classifying a country as developed or developing. As explained previously the budget of waste management depends on the economy of each country. Contrary to least developed and EAC countries, developed and highly developing countries show a significant difference in waste composition, management, prioritization and investment. Organic wastes are still ranked the first composition of municipal solid waste but it is low compared to developing countries. Papers and plastics are the second while glasses are the third. While plastics are experiencing a quick reduction due to restriction of use of plastic bags; other waste like metals, E-waste and textiles are few but much more compared to developing countries (Srivastava, 2016; Maria et al., 2020). The reduction of organic waste in these countries is due to their industrialization which directly cause a significant difference of other kinds of waste compared to developing countries (Wang et al., 2020).

Over increase of solid waste is a challenge to all countries across the world, but management and treatment is experiencing a big difference between developed and developing countries. There is a big difference from waste generation to the end use; for instance, in 2015, 48.9% of waste generated at Umbria, Italy was sorted at generation site. Recyclable wastes are transferred to recycling while organic wastes are composted at composting sites (Maria et al., 2020). Despite population growth, law of waste prevention helped Nottingham, England to achieve waste reduction from 123,615 tons in 2006/2007 to 115,170 tons in 2016/2017 (Wang et al., 2020). This improved waste collection and reduction lead to sustainable transportation to the final treatment.

Usually, the frequency of waste transportation depends on the characteristics of waste. Time interval of organic waste transportation is shorter than other kinds of waste, this reduces the risk of decomposition at collection site. Organic wastes are composted at designated composting site thus produce organic fertilizers as well as biogas. Recyclable inorganic wastes are also transferred to recycling companies with a long-time interval of transportation frequency. All these developed methods lead to almost 100% waste collection, diversion of waste which could be landfilled at a range between 40 and 80% of the total generated waste in European Union. Diverted wastes are well managed by energy recovery as well as production of other valuable materials (Srivastava, 2016; Pomberger et al., 2017; Wang et al., 2020). Like developing countries, budget of waste management in developed and highly developing countries also depends on the economy of each country. In developed and highly developing countries, this budget is distributed from waste generation to the final disposal. Onsite sorted wastes are sold to scavengers or directly to the recycling companies which also produce other valuable materials. This increases the will of local people on waste sorting (Mühle et al., 2010; Fei et al., 2016). Contrary to developing countries, facilities of waste management in developed and highly developing countries are available in big cities as well as in small cities or even in some rural areas. Table 3 shows that while developing countries are still straggling with insanitary landfills, open dumping and inappropriate disposal, some developed countries achieved zero landfills while others have sanitary landfills(Mühle et al., 2010; Pomberger et al., 2017; ‘Eurostat Regional Yearbook, 2018, 2019).

Insanitary landfills and open dumps are still covering almost all collected solid waste in EAC countries. While in developed countries almost all quantity of waste is sorted at generation site before collection and treatment; in EAC and other developing countries, wastes are collected with a very poor sorting. The final unsustainable disposal of these wastes causes a serious health problem to the population near disposal site and environment in general. Note that the data shown in Table 3 illustrate the general characteristics of solid waste in the listed countries. For EAC and other developing countries, only data of urban areas have been highlighted. This is due to lack of enough information of solid waste management in these countries and lack of waste prioritization which abandon rural areas. As shown in the table, percentage of landfills in some developing countries is marked by (*), these landfills are classified as insanitary without gases recovering or leachate recycling and poor site selection. Some countries use open holes without even compaction and consider them as landfills while others confuse landfills and open dumps. According to the characteristics of sanitary landfills, these are not sustainable (Ahmed and Ali, 2004; Scarlat et al., 2015; Kasmiro Gasim, 2019;

Alam and Qiao, 2020).

GOVERNMENT AND PRIVATE SECTORS' CONTRIBUTION ON SOLID WASTE MANAGEMENT IN EAC

Almost all treatment and management of solid waste in EAC countries are in charge of governments; only a small part is on the hands of private companies (Kirama and Mayo, 2016). Each side has its contribution but also some challenges either due to working principles and conditions, level of income or to their main purpose as shown in Table 4. Low profit (in terms of money) from solid waste management and treatment and lack of prioritization by many governments are the key factors affecting the investment of private companies in this field (Katusiimeh et al., 2012). While the direct profit of solid waste management in terms of money is very low, all private companies invest in this field targeting money. These affect the whole processes of solid waste management and treatment in poor communities thus resulting on focusing in urban areas where income is high (Kassim and Ali, 2006; Isugi and Niu, 2016; Lederer et al., 2017).The decisions of solid waste collection and management by private companies is under the rules and regulations of governments. A big challenge is the implementation of these rules by companies and the follow up of the governments. So, governments must do their best to evaluate the implementation of rules and regulations of solid waste management by private companies and encourage them to work in all regions of countries (low and high income).

Awareness of EAC people on the importance of solid waste management

Awareness of EAC's people on the management and treatment of solid waste is very critical. The causes of these poor understanding are different but can be grouped as follow; lack of SWM prioritization by governments. This is a big challenge which causes total failure of almost all projects of SWM. Life change with new living standard in the past, EAC countries did not consider SW as a problem, but nowadays it is a big challenge due to population growth and change in living condition. So, solid waste must be taken as a priority by authorities and train people to raise their knowledge on this issue. Knowledge of local leaders on SWM will help to overcome the risk of failure of projects of solid waste management and treatment because there will be a common understanding with people (Mbuligwe, 2002; Henry et al., 2006; Okumu-Okot, 2012; Isugi and Niu, 2016). Illiteracy and economy, in many EAC countries, solid waste management is the responsibility of government and this causes a big problem of carelessness of SWM infrastructures by people. This is mainly due to lack of adequate information on the importance of those infrastructures to the surrounding population (Guerrero et al., 2013).

Income of EAC is also another challenge because of poor and unstable resources. This affects prioritization of budget of SWM and results in dumping or inappropriately throwing a big percentage of their wastes. It also causes many difficulties to private companies which rely almost 100% on money (waste management fees) from people they serve (Katusiimeh et al., 2012; Kirama and Mayo, 2016; Sandhu et al., 2017). This causes unaffordability of many people (especially poor people) to the service due to high cost. It also results on throwing their waste in water bodies, streets, open air places and so on. However, some money can be gained from advanced waste management (composting, sanitary landfill through gas recovery, incineration, waste to energy and so on). To overcome these; governments are requested to increase budget of waste management and prioritize recycling than disposal (Katusiimeh et al., 2012). This is a key solution to success of SWM projects through the reduction of cost of handling and always relying on people. Especially on waste to compost, this is an important solution which will provide enough compost to EAC farmers. Compost is an important fertilizer on soil remediation (bio-remediation); erosion control through improving soil water holding capacity and it is also very cheap compared to chemical (inorganic) fertilizers. So, the problem of awareness of EAC people on the importance of management and treatment of solid waste will be solved together by local government, private companies and NGOs through training people to raise their knowledge on SWM (Henry et al., 2006; Okumu-Okot, 2012).

Sustainable waste management provides many opportunities as it is shown in Table 5, there are many possibilities of turning wastes to important products based on experience of developed and highly developing countries. In China, wastes are sustainably managed through recycling, composting, and waste to energy (WTE) and sanitary landfilling. Clear plan, ambition and growth of economy show a remarkable positive change in sustainable waste management especially WTE. European countries, US and Japan are three first producers of energy from waste for long time; however, the rapid growth of Chinese economy and their interest in WTE ranked this country to the 4th position in 2012. In 5 years, from 2007 to 2012, Chinese WTE plants increased from 66 to 100 and since the beginning of 21st century, the quantity of solid waste transformed to energy increased from 2 to 14 million tones. These rapid increases show relationship between economy and waste management system (Dong, 2011; Abdallah et al., 2019; Sharma and Jain, 2020). Economy of EAC countries is a big obstacle to the implementation WTE system, but characteristics of their solid waste and the will of different sectors show other opportunities which can

Table 4. Some key factors affecting SWM in developing countries.

Government	Private companies
Lack of people awareness	Lack of people awareness
Lack of enough equipment and infrastructure	Lack of enough equipment and infrastructure
Investing without benefit (in terms of money)	Waiting for more benefit (in terms of money)
Climatic conditions	Climatic conditions
Illiteracy of people	Illiteracy of people
Improper housing	Improper housing
-	Focusing in high income people

Table 5. SWOT (Strengths, weaknesses, opportunities and threats).

Strengths	Weaknesses
Will of different persons on solid waste management	Many solid waste management projects focus in high income communities
Rules and regulations of environmental protection	Some in-charges of environmental protection are not specialist.
Availability of environmentalists in all EAC countries	Lack of organization
Investors and private companies in inorganic and organic solid waste recycling	Unsustainability of the available solid waste management system (landfills and composting)
-	Lack of enough information on SWM in EAC people
Opportunities	**Threats**
High percentage of organic waste	Unplanned changes in leadership
Big market of compost	Insecurity
Good climate for small scale and local composting	Corruption
Willing of private companies to invest in solid waste management	Illiteracy
Will of governments on prioritization of SWM	Climatic conditions
Enough market of energy from solid waste treatment	Lack of enough infrastructures and equipment
-	Economy

solve this problem. Generated solid waste in EAC is dominated by organic waste; so, sustainable composting can cover a big proportion of their waste. Based on the quantity of waste dumped or unsanitary landfilled in EAC, reinforcement of sanitary landfill is also needed to reduce the risk of secondary pollution. Some pilot project of WTE must also start; so, from the increase in economy and WTE experience; future change of the reduction of waste composted or landfilled to WTE will be achieved.

Conclusion

This paper summarized the situation of solid waste management in EAC countries and analyzed their problems. It is found that income level determines the characteristics and management system of waste generated all over the world. High cost of waste management tends to be a barrier in EAC countries and results in environmental pollution from insanitary landfill, dumping, unsustainable composting and direct

disposal of waste into inappropriate places. Unstainable waste management in EAC starts from waste generation to the final disposal due to poor sorting and collection. More than 62.5% of EAC solid waste are organic; these waste can be sustainably composted and produce quality compost to EAC farmers. Sustainable composting and sanitary landfill will result on diverting dumped and inappropriately disposed waste to landfill and composting. Experience of developed and highly developing countries showed that WTE is more sustainable and increase with economy. EAC countries should start pilot projects of WTE and make it a future priority with the economic growth.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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