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Review

Vermicomposting: A management tool to mitigate solid waste

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ABSTRACT

Solid waste management is a serious ecological problem in Saudi Arabia due to rapid industrialization, population growth and urbanization. Recycling and sorting are in their infancy in Saudi Arabia and huge amounts of mixed household and industrial wastes are still dumped without any pre-treatment. Solid waste management techniques such as incineration, pyrolysis and gasification have high investment costs. Composting and vermicomposting of solid organic waste have been considered as an economically viable and sustainable waste management technologies. However, wastes often contain pollutants, such as heavy metals that are toxic to decomposer micro-organisms. Thus, heavy metals are a challenge for the successful biological treatments. Waste may also contain a mixture of organic pollutants that certain microbes, such as micro-algae are known to degrade. The present review paper focuses on understanding the role of vermicomposting as a management tool in mitigating solid organic wastes. It is noteworthy to mention that the microbes also play a pivotal role in the degradation process, wherein the enzymes secreted during the process aid in decomposition of complex molecules into simpler compounds. Also, the extracellular polymeric substance secreted by the earthworm under metal stress serves a source of nutrient for the bacteria to flourish. Henceforth the goal of discussion in present review shows the way forward in using vermicomposting as a novel approach in dealing with solid organic waste.

Contents

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1. Introduction

Municipal solid waste has become a severe environmental problem due to rapid population growth, industrialization and urbanization (Elkington and Hartigan 2008). A number of decisions have been made to recycle and sort this waste on individual, community and government level but still large amounts of mixed industrial and household wastes are being dumped. Municipal solid waste management majorly affect the overall living standards of communities such as cleanliness, health and productivity (Bahçelioğlu et al., 2020, Ugwu et al., 2020). Proper management of solid wastes is mandatory and need urgent action for the persistence and appropriate functioning of societies (Bui et al., 2020). Poor waste management is contaminating the biosphere including oceans, rivers and seas; thereby causing flooding, obstructing drains, transmitting diseases through vector breeding, elevating respiratory problems via airborne particles created from waste burning, harming animals by consumption of waste unknowingly and a major demise in economic development by diminishing tourism (Desa et al., 2012, Sharma et al., 2020).

Increases in economic growth and rapid urbanization are directly related to increase in per capita waste generation (Venkiteela, 2020). Thus, municipal waste management is much expensive in urban areas (Rathore and Sarmah, 2020). In low-income countries, waste management is the highest budget item comprising of about 20 percent of municipal budget, more than 10 percent in case of middle-income countries and about 4 percent for high-income countries (Luttenberger, 2020). Complex waste management operations are costly and need funding along with basic necessities like clean water, health care, education and other utilities (Smyth et al., 2010). This management system is administered by local authorities having limited funding and limited capability for planning, operational monitoring and contract management (Mongkolnchaiarunya, 2005, Pasang et al., 2007). These factors make municipal waste management a complex proposition on path of economic development in case of low and middle income countries and their efforts to report the underlying issues (Kassim and Ali, 2006, Tukahirwa et al., 2010).

Annual production of global municipal solid waste is about 2.01 billion tons, with approximately 33 percent, not managed in environmentally safe manner (Wang et al., 2020). The worldwide waste generation rate ranges from 0.11 to 4.54 kg per person per day with maximum rate of 0.74 kg per person per day (Farmanbordar et al., 2020). High income countries account only for 16 percent of world's population, generating an average of 683 million tons i.e. 34 percent of overall global waste (Abu Tayeh et al., 2020).

It is expected that global waste can grow up to 3.4 billion tons till 2050 as shown in a study done in 2018 (Hoque and Rahman, 2020). According to literature, it is estimated that the daily per capita rate of waste generation can increase up to 19 percent till 2050, comparing low and middle income countries estimating an average of 40 percent increase in waste generation rate (Fig. 1) (Korkut, 2018). Waste generation rate in low income countries is found at much increased rate as compared to high income countries (Ye et al., 2020). Thus, total waste generation in low income countries is expected to increase three folds till 2050 (Kaza et al., 2018a).

According to a recent survey, maximum waste generation is done by Pacific region and East Asia having 23 percent, least waste production i.e. 6 percent, by North Africa and Middle East region on a global scale (Fig. 2), (Scarlat et al., 2015). Some fastest waste growth regions of the world consist of South Asia, North Africa,

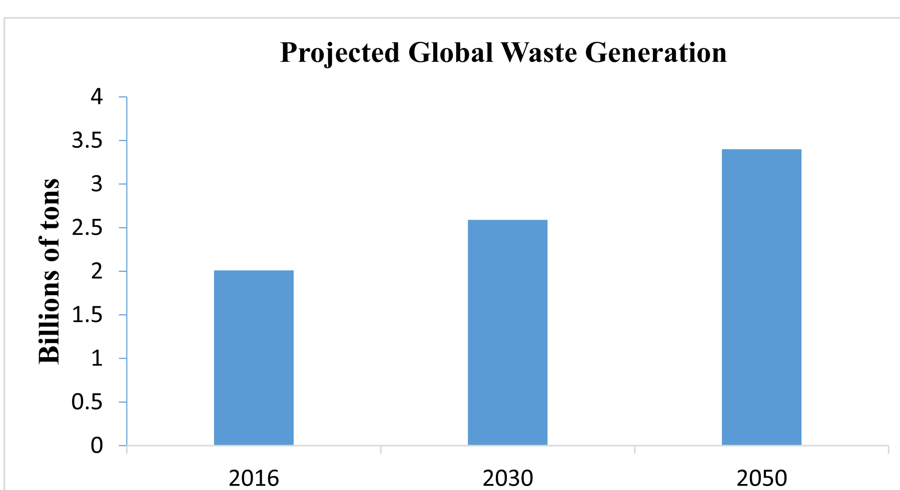

Fig. 1. Projected global waste.

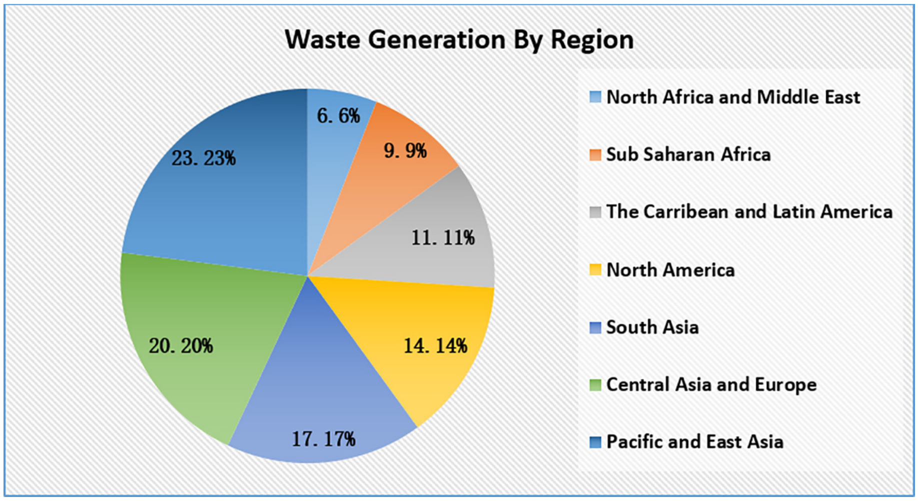

Fig. 2. Waste generation by region.

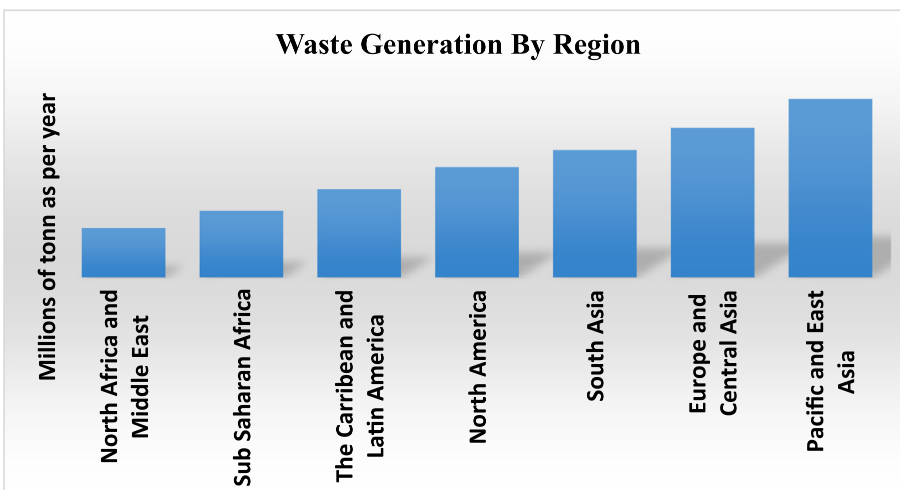

Fig. 3. Continent-wise generation of waste by region.

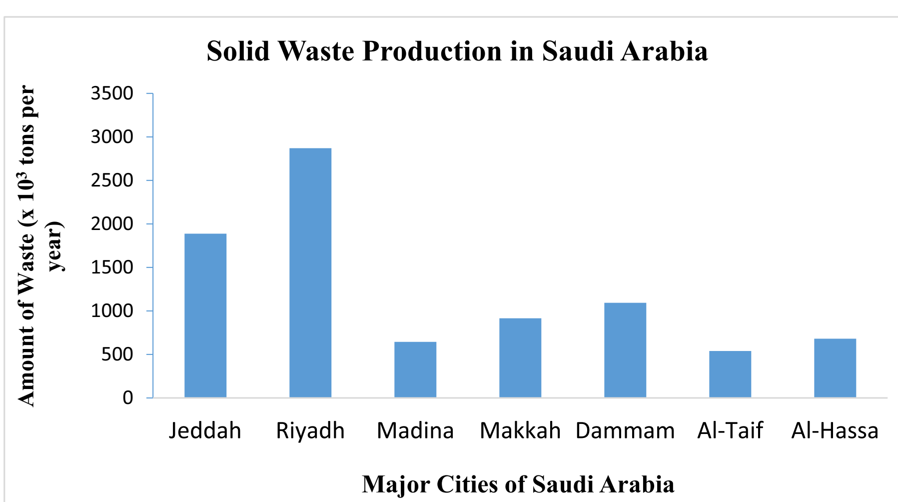

Fig. 4. City-wise solid waste production in Saudi Arabia.

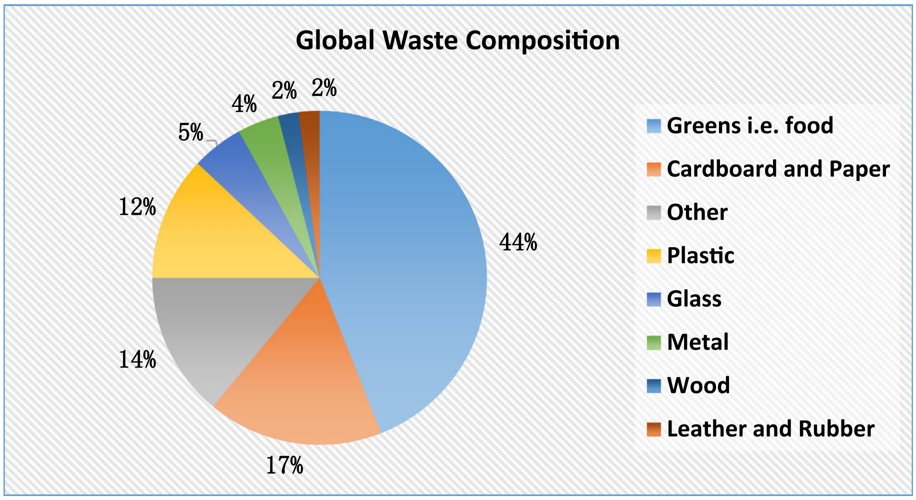

Fig. 5. Distribution for various waste composition globally.

Middle East and Sub-Saharan Africa, with double and triple folds in growth rates respectively till 2050 (Diaz-Ruiz et al., 2018). In all these regions, a huge amount of waste is openly dumped and routes of waste growth have immense implications for health, environment and prosperity, requiring imperative action (Parfitt et al., 2010, Diaz-Ruiz et al., 2018).

Collection of waste is a precarious step in waste management, although variation can be easily observed in rates depending upon the income levels. Kaza et al., (2018a) reported that waste collection in low income countries account for 48 percent of waste in urban areas, but this fraction drops significantly to 26 percent in non-urban areas. Talking about global regions such as Europe, North America and Central Asia is known to collect about 90 percent waste while Sub-Saharan Africa collects approximately 44 percent (Fig. 3) elaborated by (Kaza et al., 2018a).

1.1. Solid waste management in Saudi Arabia

Saudi Arabia is located in South West Asia and encircles the Arabian Gulf at east to the Red Sea at West. The country possesses a huge population of 34.8 million as described in 2020 (World Bank Data). Much of the solid waste has been found to be reported in Saudi Arabia due to rapid industrialization, urbanization and population growth in the last few decades (Gajalakshmi and Abbasi, 2008). About 3.4% increase in population growth was observed for the last four decades containing about 50–80% increment in urbanization from 1970 to date (Shahzad et al., 2017). This enormous population growth and urbanization has created huge amount of abandoned solid waste generation including eight major cities of Saudi Arabia as mentioned in the literature (Ouda et al., 2013) and elaborated in Fig. 4.

Total municipal solid waste generated in Saudi Arabia is 15.3 million tons per year with the average rate of 1.4 kg per/capita/day (Zafar, 2020). This municipal solid waste is regulated by Local Affair & Ministry of Municipalities and managed by local municipalities which are responsible for collection, transportation and waste disposal to landfill and dump sites without using energy (Ouda et al., 2013). Disposal of unchecked wastes is usually done through combustion and landfill dumping. Organic wastes are converted into compost by using compost facilities (Nizami et al., 2015). These prevalent improper waste disposal treatments are causing serious damage to the environment as they can trigger pollution of surface waters, grounds and can create malodors (Al-Sabahi et al., 2009).

2. Municipal solid waste pollutants

Waste pollutants are categorized on the basis of different types of materials present in municipal solid waste. The composition of pollutants in the waste is generally determined using a standard waste audit which deals with the garbage samples collected from final disposal sites or generators, sorted in predefined categories and weighed (Kaza et al., 2018b). Municipal solid wastes (MSW) consist of five main categories i.e. food waste, metal, paper, plastic and glass etc. Kaza and Bhada-Tata (2018) elaborated that green waste including food is the world's largest waste category accounting up to 44 percent of overall waste. Another major contribution is done by dry recyclables including paper, metal, plastic, cardboard and glass accounting up to 38 percent waste. The global waste composition is described as follows in the Fig. 5.

Income is another important factor in waste pollutants. Organic matter percentage decreases on increasing income level. Plastic, paper, wood waste and rubber are the most found consumed goods in waste present in high income countries as compared to low income countries. Moreover, less green and food waste i.e. 32 percent is generated in high income countries but producing more dry recyclable waste i.e. paper, plastic, metal, card board and glass i.e. 51 percent out of total waste. While low income and middle income countries generate 56 percent and 53 percent of food and green waste, respectively (Kaza et al., 2018b). Organic waste is found to increase as economic growth decrease in low income countries. Dry recyclable materials account for 16 percent of total waste in low income countries. Almost all global regions show an approximate of 50 percent of organic waste except Central Asia, Europe and North America which are responsible for generating higher amounts of dry waste (Kaza et al., 2018a).

2.1. MSW pollutants in Saudi Arabia

Municipal solid waste is collected at waste dumping sites and varies among different communities and cities (Chang and Chen, 2010). Saudi Arabia contains huge amount of municipal solid waste with highest percentage of organic wastes such as about 66% including food wastes and paper materials (Hassan, 2020). Food waste is being produced from different sources like restaurants, hotels, homes, canteens, vegetables and fruits refuse and peel stuff etc. (Li et al., 2013). Recent studies have shown the composition of food waste include meat (25%), rice (38.7%), fats (13%) and bakery products (18.7%) etc. as major fractions (Adhikari et al., 2008).

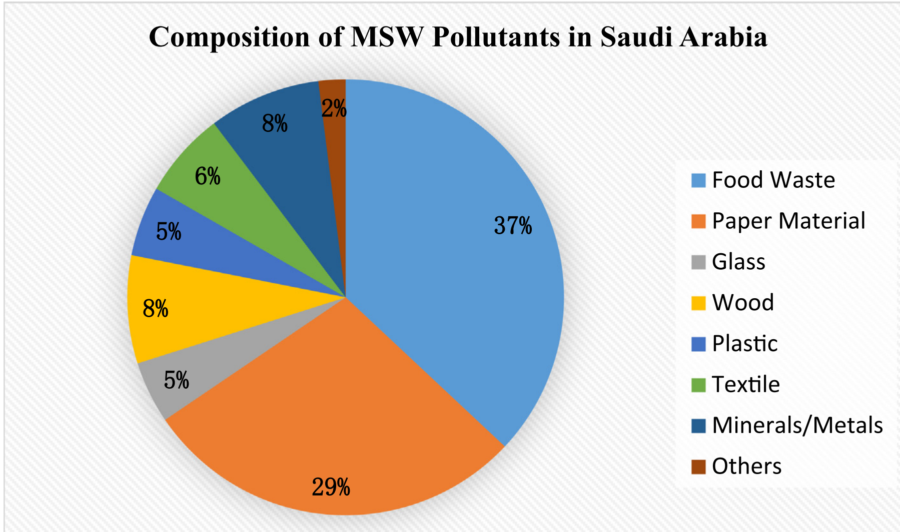

Fig. 6. Distribution for various waste composition in Saudi Arabia.

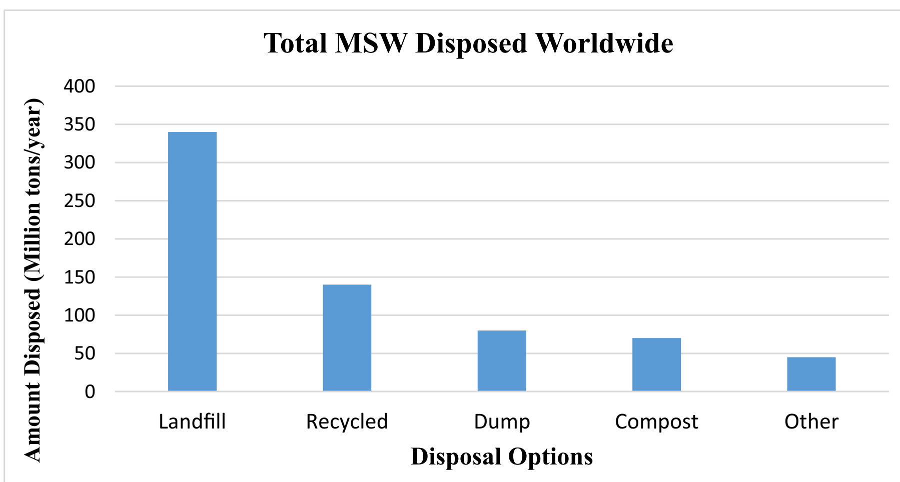

Fig. 7. Amount of disposed waste in various segments of waste management.

Table 1
List of technologies utilized and their impact on environment and economy.

Sr. #	SWM Technologies	Effect on Environment	Effect on Economy
1	**Waste Dumping**	Odor created due to ground water pollution	High Operational Cost
2	**Incineration**	Air Emissions i.e. Bottom Ash & Fly Ash	Thermal Energy
3	**Composting**	Biodegradable Organic Waste only	Organic Fertilizers
4	**Vermicomposting**	Degrade Organic Waste using Earth Worms Reduce Heavy Metal	Low Operational Cost
5	**Pyrolysis**	Degrade Plastic only, Air Emissions	Crude Oil i.e. Char & Liquid Fuel
6	**Anaerobic Digestion**	Degrade Organic Waste, GHG emissions decreased	Bioenergy (Methane)

Paper waste include different cardboard, wasted papers, box board, magazines, newspapers, bags, tissue papers and toilet papers etc. (Zhang and Sun, 2018). Plastic is another most abundant solid waste produced in Saudi Arabia (Zafar, 2021) due to the large usage of disposable plastic bags and containers for food and drinks, during the Hajj and Ramadan days (Abdul-Aziz et al., 2007). Textile, wood products, glass wares, bottles, ceramics and bulbs also account for an important fraction of municipal solid waste. Some minerals and metals are also found in solid waste including knives, aluminum cans, wire bottles and foils etc. accounting a major fraction i.e. 8.3%. Apart from all these pollutants, rubber, leather, fibers, soil, yard waste, tyres, electronics and appliances are also found in municipal solid waste of Saudi Arabia (Fig. 6) (Khan and Kaneesamkandi, 2013).

3. Solid waste management techniques

The above mentioned waste management practices (Fig. 7 & Table 1), are responsible for large production of greenhouse gas (GHG) emissions i.e. CH_4, CO_2 and N_2O as elaborated by (Rahman and Khondaker, 2012). Moreover, it is expected that the dumping sites present in Saudi Arabia will cross their fulfilling capacities in the upcoming years (Ouda et al., 2013).

Vermicomposting has a bundle of advantages over all the other waste management methods i.e. this process can be carried out indoors as well as outdoors, allowing whole year round composting (Rodríguez-Canché, 2010). This process allows obtaining organic nutrients sources for the crops in less time, which are nutritionally, physically and biochemically efficient as compared to other composts (Yadav et al., 2010). Vermicomposting is known as low cost technology process used for the processing or treatment of organic waste. The comparison study done between conventional composting and vermicomposting elaborated that vermicomposting resulted in an enriched compost with high quantities of N, K and P content leading to a decrease in heavy metal content (Cardosa Vigueros and Ramírez Camperos, 2002). Solid wastes can be decomposed into valuable compost using vermicomposting process, providing an efficient substitute for chemical fertilizers and hence reducing pollution too (Monroy et al., 2009). Therefore, it is very important to use some advanced waste to energy and vermicomposting process instead of these already prevalent waste management practices.

4. Detoxification of MSW pollutants

4.1. Role of biochar

Biochar play a crucial role in improving compost quality and soil health as a whole. Biochar is basically made by adopting pyrolysis procedure of any organic material such as tree bark, cow-dung, dried plant part etc. wherein the airflow is kept at minimal at high temperature. Biochar is typically porous, light-weight with high carbon content and exhibit a portion which doesn't decay easily owing to its stable structure (Pudełko et al., 2021). Although it has high ash content and low nutritional value, it can improve the physical structure of soil and aid in better yield. It has been found in many researches (Rehman et al., 2020) that biochar aid in improving the physical property of soil by sequestering the carbon; thereby improving the crop yield (Al-Harbi et al., 2020).

Composting is a process that involves the decomposition of organic solid wastes into humus i.e. known as compost in the presence of air. This humus like material acts as an excellent fertilizer for plants (Lobo and Dorta, 2019). Another major type of composting known as 'Worm Composting' or 'Vermicomposting' is an enhanced humification (decomposition) process carried out in the presence of earthworms under non-thermophilic conditions. In this process of vermicomposting, organic solid waste is stabilized into a dark colored, nutrient rich and earth smelling soil conditioner compost having an abundant quantity of major and micronutrients (Abul-Soud et al., 2009).

It is noteworthy to mention that biochar helps in faster degradation during vermicomposting and also reduces the heavy metal content by absorbing its soluble form (Paul et al., 2020). During composting, biochar is known to improve free air space attributing to increase in air circulation that provides better environment for the aerobic bacteria to flourish and aid in faster degradation (Antonangelo et al., 2020). Owing to the porous nature of biochar, excess water produced during the composting process is soaked in and prevent leachate formation. Furthermore, biochar also acts as a bio-catalyst during the degradation process that accelerates the decomposition of organics and yield quality compost in shorter span (Siedt et al., 2020). Biochar also reduces the bioavailability of heavy metals by immobilizing those (Boostani et al., 2021); thereby mitigating the inhibition effect of metals (present in MSW) on the bacterial growth and their metabolism.

4.2. Role of Eisenia fetida

Eisenia fetida is a European species which was introduced into the Indian sub-continent. It has higher reproduction rate as compared to other species of earthworms such as *Eudrilus eugeniae*, and *Perionyx excavatus*. Earthworms are known to produce compost during the vermicomposting process through the ingestion of complex organics and excreting simpler forms (Van Groenigen et al., 2019). Herein, *Eisenia fetida* has excellent capacity to convert organics such as food waste, garden waste, agricultural waste, MSW etc. into quality compost (Yuvaraj et al., 2020). Also, it plays a greater role in sequestering heavy metals and reduces its bioavailability through the process of bio-mineralization. It is noteworthy to mention that the skin tissues of earthworm secrete extracellular polymeric substance (EPS) under metal stress and are responsible for binding with the heavy metals; thereby mitigating its mobility and arrested them onto its skin (Khan et al., 2019). This EPS also acts as an enzyme for the bacterial degradation of waste and aid in improving their population. Likewise, it has been found that such EPS improve the compost quality and improve its nutritional value has it comprises of carbohydrates and protein as its primary ingredients (Guhra et al., 2020). Henceforth earthworm has a very crucial role to play during vermicomposting period and give quality compost as final product.

5. Vermicomposting process

5.1. Role of Microalgae

Microbes are known to play a pivotal role in the bioconversion of complex organics into simpler forms through degradation process. Functional profiling of microbiota in casts of *Eisenia fetida* during vermicomposting suggests that the microbial community is affected by the pH and rearing substrate (Ameen and Al-Homaidan, 2021; Budroni et al., 2020). Gusain and Suthar (2020) found that higher activities of β-galactosidase, dehydrogenases, proteases, and phosphatases were recorded during vermicomposting of duckweed. Also, it has been found that amendment with nano-carbon or biochar greatly enhanced microbial activity with higher decomposition rate and enzymatic activities (Cao et al., 2020). Tossavainen et al., (2017) investigated that composting leachate enhanced the growth of bacteria and algae in co-culture, wherein nutrients from leachate were effectively converted into algal biomass. It has also been found that the growth of algal biomass didn't hamper the bacterial growth. Algal culturing during composting can also improve nutritional value of the end-product and can act as soil conditioner attributing to greater yield (Alobwede et al., 2019). Cole et al., (2017) described that algal biomass can be used to capture nitrogen and phosphorous from sewage wastewater and then using it during composting to enrich the end product. Therefore, algae can serve as a source of nitrogen and phosphorous during composting that can ultimately improve the N, P, K value of the end compost; thereby making a nitrogen-rich end-product which is necessary for plant growth. Henceforth it is imperative to investigate the microbial community (especially micro-algae) and its biodynamics in order to better understand their role in the degradation process that aid in the development of quality compost.

5.2. Bioavailability of heavy metals

Heavy metals such as cadmium, nickel, copper, etc. are known to hinder the vermicomposting process through the process of bacterial inhibition and also alleviate the reproduction capacity of earthworm under metal stress. However, earthworms have a unique mechanism to mitigate its hindering effect (Wang et al., 2013). Earthworms secrete a mucus-like substance under metal stress that aid in reducing the bio-availability of metals through the formation of organic–metallic complexes and bio-accumulate them on the surface of their tissue (Swati and Hait, 2017). Also, it is noteworthy to mention that the EPS secreted by the earthworm and the microbial communities associated during vermicomposting tend to arrest the mobility of metals using the process of enzymatic action in gut- and cast-associated processes (Sun et al., 2020). The organics secreted by the earthworm has functional groups that bind with the metals and form organic–metallic complexes; thereby reducing metal toxicity attributing to lesser metallic stress during vermicomposting. Henceforth the bioavailability of metals is alleviated through bioconversion of metals during the composting process.

6. Recommendations for MSW management in Saudi Arabia

In Saudi Arabia, the huge generation of solid waste indicates its magnificence and is considered one of the biggest problem to the local communities (Koval and Mikhno, 2019). Thus, government and local bodies are taking initiatives to overcome this big challenge by using many strategies and employing certain policies (Vaverková et al., 2020). Some of the major obstacles that occur in proper municipal solid waste management in Saudi Arabia include lack of consistent research and data collection, lack of competent manpower, poor administrative and institutional arrangements, insufficient legal and regulatory protection, shortage of proficient private operators leading to financial, equipment and technical difficulties (Astrup et al., 2015). Therefore, following are some of the proposed recommended ideas towards sustainable solid waste management as described as below:

6.1. Solid waste management plans

Firstly, there should be some policy strategy and planning for proper solid waste management. These local and regional waste management plans help in the implementation of policies and achievement of targets (Al-Ajlan et al., 2006). The primary role of these waste management policies is to give information about waste sources, their amount and disposal options. These plans also help in the identification of areas undergoing certain technological waste minimization treatments (Memon, 2010). Furthermore, it also enable to understand financial requirements in the operation and treatment of solid wastes. To solve all these waste management problems, many authorities and participants require coherent planning to avoid unnecessary repetition of efforts. (EU Commission, Environment, 2003).

6.2. Zero-waste policy

Government and local authorities should imply a zero-waste policy by using longer-lasting reusable products that will also help in sustainable economy (Vaverková et al., 2020). The products should be designed in accordance with their maximum shelf-life and recycling of their components. Zero-waste policy help in merging industries, businesses and communities in such a way that waste product of one person serve as a feedstock of another one, resulting in pollution prevention (Ouda et al., 2018). Plastic bags should be forbidden and encouraged to sort out these organic, plastic and metallic waste at home (Beigl et al., 2008). Electronic gadgets should be made recyclable that its parts can be used later on and proper disposal of toxic elements should be present instead of burning (Panda et al., 2010). Incineration is not the only solution of all the dumped solid waste as it leads to greenhouse gas emissions. Implementation of this policy will help to get rid of land, water and air pollution that poses a severe threat to human, animal and plant health (Khan and Kaneesamkandi, 2013). An overview of recommendations for solid waste management in Saudi Arabia is described in Fig. 8.

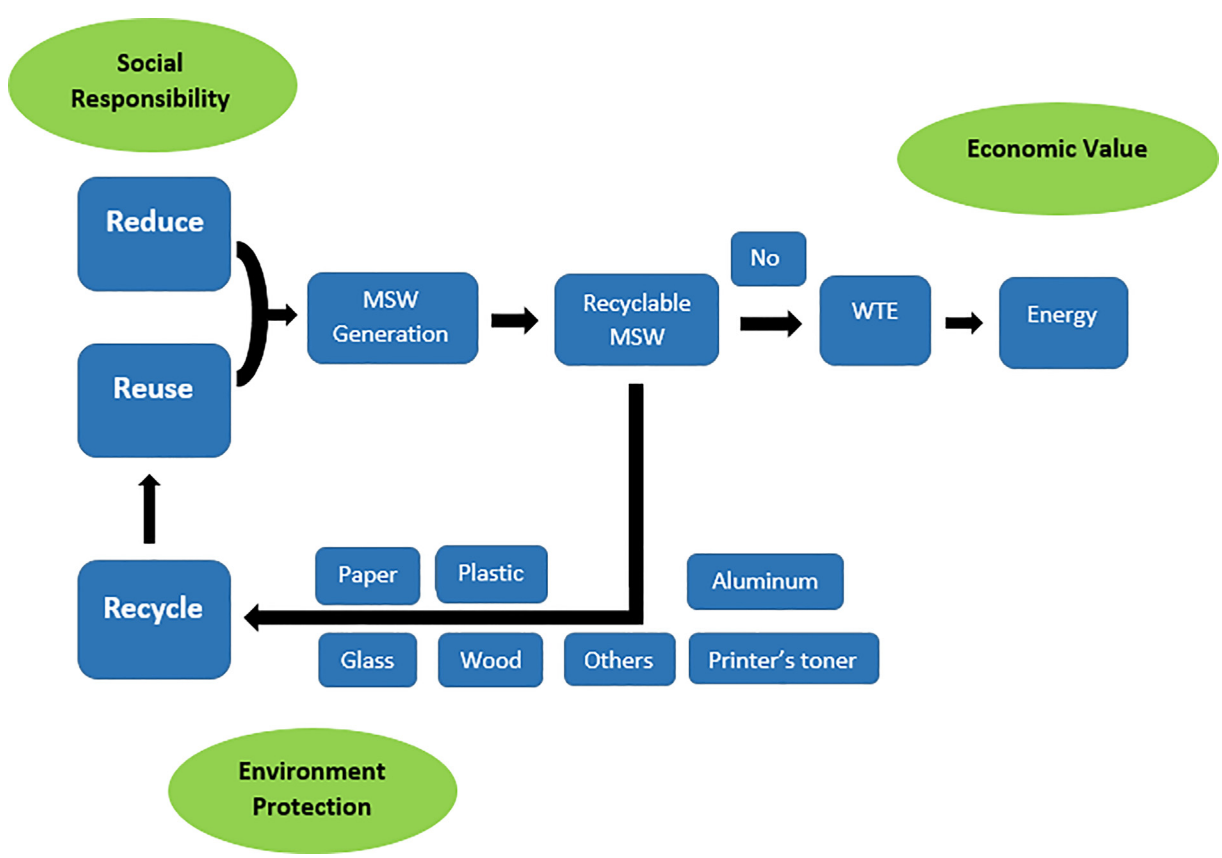

Fig. 8. An overview of MSW management recommendations (Hadidi et al. 2020).

6.3. Waste sorting

At individual level, solid waste can be sorted out to achieve a sustainable environment (Nilsson, 2010). Local authorities also need to ponder on this issue and implementation of 'three bins system' should be done (Sharma and McBean, 2009). They can either be labelled or colored differently to dispose the solid wastes separately (Lebersorger and Schneider, 2011). Recyclable solid waste can then directly be sent to recycling industries and processed accordingly, saving labor and time too (Sharma and McBean, 2009).

6.4. Recycling

The 3Rs system i.e. recycling, reuse and recovery of energy, is still at its initial stage and need to be implemented frequently (Alruqaie and Alharbi, 2012). Recycling of solid wastes is done by an informal sector and is labor intensive process (Nilsson, 2010). It is reported that Saudi Recycling Company (SRC) is being planned to create by using Public Investment Fund (PIF), which will act as waste management body responsible for domestic recycling projects in Saudi Arabia (Alruqaie and Alharbi, 2012). The rate of solid waste recycling is only 10% currently and the Saudi Government aims to increase this rate up to 85% using SRC using a national strategy plan named as 'Vision 2030′ (Kabirifar et al., 2020). Thus, recycling should be done to a greater extent for attaining sustainable waste management goals.

6.5. Education and awareness

Of the more important factor that needs to be implemented in Saudi Arabia for better management of solid waste programs is 'continuous awareness program' (Hadidi et al., 2020). Proper public education is mandatory for the people to understand modern techniques used for waste management services. This public education also helps them to be aware about the importance of waste minimization on an individual level so that they can evaluate the reasons behind management of solid wastes sustainably (Beigl et al., 2008).

6.6. Enforcing law

To accomplish sustainable waste management system, proper law enforcement is necessary to be implemented by the Government against those who don't follow the law by dumping wastes haphazardly (Tolba and Saab, 2008). Local authorities of Saudi Arabia should ensure the implementation of 'pay as you throw' program to abide by all the people present in the country including tourists too (Lebersorger and Schneider, 2011). Secondly, rules should be set for the consumers whenever they buy a certain product, an excise tax along with the product charges should be paid. The amount collected should then be used for the waste management services. The product charges act as policy mechanisms and should be implemented by national or regional government of Saudi Arabia (Tolba and Saab, 2008).

6.7. Innovative waste reduction initiatives

Some innovative waste minimization initiatives can be made to sort out waste management problems in Saudi Arabia (Beigl et al., 2008). One of them is 'upcycling' or 'creative reuse' of the unwanted waste materials into novel products that can serve as a potential environmental value (Panda et al., 2010). For example, tree trunks that were dumped can be converted into furniture amenities or wooden footpaths. Moreover, wood chipper can also be used for reducing wood in smaller woodchips that can be used in soil fertilizers and landscapes by minimizing 'tree trimming waste' up to 40 percent (Zafar, 2018). The loader trucks required for landfill trips will not then be used and transport cost and time will be saved (Nilsson, 2010). In 2019, an initiative about transforming about 9 tons of waste wooden pallets in 1200 planter boxes was done under the cost of 14,400 USD. In Saudi Arabia, the estimated disposal cost per ton MSW is about 151.2 USD (Khan and Kaneesamkandi, 2013). Hence, the disposing cost of discarded wooden pallets is estimated to be 1360 USD, saving the landfill dump sites with these wastes.

6.8. Composting

Composting is one of the waste management technique used for waste reduction destined for disposal (Hoornweg and Bhada-Tata, 2012). This compost contains a lot of organic stuff that can be sold out to farmers aiding in the soil fertility and improving crops production (Adhikari et al., 2008). Government should promote the development of novel technologies that can aid in the conversion of solid waste to compost and accepting it as a soil amendment product (Turki et al., 2016). This project needs time to develop in Saudi Arabia due to the lack of consent and cooperation between communities, informal sector, formal waste sector and local authorities etc. (Edjabou et al., 2015)

6.9. Waste to energy

Saudi Arabia possesses a harsh environment having temperature extremes as 50 ◦C in summers and can reach 0 ◦C in winter season (Ouda et al., 2017). This temperature variability affects the electricity demand for whole year, leading to a surge in demand in summers for air conditioning systems (Hasanov, 2019). This increased electricity demand has been fulfilled using fossil fuels i.e. gas, heavy and crude oil powered plants but Government of Saudi Arabia has been trying to reduce this reliance on fossil fuels by the establishment of King Abdullah City of Atomic and Renewable Energy (KACARE) program (Nizami et al., 2015). This program aims to generate 72 GW of energy from indigenous renewable energy sources i.e. wind, solar, nuclear and waste to energy (WTE) till 2032 (Goldstein et al., 2020). Saudi Arabia has potential to generate energy from waste (WTE) and play a vital role in the development of country's economy (Ouda et al., 2017). Energy content obtained from solid waste pollutants is described in the following Table 2.

The energy consumption rates as well as the energy created from mass burning of solid waste is described in the give table, indicating the potential role of WTE conversion in supplying electricity to enough households in Saudi Arabia.

There is a dire need to the development of more sustainable waste management approaches with respect to social, environmental and economic value (Ouda et al., 2017). Government of

Table 2
Energy Content of MSW (Ouda et al. 2013).

Material	Energy Content in Material (kWh/kg)	Energy Content in Waste (kWh/kg)
Paper	4.39	1.21
Plastic	9.05	0.46
Glass	0.0	0.0
Wood	4.73	0.24
Textiles	5.2	0.22
Organic	1.55	0.1
Others	3.36	0.28
Total energy for mass burn with recycling (kWh/kg)		0.38
Total energy contents of complete mass burn (kWh/kg)		2.51

Table 3
Forecast for electricity demand and two Waste to Energy (WTE) scenarios (Ouda et al., 2019).

Year	Per Household Consumption (Kwh)	Per Capita Consumption (Kwh)	Number of Households	
			Mass Burn with Recycling	Complete Mass Burn
2010	44,340.8	7918	4349	29,852
2015	52,337.6	9436	4354	29,478
2020	61,661.6	11,011	4264	28,717
2025	72,766.4	12,994	4096	27,707
2030	85,797.6	15,321	3882	25,951

Saudi Arabia should take important measures in the development of WTE technology more efficiently by using multi-criteria decision making approaches to add value to the economy of the country (Omar Ouda et al., 2017) see Table 3.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authorship Contribution Statement

All authors contributed to data analysis, drafting, or revising the manuscript. All authors approved the final manuscript and are accountable for all aspects of the work.

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