Waste Management in India – An Overview

R. Dhana Raju

Former (i) Associate Director, AMD, Dept. of Atomic Energy, Hyderabad-500 016 and (ii) Honorary Visiting Professor, Dept. of Applied Geochemistry, Osmania University, Hyderabad-500 007, India

Email: dhanaraju.reddi@gmail.com

***Abstract*—** As the global generation of waste (i) is of the order of > 2 billion tons per year and is expected to reach ~ 3.5 billion tons annually by 2050 and (ii) has a critical bearing on the worldwide problems of pollution control (PC), global warming (GW) and climate change (CC), a government-aided and monitored, and people-participated waste management (WM) is desirable for a hygienic, healthy and sustainable society. Aiming this and targetting for zero-waste, the WM has been undertaken in India − from the collection of waste at source to its minimal, safe and monitored disposal in a landfill, with intermediate stages of transportation, segregation and recycling for value-added products −, under the Swatchh Bharat Ayojan (Clean India Mission) programme. All the above stages of WM have been adopted in various ways in both the urban and rural areas. Based on a yearly evaluation of the WM, some cities and states have been designated as "clean". An account of the presently followed methods of WM and their results in some of these clean places as well as generation of many value-added products by recycling different types of waste material is presented in this article. In the light of the above information and data, and aiming zero-waste in the country's WM, the following aspects are discussed: role of decentralised and centralised WM; integration of WM with PC, GW and CC; effluent and sewage treatment plants for WM; public awareness-commitment-participation for a monitored, efficient WM; reduce as an important tool for WM, especially to minimise the large-scale generation of food-waste, and its relevance, as per the Indian concept of Aparigraha (take only what one needs); and WM as a widely distributed, micro- to small-scale industry for generation of both wealth and employment.

***Keywords*—** Waste management, Swatchh Bharat Ayojan, clean cities-states-metros, India.

1. INTRODUCTION

Waste is the discarded material, generated after its primary use. It is of various types and differently classified, based on specific parameters. Thus, based on its (i) *nature*, it is of two types – biodegradable (wet) and non-biodegradable (dry); (ii) *source* − domestic, agricultural, industrial and commercial types; (iii) *toxicity* − hazardous and non-hazardous types[1]; and (iv) bearing on *environmental pollution* − 5 types: *solid* (garbage, sludge and refuse; five major types of glass, ceramics, plastic, paper and metals), *liquid* (point [manufactured] and non-point [occurring naturally in the environment] source); *organic* (decomposes with time and turns into manure by micro-organisms), *recyclable* (metals, plastic, electronic [e-] waste, furniture etc.) and *hazardous* (inflammable, corrosive, toxic and reactive material) waste[2]. The processing of waste involves, sequentially, the collection, transportation, sorting, treatment, recycling for recovery of diverse value-added products (VAPs) and monitored/regulated final disposal in a landfill. There are different methods of disposal of waste, such as *Incineration* (controlled combustion of garbage to reduce the volume of waste by ~ 90% and is the most hygienic way of waste disposal); *Waste compaction* (waste materials such as cans and plastic compacted into blocks and sent for recycling, which prevents oxidation of metals); *Biogas generation* (biodegradable waste converted into biogas, using micro-organisms); *Composting* (burial of organic waste under soil and left to decay under the action of microorganisms, resulting in a nutrient-rich manure for agriculture); *Vermicomposting* (degradation of organic matter into manure by using worms); and *Landfill* (the waste that cannot be recycled or reused spreads as a thin layer in low-lying areas across human habitations)[3]. All these aspects come under the general term "Waste Management" (WM) that comprises five R's, viz., reduce, reuse, recycle, recover and residual management[3].

In India, which is the second highest populated country (> 1.3 billion) and generating the highest amount of waste in the world (277.1 million tons in the year, 2016, as per the World Banks "What A Waste 2.0" report of 2018), the notable features of waste and WM scenario are as follows: (i) Generation of > 62 million tons of garbage per year, out of which < 70% being collected, with hardly 19% of the collected being treated and processed, and the rest being dumped in landfills; (ii) Urban India is the world's third largest producer of garbage; (iii) 60% of the waste generated in the country comes from top 10 metropolitan cities; (iv) Waste generated is estimated to grow exponentially; (v) WM industry is estimated to grow at 7% annually; (vi) WM

segments include (a) solid waste (with 7% compound annual growth rate, CAGR), (b) plastic and e-waste, each with 10% CAGR and, bio-medical waste with 8.4% CAGR); (vii) the top 5 cities generating highest municipal solid waste (MSW), in million tons, being: Delhi – 3.5, Mumbai – 2.7, Chennai – 1.6, Hyderabad-1.4 and Kolkata – 1.1; (viii) The growth drives are urbanisation and industrialisation, institutes and social responsibility from corporate companies, increased awareness on the environmental impact and reusability, operational advantages of low-cost labour, import of waste etc., and the Government (Union and State) initiatives like the *Niti Ayog*; (ix) The potential areas of opportunity are sources of segregation, material recovery units, waste treatment plants and recycling markets; (x) The challenges are (a) lack of collection and segregation at source, (b) scarcity of land, (c) lack of interest amongst consumers and (d) unorganised and decentralised sector; (xi) The concerned and capacity-building government departments are the Ministries of Environment, Urban Development, New & Renewable Energy, and National Institute of Urban Affairs; and (xii) The industry associates are the (a) Associated Chamber of Commerce & Industry (ASSOCHAM), (b) Confederation of Indian Industry (CII), (c) Federation of Indian Chamber of Commerce and Industry (FICCI) and (d) National Solid Waste Association of India (NSWAI)[4].

In the above scenario, different cities and rural areas in India have been adopting various methods (given earlier) of WM under the *Swatchh Bharat Ayojan* (Clean India Mission) of the Govt. of India to reach the ideal target of "Zero-Waste" for a healthy, hygienic and sustainable society. In this article, the following items are presented: (a) salient aspects of the presently followed methods of WM and their results in a few Govt. of India year-wise designated *clean* cities and states as well as some metros in India (collected, examined and compiled from the published, open-access literature); (b) recycling of different major types of waste for value-added products (VAP) and employment generation through startups; and (c) in the light of (a) and (b), advancing some useful suggestions for zero-waste targeted better WM on the following aspects: (i) scope of decentralised and centralised WM; (ii) better integration of WM with PC, GW and CC under one ministry; (iii) need for more effluent and sewage treatment plants for better WM; (iv) importance of public awareness-commitment-participation for a monitored, efficient WM; (v) *reduce* as an important tool for WM, especially to minimise the large-scale generation of food-waste, and its relevance, as per the Indian concept of *Aparigraha* (take only what one *needs*); and (vi) WM as an industry for a better economy and generation of more employment.

2. METHODS AND RESULTS OF WASTE MANAGEMENT IN INDIA

As per the *Swachh Survekshan* 2020 (Clean Survey, released in August, 2020) of the Govt. of India, the order of top 20 *cleanest cities*, with name of the respective state in parenthesis, in India are as follows: 1. Indore (Madhya Pradesh) for the fourth consecutive year, 2. Surat (Gujarat), 3. Navi Mumbai (Maharashtra), 4. Ambikapur (Chhattisgarh), 5. Mysuru (Karnataka), 6. Vijayawada (Andhra Pradesh), 7. Ahmedabad (Gujarat), 8. New Delhi (Delhi), 9. Chandrapur (Maharashtra), 10. Khargone (Madhya Pradesh), 11. Rajkot (Gujarat), 12. Tirupati (Andhra Pradesh), 13. Jamshedpur (Jharkhand), 14. Bhopal (Madhya Pradesh), 15. Gandhinagar (Gujarat), 16. Chandigarh (Union Territory), 17. Bilaspur (Chhattisgarh), 18. Ujjain (Madhya Pradesh), 19. Nashik (Maharashtra) and 20. Raigarh (Chhattisgarh)[5]. The *cleanest states* of India are: 1. Chhattisgarh, 2. Maharashtra and 3. Madhya Pradesh[6]. The 8 metro cities are Delhi, Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Pune and Ahmedabad. In these, the waste management (WM) has been carried out since over a few years aiming at "zero-based waste" under the *Swatchh Bharat Ayojan* (Clean India Mission). The WM comprises an overall pattern of (i) collection of wet and dry waste separately at source; (ii) transportation either to a central station under the centralised system or to a few designated places within the cities under the decentraliszed system; (iii) processing of wet waste to generate bio-energy/fuel and fertiliser by composting; (iv) segregation of dry waste into different types, such as agricultural, plastic, paper, electronic, metallic, chemical, bio-medical etc.; (v) recycling of these different types for (a) extraction of valuable contained metals and (b) economy-improving and employment-generated value-added products; and (vi) finally, landfilling of the least, left-out amount of waste, after the above stages of processing.

In response to the ever-present challenge of achieving sustainability and dealing with the climate change, a movement called, *zero-waste*, has become very trendy. Zero-waste is the process of eliminating all trash, especially single use plastic, from everyday life, and the first principle of zero-waste is to reduce purchasing. Before the use of plastic, there are many examples for the practice of zero-waste concept in India, such as (i) use of metal tiffin boxes to hold food and snacks; (ii) serving of tea and coffee in glass cups; (iii) buying of

fruits-vegetables-groceries at markets and putting them into cloth bags; (iv) water in ceramic jugs for drinking; (v) bulk purchase of rice, biscuits, dried fruits etc., on the street, all of which remind that the world once functioned without the ever present plastic bag or bottle. Plastic-waste is a huge issue for the environment due to its long lasting damage[7]. In June 2018, Mr. Narendra Modi, the Prime Minister announced that India would eliminate single-use plastics by 2022. Steps like this as well as the efforts of both the central and state governments, and citizens of India for a zero-waste management in the country under the *Swatchh Bharat Ayojan* (Clean India Mission) have been under implementation for making both the urban and rural areas more hygienic, healthy and environmentally benign for a sustainable development of the society. As a part of this, systematic and scientific WM has been adopted in different cities and states of India. Salient aspects of WM, being presently adopted in a few clean cities – Indore, Surat and Mysore –, the clean states of Chattisgarh and Kerala, and the metros of Delhi, Mumbai, Kolkata, Bengaluru and Hyderabad, as a few examples of WM in India, are presented in the following.

2.1. Waste Management (WM) in a few Clean Cities

2.1.1. WM in Indore, Madhya Pradesh*:* Indore (22.7196º N. Lat.:75.8577º E. Long.), with a population of 1.99 million, is the cleanest city of India since 2017. It generates > 1,115 metric tons (Mt) of garbage a day and all of it is collected from the source – door-to-door from households and bulk collection from > 600 commercial establishments, using partitioned vehicles having 3 separate collection bins for *wet* (biodegradable), *dry* (other than biodegradable, inert street sweepings and includes recyclable and non-recyclable waste, combustible waste and sanitary napkins and diapers etc.) and *hazardous waste* (sanitary pads, lead acid batteries etc.) in GPS-enabled tippers. The tippers carry the waste from the households to a garbage transfer station (GTS). At a GTS, the tippers unload the wet waste into dedicated compactors that compress and load the wet waste into dedicated hook loaders. There is a computerised facility at the "weighment bridge facility" (WBF), where the weight of all the wet waste is weighed and recorded, followed by its movement to a processing plant. The wet waste is processed in two places – at decentralised waste processing units and a central processing plant, where it is processed into compost. Like the wet waste, the dry waste is collected, transported and weighed at WBF, and is processed in the central dry waste processing facilities at Deveguradiya, where it is segregated into different components, such as metal, rubber, board, plastic etc. This segregation has been done by > 340 rag-pickers, employed for two "Material Recovery Facilities" (MRF) at the plant. In the dry-waste processing, inert is recovered at both the MRFs. The inert is weighed, logged and then transferred to the sanitary landfill at the same complex. The domestic hazardous waste, including biomedical, is sent straight from a GTS to the "Central Domestic Hazardous Waste Treatment Facility" for incineration by an external contracted agency. After incineration, the remains of this waste are also sent for landfilling in a separate facility, termed as "hazardous landfill", meant exclusively for this waste[8].

2.1.2. WM in Surat, Gujarat*:* The city of Surat (21.1702º N. Lat.:72.8311º E. Long.), with a population of 4.46 million, is well known as the "diamond city" of the world, because of it being a hub for diamond cutting and polishing, with ~ 90% of the world's diamonds being processed here, as well as the "textile hub" of the nation as it is famous for its silk fabric and cotton mills in India. It is the cleanest city in the state of Gujarat, with no. 2 position in the all India rankings of clean cities for the year 2020, and was adjudged as the best city in the country for "Solid Waste Management" (SWM). In Surat, the SWM is integrated with other activities, such as sewerage, water supply, health care and engineering departments, with emphasis on the systems of complaint & grievance redress, litter prevention, slum up-gradation and rehabilitation, together with positive involvement of citizens, penalising truants and creating public awareness for hygiene and cleanliness. The WM in Surat has been carried out in three sequential phases, viz., *primary collection* of solid waste and its *transportation*; *secondary transportation*; and *treatment of municipal solid waste* (MSW). The primary collection of an average of 2,150 Mt waste per day and its transportation involves the following: day-time sweeping, lifting by containers, door-to-door collection in 7 zones covering almost the entire city, segregation at source, use of underground modern dustbins for storage and night scraping & brushing activity, collection and transportation of hotel-kitchen waste by an association of ~ 300 hotels & restaurants, deploying 18 vehicles and societal action under the '*ANUDAN'* scheme for urban dweller units in an area of > 500,000 sq. m, with a minimum contribution of Rs. 1,600/- per each of > 862 societies of housing colonies and manpower of > 800 (1 US $ is presently equivalent to ~ Rs. [INR] 75/-). Under the secondary transportation phase, the collected MSW in semi-closed vehicles has been sent to eight modernised refuse transfer stations in respective zones,

from where the mechanically-compacted waste is being sent to the Khajod disposal site. At the refuse transfer station, all the primary collecting vehicles from door-to-door garbage collection and sweeping activity reached to transfer station, from where secondary transportation vehicles are loaded for the purpose of transferring it to disposal site. Here, the primary collecting vehicles are sent to the "Elevated Platform through a Ramp". Chutes are provided at the elevated platform to receive the MSW from where it is unloaded by primary collection vehicles. The secondary transport vehicles are kept underneath the chutes. MSW that is unloaded from primary collection vehicles is transferred into the closed containers, provided with a compactor system. The chute portion of transfer station is covered on the top with an FRP-sheet and the whole structure is kept closed with concrete louvered blocks. Transportation of container is carried out on hook-lifting vehicles. Containers are fully closed with leak-prof door-opening system. This way, the covered leak-proof containers prevent spillage of garbage on roads with no foul odour, as the transfer station is semi-closed and transport containers are fully closed. The next stage of treatment of MSW has been carried out at the centralised, integrated MSW-processing treatment plant, located at Khajod, started through PPP (Public Private Partnership) in January, 2016 to treat a minimum of 600 Mt per day against a total generation of ~ 2,000 Mt/day. The construction, operation and maintenance of this plant is by a private agency to which 25 ha of land was allotted by the Surat Municipal Corporation (SMC) at a token rent of one Rupee/sq. m/y for the concession period of 2 y. In this plant, the technology that is involved in the processing of MSW comprises segregation of 100% MSW and treatment of 35−40% dry organic material and 3−5% recyclables, such as plastic, MS and rubber items. For the treatment and final safe disposable of bio-medical waste (BMW), the SMC has signed a concession agreement with a private agency to establish, operate and maintain the centralised BMW treatment facility with a treatment charge of Rs. 10/- per kg and the private medical practioners in the city were asked to join the common treatment facility. For this, 4,200 sq. m of land at a token rent of one Rupee/per sq. m/annum for a period of 14 y with a minimum 200 kg/day BMW to be deposited by the SMC with a provision for collection of 2,500 kg/day BMW from all health centers by the SMC. In this facility, the BMW is processed by incineration (in one unit with a dual chamber to treat 200 kg/h), autoclave (1 unit – 125 kg/h) and shredder (4 units, each 100 kg/unit capacity). For the processing and recycling of plastic waste, there is a centralised plastic waste management plant, commissioned in June, 2017 with a capacity of 20 tons per day (TPD) and operated by a private agency with a tie-up with rag-pickers and an NGO to lift street-level plastic. An organic waste management plant is proposed to collect separately the organic waste generated by the hotel & restaurant kitchens, vegetable and non-vegetable municipal markets and slaughter houses, private gardens and cattle-farms, transport and processing for bio-fuel and bio-energy. For this, 25 organic waste collection (OWC) units were installed at different vegetable and non-vegetable municipal markets & slaughter houses, besides > 50 OWC units installed by residential welfare societies in their premises. For the WM of construction and development (C & D), a private agency was engaged to process 300 TPD C & D waste to produce various recycled construction materials, such as sand, block, paver blocks etc., in a 3-acre land rented at Kosad, and the plant is commissioned in February, 2019 with a capacity to treat 300 TPD. This agency directly collects charges from the users/generator-agencies and deploys GPS-based vehicles for efficient monitoring and the SMC will make compulsory for utilisation of 20% recycled products in all its tenders for C & D. Under the dump-site remediation, the SMC started the work under the *Swatchh Bharat Mission* for scientific closure of accumulated waste, dumped open by it during 2001−2006 and was the first to develop a scientific land-fill (SLF) site in the country with a capacity of 125,000 cu. m, the capacity of which was exhausted in 2011 and the same has been under extension work at present to have a capacity of 600,000 cu. m. Since 2011, the second SLF cell with 625,000 cu. m capacity was constructed and this cell is also utilised. The coming-up MSW treatment facilities in Surat include (i) a waste to energy plant of 1,200 TPD capacity, (ii) a centralised waste processing plant of 2,000 TPD capacity and three units of decentralised organic waste processing plants each of 20 TPD capacity[9].

2.1.3. WM in Mysuru, Karnataka*:* The city of Mysuru (12.2958º N. Lat.:76.6394º E. Long.), with a population of 0.938 million, is the second largest city in the state of Karnataka in southern India. It was the capital of the former princely state of Mysore and is a heritage, green, cultural, royal, most lovable, planned city with a palace. It is considered as a paradise for retired people. Tourism is its major industry with about 3 million visitors visiting every year, while the IT sector has emerged as a major employer, alongside the traditional industries. It generates 402 Mt of MSW per day from the following sources: people (~ 80%), commercial units (1.9%), hotels & restaurants (2.7%), function halls (1.5%), street

sweeping (4.2%), garden waste (4.7%), chicken & mutton shops (1.5%), and market waste (3%). Integrated solid waste management, aiming zero WM, has been adopted in this city with the following route of waste-movement: Source-segregated waste (402 tons per day, TPD) collected by push carts and auto tippers → (i) wet waste to compost unit (200 TPD) → composted (85 TPD) & landfill (90 TPD); (ii) segregated dry waste to 9 zero-waste management (ZWM) units, 45 TPD → (i) recyclables to scrap market → recycling units and (ii) non-recyclables to landfill. It is proposed to set up (a) two new compost plants of 150 and 200 TPD capacity; (b) six biogas plants with a capacity of 1 TPD each in ZWM plants; and (c) shredders of capacity of 10 TPD to increase the capacity of ZWM units. A decentralised waste management system of 5 to 10 TPD has been adopted, as per the flow-chart (Fig. 1)

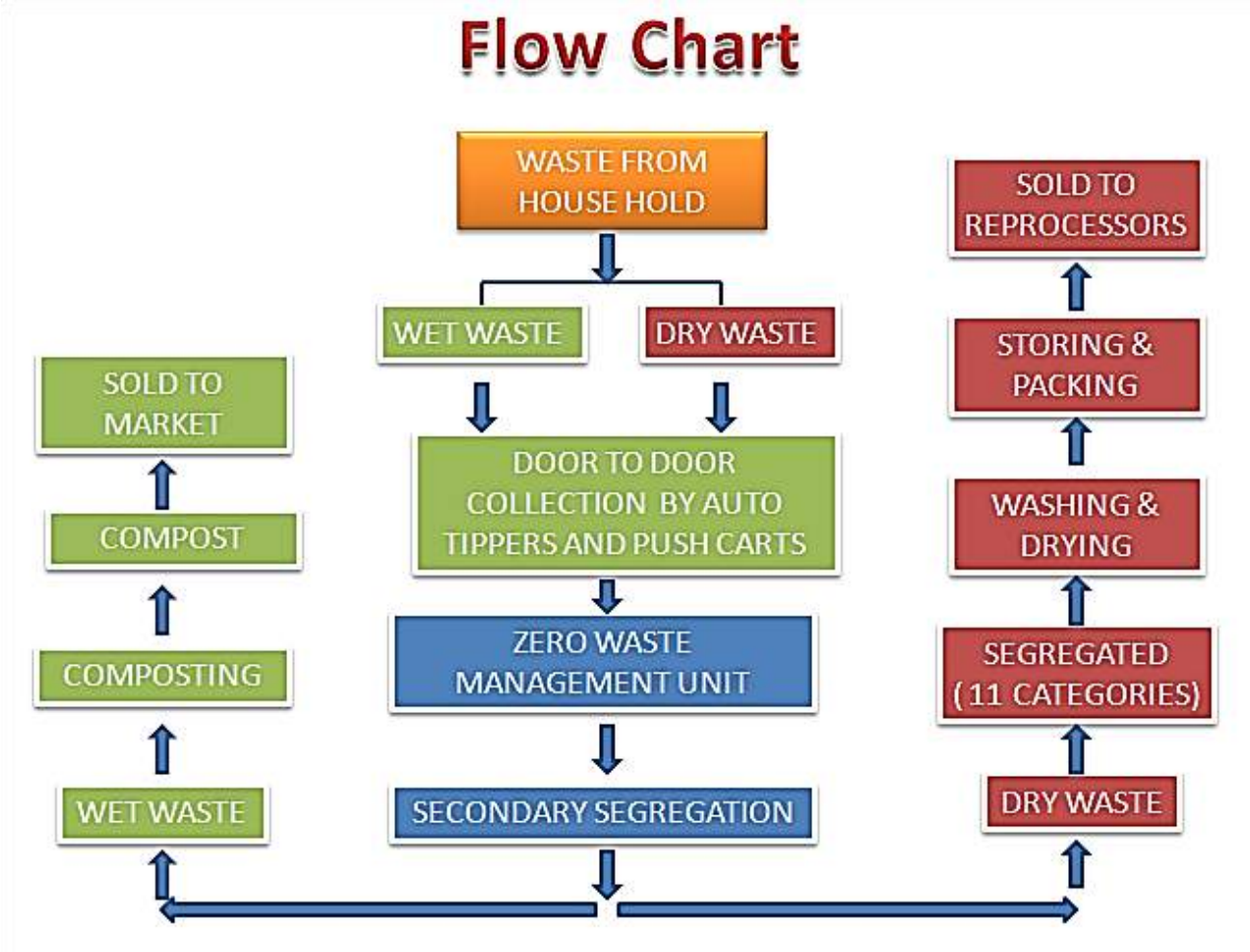

Fig.1. Flow-chart for Decentralised Waste Management at Mysuru (Credit: Ref. No. 10)

The features of ZWM model are as follows: *Decentralised*: reduce load on centralised compost plant, located at outskirt of the Mysuru city; (ii) *Cost-effective*: saves money for city by reducing cost for transport of waste; (iii) *Energy efficient and environmentally sound*: will avoid mixing of segregated waste at secondary collection and transportation level, and reduces waste sent to landfills; (iv) *High-resource recovery*: Enhances recycling of dry and wet wastes; (v) Labour-friendly: makes use of available workers and improves their earnings and quality of work; and (vi) *Sustainable enterprise*: cost and environmental benefits and availability of workforce make decentralised system administratively feasible.

The benefits of ZWM are as follows: (i) decentralised collection of waste; (ii) recovery of resources at the source level and ensuring effective management of solid waste; (iii) provides employment opportunities to people by reducing the use of machineries in operating waste-treatment; (iv) encourages community participation; (v) reduced requirement of secondary storage containers; (vi) all the collected waste was transported to a single processing plant (CompostPlant) @ sewage farm − with this strategy, the transportation

of waste is decentralised and there is a saving of both time and cost of transportation; besides, the life of sanitary landfill is enhanced; and (vii) high positive environmental impact due to the fact that there is less emission and less use of fuel, as this is a decentralised waste management system[10].

2.2. Waste Management (WM) in a few Clean States

2.2.1. WM in Chhattisgarh: In the fifth edition of *Swachh Survekshan* results, the state of Chhattisgarh gained no. 1 ranking under the category of "India's cleanest state with more than 100 urban local bodies", followed by the states of Maharashtra and Madhya Pradesh at the second and third ranks, respectively. Apart from this, out of the 129 awards distributed, the state of Chhattisgarh achieved success in 14 awards. The state's city of Ambikapur achieved the title of "India's Cleanest Smallest City", followed by the town, Bhilai Nagar, which gained the tag of "Best Self-Sustainable City" under the category of 3−10 lakh of population. In the "Cleanest East Zone" category, the state got a hat-trick with the town, Dhamtari winning for 50,000−100,000 of population, Jashpur Nagar for 25,000 – 50,000 population and Patan for up to 25,000 population category. Manure is being generated from waste. Also, a '*gobar khareedi kendra*' (cow-dung purchase centre) was started, wherein cow-dung has been sold, generates vermin-compost and earns a livelihood out of it. If cow dung were not treated properly, often it leads to diseases. In order to avoid this, the *gobar kendras* (cow-dung centres) were started. Chhattisgarh has an army of more than 9,000 women sanitation workers, who every day in the morning go door-to-door to collect segregated household waste

Presently, Chhattisgarh is known for being India's first "Open Defecation Free ++ state", which means total sanitation in terms of solid waste management, improved sewerage lines, storm-water drains and cement roads, in addition to the open defecation-free tag. Apart from this, the state does the following, which sets it apart from the rest of the states:

1. *100% door-to-door garbage collection:* Garbage is collected every day from all the 166 urban local bodies (ULBs) of Chhattisgarh.
2. *Waste segregation at household level:* All households in the 166 ULBs successfully segregate their waste at home itself, which is then taken by sanitation workers to the processing plant, where the waste gets treated effectively. Wet waste is used for composting, whereas the dry waste is recycled. Chhattisgarh is treating 1,650 Mte (metric tonnes) of waste per day on an average
3. *Integration of technology:* An online monitoring methodology has been adopted to monitor all ULBs for door to door collection of garbage so to ensure all *safai mitra* (cleaning workers) do their job effectively.
4. *Waste-pickers have been involved in Swachh chain:* Waste pickers have been involved in the *Swachh Bharat Mission* (Clean India Mission) and are given employment. Moreover, all the waste-pickers have been given ration and *aadhaar* (identy) cards, and life insurance and other government benefits.
5. *Brooming twice a day:* In all the 166 ULBs, sweeping has been done twice daily − in the morning and at night.
6. *Plastic waste management:* In all the 166 ULBs of the state, plastic is strictly banned.
7. *Small sewage treatment plants:* Instead of one big sewage treatment plant, Chhattisgarh has small sewage treatment plants that cost Rs. 200,000/- each, which treat the sewage water of respective areas effectively. Due to this, no sewage water in the state goes straight into any drains or rivers, but is reutilised within the area for gardening purposes.
8. *Public toilets:* All public toilets for women in the state are equipped with amenities, such as a sanitary napkin vending machine, an incinerator facility for effective management of menstrual waste and a feeding area for breast-feeding mothers.
9. *Godhan Nyay Yojana* (Cow-dung Utilisation Plan): Under this scheme, the state has brought out in the 164 ULBs the model of reutilising cow-dung by transforming it into vermin-compost.

In addition to the above steps, what sets Chhattisgarh apart is the creation of an army of > 9,000 women, designated as *Safai Didi* (Cleaning Sisters). Every morning, they go door-to-door to collect waste in a segregated format and then further sort the waste into various categories, and before it goes for recycling, composting or other kinds of processing has been undertaken, depending upon the type of waste. This model was first adopted by the now famous innovative city – Ambikapur, and this was further incorporated across the state. Basically, the motto in this is that garbage or waste is not just the sanitation pickers' responsibility, but all stakeholders – from rag-pickers to citizens and municipal corporation worker - are involved in the process of this WM chain. This WM model was later incorporated in all the 166 urban local bodies of the state. For this, an institution by name *Swachhata Diksha* (Clean Programme) was started in Ambikapur, where all the officials, sanitation workers etc., were given training

about the methodology and how to implement this waste model across the state successfully. Today, some people from neighbouring countries like Nepal have been trained in this institute on the methods of managing waste.

Solid and Liquid Waste Management (SLWM): Earlier all the people were just used to give waste in a black polythene bag. Over the years, with a number of awareness drives for the community members as well as training sessions for the women, the concept of segregation of wet and dry waste was introduced within the household levels. The municipality also distributes green (for wet wastage) and blue (for dry waste) garbage bins across the community. With repeated efforts and exchange of dialogue, today the community has begun to dispose of garbage in dry and wet form, separately. Now, the WM has become a duty for each and every person in the state.

Chhattisgarh's effort during the COVID Pandemic: Even before the corona-virus era, when masks and personal protective equipment were not very common, in Chhattisgarh, all the sanitation workers were trained to use these at all times, whenever they are handling waste. As a result, when pandemic struck, it was not much of an issue, in terms of personal hygiene for these workers and that is the main reason why the spread of the virus was less in the sanitation workers of the state. Moreover, the state uses all its Mayor- or Corporate-fund in buying PPE kits or bodysuits for the sanitation workers at all times, because if they are safe, the health of the state is safe. In terms of testing, whenever any sanitation worker complains of any COVID-related symptoms, the first thing is isolation of the affected person, followed by the covid-test[11].

2.2.2. WM in Kerala*:* The state of Kerala is on the tropical Malabar Coast in SW India, with a ~ 600 km long shoreline of the Arabian Sea, a population of over 35 million and spreads over an area of 3,863 sq. km. It is well known for its palm-lined beaches, backwaters, a network of canals, hill stations, *Ayurvedic*- (India's ancient medical system) and eco-tourism, the Western Ghats as inland and mountains, the slopes of which support tea, coffee and spice plantations as well as wildlife, national parks and sanctuaries, which are home for elephants, langur monkeys and tigers, all of which make it as the India's paradise and is named as one of the ten paradises of the world by National Geographic Traveller. The state has a high density of population with over 90% literate and the highest media exposure in India with newspapers publishing in 9 languages, mainly English and Malayalam. In the year 2012, Kerala witnessed struggles against a centralised WM system in at least 13 landfill sites, with half of these were closed now, and the local governments were forced to go for the decentralised WM system, presently adopted in its capital, Thiruvananthapuram and the city, Alappuzha (former Alleppy), with household WM more effective in the former as compared to the latter that utilises its community structures well for WM[12]. The centralised system refers to a mode of WM, where the waste is collected and transported to the treatment plant for processing and finally dumped off in the landfill. Urban local bodies play a vital role in this system as solid WM is one of their mandatory functions and, hence, this system still continues to be the primary method in Kerala. In the decentralised WM, the role of local government is limited, and households become the unit of waste generation as well as treatment.

2.2.2.1. *Decentralised WM system in the city, Alappuzha:* Under the programme of "Clean Home Clean City", the urban local body decided to implement the WM in Alappuzha (9.4981º N. Lat.:76.3388º E. Long.) in different phases. For the first phase, the municipality selected 12 most urban wards with a total 12,000 households, with maximum number of households having adequate land to adopt portable or fixed biogas plants (each costing Rs. 13,500/- to 17,,500/- and can treat 5-12 kg of solid waste) with 75% subsidy and those with a little or no space to go for a 2-pipe composting unit, in which daily waste is put in one of the pipes until it is full and then closed for biodegradation, while using the other pipe for waste disposal. By the time the second pipe fills, waste in the first pipe is turned into compost that could be used by households for gardening. Apart from this household waste treatment facility, the municipality introduced a community composting facility. With innovation in the decentralised WM, the technology was modified to an aerobic compost unit with a layering system to handle organic waste and carcass. The structure is a box with a ferro-cement floor and handles. Layers of cow-dung and solid waste are subjected to composting in the presence of oxygen, when the temperature increases rapidly to almost 70ºC and kills the pathogens. Micro-organisms, such as bacteria, fungi and *actinomycetes* are keys to the composting process. As composting progresses, the carbon in the waste is converted to products, such as CO_2, water and humus or compost. A kitchen bin is another technology used for composting, in which waste is stored in a bag kept inside a plastic bucket, and is designed to treat the bio-degradable waste aerobically. In the Phase I of "Clean Home Clean City" programme, 2,800 pipe compost units and 3,000 biogas plants were

distributed to households and the municipality constructed 14 aerobic units with 165 bins for the community WM. In the Phase II, 300 more aerobic bins, 10,000 kitchen bins and biogas plants were distributed. Funds were allocated for a plastic waste recycling unit and a material recovery centre. Aerobic bin clusters accept non-biodegradable waste that is sold to some companies. The transition in solid WM in Alappuzha involved both technological and non-technological factors involving coordinated work of different actors playing a crucial role in the transition. The municipality health and sanitation officials took the lead in the implementation, with gaining attention and confidence of the citizens being a major task for the officials, besides different groups, such as water & sanitation clubs, children (encouraged to segregate plastic waste at the household through an exchange programme called, "give plastic and take away books"), artists etc., to conduct various types of mass campaigns in the area. Thus, technological and non-technological factors played a critical role in the implementation of the decentralised WM in the city of Alappuzha[12].

2.2.2.2. *Decentralised WM in the state capital, Thiruvananthapuram (8.5241º N. Lat.:76.9366º E. Long.):* When the landfill-site was closed in this state capital, the Thiruvananthapuram Municipal Corporation (TMC) has decided to go for a decentralised WM system. In the initial stages, the TMC distributed PVC-pipe composts to the households, which led to failure of the technology, as aeration did not happen in pipes leading to anaerobic digestion of wastes that increased nauseous smell due to which the households were disillusioned. Then, a drive for decentralised WM began in the name of "My City Beautiful City". This programme aimed at creating awareness on effective WM and implement measures to make the city garbage-free. The TMC envisaged: (i) 60% households with the waste treatment facility; (ii) 80% households have a tie up with service team for WM; (iii) plastic and e-waste collection services; (iv) installation of adequate number of community waste treatment facilities; and (v) a common waste treatment facility in each ward, with wards that successfully implemented the programme were given clean city award. However, due to diverse reasons, such as people dumping the waste in front of aerobic clusters coupled with their non-maintenance and incompetent implementation of the new programme, the community WM under decentralised system in Thiruvanthapuram faced serious challenges, unlike in the city, Alappuzha. Then, household campaigns were conducted to create awareness and ensure engagement of public in the programme. Three types of waste treatment facilities, viz., pipe composts, kitchen bin and biogas plants were made available. The kitchen bins are normal plastic laundry basket with a sac, choir residues and inoculum. One sac is placed in the basket and waste is put on the already placed choir residues and inoculum. The process continues, and when the sac is full, it is removed and a new sac is placed. The first sac is then kept for a month for bio-conversion. Biogas plants were distributed by many private agencies. The decentralised WM programme in Thiruvananthapuram is implemented through some private and non-governmental agencies, which were allowed to distribute kitchen bins, collect non-degradable wastes from households and provide required service for treatment of bio-degradable waste, as and when required. One such NGO agency is "Harithagramam" that is engaged in promoting organic agriculture. As the issue of solid waste increased in the city, the organisation decided to spread their activities to solid waste management as well. The organisation reached an agreement with the TMC in 2015 to distribute kitchen bins (provided by the TMC), choir pits and inoculam to the households for composting and provided services whenever necessary. The organisation also collects non-degradable plastics once in a month and electronic waste once in three months from the households. The collected plastics and electronic waste are then handed over to the TMC for sale to the recyclers. The agency takes a monthly user fee of Rs.200/- from the households. The installation cost of kitchen bins for the household is Rs.200. The "Harithagramam" currently has 20 staff and each staff covers 250 households. Currently, the organisation provides service to 3,531 households across 18 wards. The staff of the organisation collects organic compost from the household kitchen bins, stores it at a repository located in a place, *Vanchiyoor* and sells it to farmers for agricultural purposes. The revenue generated from the sale of manure is then used for the expenses of organisation[12].

2.2.2.3. *WM at Amritapuri, Kerala:* Nestled amongst the palm trees of Kerala, with a stunning stretch of sea on one side and meandering *ghats* (hills) on the other, sits the considerable complex of *Amritapuri*, the home to one of India's few female gurus. There are 3,500 people living here permanently and several thousand more visitors at any one time in search of spiritual enlightenment from *Amma* (which translates as "Mother"), who is renowned for bestowing a blessing in the form of a hug to all who meet her. A lady by name, *Mahita*, originally from the USA, has been at the ashram for 11 years dealing with waste on the

frontline. During this period, she has installed numerous waste points composed of clearly labelled bins for different types of waste. With the *Amma's* support and guidance, she has also built a materials-recovery facility (MRF) to sort all the waste collected. Of the four tonnes of waste processed daily by the MRF, half of it is organic. This organic waste is recycled by its treating in a circular, closed-loop system for its composting locally, with the compost used on the 1,000 acres of farmland owned by the organisation. The food grown there is subsequently used to feed those who are most in need. The non-organic waste is mostly sold to external recyclers, making the MRF financially profitable for the ashram and an overall contributor to the charitable work of the organisation. The easy things to sell are metals, card, PET and other hard plastics, all of which have roughly equal value. India has a well-established industry for recycling PET plastics, with between 60% and 70% recycled, and the PET recycling market worth over £ 380 million. An abundance of harder to recycle materials, such as soft plastics (e.g., crisp packets and sweet wrappers), pens, toothbrushes and tetra-packs does present a problem, and the ashram MRF struggles to find anyone to take these waste streams. Generally, in India, there is a serious lack of metals recycling capacity. While it is positive to see hard plastics being recycled in large quantities, metals lag behind with a recycling rate of just 20–25%. The urgent need for improvements in this neglected market presents not just a challenge but also a golden opportunity, with both potential environmental and economic benefits. As India continues to develop economically, the amount of waste it produces only increases and there is still much to be done to ensure proper collection, sorting and disposal countrywide. Ultimately, India will only solve its waste problems with a combination of extensive waste management services and changing public attitudes. There have been national efforts to change attitudes, such as the "*Swachh Bharat*" ("Clean India Mission"), for which the ashram input into the campaign strategy. This programme was launched in 2014, but so far while there has been progress in reducing public defecation thanks to provision of toilets, there is still a lot to be done when it comes to reducing littering on the national scale. Madam *Mahita* recognises the need for a better government policy, and she would like to see fines for littering and the introduction of a deposit refund scheme (DRS), in which a small charge is attached to packaging at the point of purchase and refunded when returned to the vendor. She is confident that a DRS scheme would work well in India, and could provide significant additional income to India's 1.5 million rag-pickers. Whether or not this would, in turn, undermine the scheme's overall aim of preventing people from littering in the first place is unclear, but any such scheme would need to take this into consideration. Currently, legislation on plastic usually comes from the state rather than federal level of government. At the start of 2019, Tamil Nadu became the 4th Indian state to implement a plastic ban, covering 14 different items, including plastic bags, straws and films. The waste management at *Amritapuri* is still more advanced than it is in much of the rest of the country. The approach now taken is for the ashram MRF to serve as a learning centre, and anyone in India is welcome to come and see how it operates. There are numerous ashrams across India, as well as other community groups, that could gain by learning from the *Amritapuri* model[13].

2.3. Waste Management (WM) in a few Metro Cities

2.3.1. WM in Mumbai*:* Mumbai (19.0760º N. Lat.:72.8777º E. Long; previously known as Bombay until 1996) is a densely populated (~ 13 million) India's largest city with a natural harbour on the west coast of India. It is the state capital of Maharashtra and has a coastal stretch of 603 sq. km. It is the financial capital of India and is a global city, known for being the home to one of the highest number of billionaires as well as having huge global influence. Along with the neighbouring cities of Navi Mumbai and Thane, it forms the world's 4th largest urban agglomeration with a population 19.1 million. Such a huge habitat obviously generates a huge amount of waste of many kinds, the management of which is a massive task for the local administration.

Mumbai generates waste to the tune of approximately 11,000 tonnes per day. The waste consists of mixed waste (bio-degradable and recyclable) and debris and silt. The bio-degradable waste (wet waste) is made up of vegetable and fruit remainders, leaves, spoiled food, eggshells, cotton etc. Recyclable (dry waste) consists of newspapers, thermocol, plastic, battery cells, wires, iron sheets, glass etc. Debris includes construction waste, renovation waste, demolition waste etc. Silt comprises earth and clay from drains and road corners. The Municipal Corporation of Greater Mumbai (MCGM) is formally responsible for the management of waste in the city. The prevailing approach has been one of collection and disposal of garbage, collected from communities by the municipal authorities and disposed at the dumping sites. Of the garbage being dumped into the bins, a considerable amount is removed by rag-pickers, who then sort it out and sell them to those who deal in recyclables, such as paper, plastics, metals etc. This industry is one that is large but informal, where the rag-

pickers provide the recyclables and the transactions run into millions of rupees. This informal industry helps in the reduction of waste being transported to the dumping grounds. There are people, generally known as *kabadiwallas*, who collect old newspapers, magazines, metal scrap and other such items, and sell them to shops dealing in the same. Besides cash transactions, the deals also involve barter; a popular exchange being garlic against plastic. The garbage collectors employed by various housing societies manually collect the waste generated at the household level and dump it in the garbage bin at specified street corners. In the case of South Mumbai, trucks collect garbage from the garbage bins and transport it to a transfer station which is located in the area, known as *Mahalakshmi*. A separate transport is arranged for transferring the garbage from *Mahalakshmi* to the northern part of Mumbai, where the dumping grounds are situated. From all other parts of the city, garbage is sent directly to the dumping grounds. Nearly 95% of the waste generated in the city is disposed in this manner. All the dumping grounds are nearly 30−40 km from South Mumbai, which explains the huge costs on transportation. The increase in the population of the city has forced people to settle near the dumping grounds. This has led to the twin problems of people living in unhealthy conditions and protesting for the closure of the dumping grounds, as dumping causes health hazards for the people in the vicinity. The waste that offers an incentive after selling like paper, metal etc., is sold to informal dealers by rag-pickers. But the organic waste, old batteries, polystyrene (thermocol), polythene bags, debris, to name a few, do not have such incentives and these are in huge quantities. Also, since it takes a long time to decompose, when dumped, such waste occupies and fills the low-lying areas. In fact, the search for a new dumping ground starts only when the filling area of the dumping ground is exhausted. The waste at the dumping ground is covered with debris and spread evenly in layers. The organic waste undergoes natural decomposition and generates a fluid, which is known a leachate, and is very harmful to the ecosystem, if not treated properly. The leachate penetrates the soil and, if not prevented, pollutes the ground water. Also, flies, mosquitoes and many other pests breed on the waste and unless properly maintained, the dumps are a public health hazard. In Mumbai, every day 2,000 tonnes of debris is generated officially, of which some part goes to the dumping ground for spreading over the organic garbage, as earth is expensive. The remaining debris is spread next to the roads, in the creeks, next to railway tracks and on open grounds. As Mumbai has a coastal stretch of 603 sq. km, it has numerous creeks. These are channels of water which occupy marshy land during high tide. The salty water occupies the land during high tide and drains off during low tide. This nurtures plants called mangroves. These plants, in turn, have leaves which provide oxygen to the water for fishes to breed in the creeks. In many areas, like Versova, Gorai, Charkop and Mankhurd, the entire eco-system of the creek has been destroyed as waste is dumped surreptitiously. Increasing prices of land and more construction activities are forcing the demolition of old structures and building new structures, thereby creating more debris waste. Debris, being very bulky in nature, requires more space, reducing the life span of the dumping ground. Therefore, municipalities, generally, refuse the entry of debris into dumping grounds other than what they need to cover the garbage. Finding few viable alternatives, people just dump the debris by roadsides. Over time, people start dumping organic waste on top of debris not only compounding the waste disposal problem but also creating a health hazard[14].

2.3.1.1. *Schemes Run by MCGM:* (i) *Slum Adoption Scheme*: It was experienced that because of the heterogeneous population in the slums, there is no sense of belongingness and it was realised that an attempt should be made to motivate and involve the slum population by attaching certain incentives to work in cleaning the slums and maintaining hygiene. It is in this background that the “Slum Adoption Scheme” through community-based organisations and public participation has been started by the MCGM. (ii) *Advanced Locality Management* (ALM): This is a local management of solid waste by citizens who organise themselves to manage their waste. Wet waste is segregated at household level and composted locally in any available area, planters etc., and sweepers or rag-pickers take dry waste away. There are in all 643 ALMs along with 276 vermi-compost pits spread over six zones of the MCGM's jurisdiction. This way, approximately 20-25 tonnes of garbage per day are prevented from reaching the dump yards. An encouraging fact is that women run 80% of these ALMs. The MCGM has also established vermi-compost projects on its own, one each in the eastern and western suburbs, respectively, to demonstrate to the citizens, the benefits of vermi-culture technology. The success of any ALM depends entirely upon people's participation. The organisation of the community, training and initiation is done jointly by residents and MCGM, and is initially funded by residents and the Corporation. At later stages, the activities are completely funded by the residents. (iii) *Recycling Debris*: Debris is recycled to make new construction-related products, such as bricks and interlocking pavers. City and Industrial Development

Corporation (CIDCO) and YUVA, an NGO, have collaborated on this effort to convert the debris and reduce the load on dumping grounds. Presently, the plant in Navi Mumbai converts three tonnes of debris per day. Set up in 1999, this plant is one of its kinds in the whole of India and has been successful in developing products conforming to the Indian Standard Codes of practice of the Central Government. (iv) *ParisarVikas Scheme*: *Stree Mukti Sanghatana* (Woman liberation organistion), an NGO, has initiated a scheme which focuses on uplifting the most downtrodden section of the society - the rag-picker women and children. This scheme is an ideal solution, since rag-pickers together with the ALM system manage the upkeep of the environment. The rag-pickers play an important role in managing the solid waste; they retrieve all possible recyclable items from waste and, thus, put these materials back to proper reuse. But, sadly the rag-pickers are never recognised for the invaluable service they provide to the city's solid waste management. Lastly, the citizens of Mumbai have to be trained in the three "'R's" (reduce, reuse and recycle) with respect to management of waste[14].

2.3.1.2. Mumbai Waste Management Ltd. (MWML): **This** is a special purpose vehicle of the Ramky Group. It was incepted in the year, 2002 and spreads across 100 acres, housing a secured landfill with a capacity of 120,000 Mt/annum, stabilisation treatment plant (60,000 Mt/annum), incineration plant (30,000 Mt/annum), environmental laboratory and waste storage facility, equipped with a Hi-Tech laboratory and can meet end-to-end environmental testing/monitoring requirements of the industry. MWML also provides services for disposal of date-expired, damaged and rejected goods from different departments and organisations, such as narcotics, customs, postal, airport, and warehouses of pharmaceuticals, chemicals, research institutions etc.,[15].

2.3.1.3. *Maria D'Souza's mission for zero-waste by100% waste segregation:* Mrs. Maria D'Souza (68 y), a retired teacher has successfully implemented 100% segregation of waste in 44 housing societies, with herself heading the society no. 33 for implementing the concept of "Advance Locality Management" (ALM), introduced by the Municipal Corporation of Greater Mumbai (MCGM) in 1997 to work, in collaboration with the citizens, towards a green future by forming committees. Under this, each zone in the metropolitan city has an ALM committee, made up of residents who come together and raise local environmental issues with the municipal body and also propose solutions which are then implemented with the help from MCGM. After facing some initial problems, including harassment from some locals, she worked on introducing waste segregation and composting in housing societies. Maria's own society was the first one to implement the segregation of dry and wet waste. Interestingly, it was also the first one to start the on-site composting of wet garbage in 2013. She and her team visited each building, conducted a presentation and drew people's attention to inflammatory issues, such as overflowing landfills, garbage burning, rag-pickers exposing themselves to health risks and finally the residents breathing in toxic gases that are released from the landfills. After the Maria's society went zero-waste by converting all the wet garbage into compost and sending dry waste to recycling centres, the neighbouring societies followed suit. Eventually, two schools and churches went waste-free. Maria made a comprehensive list for local companies that supplied composting units and distributed them to all the societies. Depending on the volume of waste generation, the societies installed composting units. Most of the housing societies have composting units that convert the waste in less than a month. While some of them have trained the house-keeping staff, some have hired men to carry out the process. Furthermore, a few societies are recovering their capital costs by selling organic compost. After the MCGM made on-site composting mandatory for buildings producing over 100 kilos of garbage in 2018, Maria's mission came to a halt[16].

2.3.2. WM in Delhi*:* Delhi (28.7041º N. Lat.:77.1025º E. Long.), officially known as the "National Capital Territory (NCT) of Delhi", is a city and a union territory of India, with New Delhi being the capital of India. The NCT covers an area of 1,484 sq. km. According to the 2011 census, Delhi's city proper population was over 11 million, the second-highest in India after Mumbai, whereas the whole NCT's population was about 16.8 million. Delhi's urban area is now considered to extend beyond the boundaries of NCT and includes the neighbouring satellite cities of Ghaziabad, Faridabad, Gurgaon and Noida in an area called the "Central National Capital Region" (CNCR) and had an estimated 2016 population of over 26 million people, making it the world's second largest urban area, as per the United Nations. Delhi is the second-wealthiest city in India after Mumbai and is home to 18 billionaires and 23,000 millionaires. It has the second-highest GDP per capita in India. Delhi is of great historical significance as an important commercial, transport and cultural hub as well as the political centre of India.

The Solid Waste Management (SWM) bye-laws 2018 for the NCT were notified on January 15, 2018, under

the Section 5 of the Environment (Protection) Act and shall be enforced by all the five local bodies −New Delhi Municipal Corporation (NDMC), South DMC, North DMC, East DMC and Delhi Cantonment Board (DCB) − in their respective jurisdiction. The five municipal corporations, comprising over 280 wards, generate approximately 14,000 tonnes per day (TPD) of solid waste and over 10,500 TPD of garbage is collected, with per capita generation ranging from 550−600 grams per day. The city has a processing capacity of 6,100 TPD in three incineration plants and two centralised composting units, and ~ 4,600 TPD is disposed off in three dumping sites of Delhi− Okhla, Bhalswa and Ghazipur. Section 4 of the bye-laws emphasizes generator's responsibility to segregate waste at source, with every generator has to segregate waste into three streams: biodegradable (wet waste, in green coloured bins), non-biodegradable (dry waste, in blue bins) and domestic hazardous waste (in black bins). Gated colonies, residential welfare associations (RWAs), hotels and restaurants need to ensure in situ processing of wet waste, as far as possible. The recyclable waste from bulk generators, commercial areas and hotels needs to be collected by authorised waste- pickers or recyclers. Under Section 5 of the bye-laws, MCD (Municipal Corporation of Delhi) will provide door-to-door collection and transportation of segregated solid waste, including in slums and informal settlements by integrating informal door-to-door collection system with the municipality. Area-wise time slots for waste collection will be set and published on the website of MCDs. The MCDs will also ensure in situ treatment of biodegradable waste, for instance, in fruit and vegetable markets, residential areas and RWAs. Under section 6 of the bye-laws, all the secondary storage points (*dhalaos*) will have covered colour-coded containers for storing wet, dry and domestic hazardous waste. The MCDs shall convert the existing *dhalaos* into recycling centres for further segregation of dry waste. Households should be able to directly deposit or sell their recyclable waste to authorised waste dealers at these recycling centres at pre-notified rates. The MCDs will involve informal sector for managing these recycling centres. Moreover, a deposition centre will be made available in each ward for collecting domestic hazardous waste. Under section 8 of the bye-laws, preference will be given to the decentralised waste processing, such as bio-methanation, composting and any other method for bio-stabilisation of biodegradable waste so that transportation cost and environmental impacts are minimised. For waste-to-energy plants, absolute segregation of waste has been made mandatory. The MCDs need to ensure that horticultural, park and garden waste is processed in parks and gardens as far as possible. All the inert and residual waste has to be disposed off in a manner prescribed under the Solid Waste Management Rules, 2016. All brand owners, who are responsible for selling their products in non-biodegradable packaging material, will have to put in place a system to collect back the packaging waste generated. The bye-laws also hold the manufacturers/brand owner's/marketing companies of sanitary napkins accountable for generating waste. They have to now explore the possibility of using all recyclable materials in their products and educate masses for proper wrapping and disposal of such waste. Under section 11 of the bye-laws, user fee shall be fixed for services, such as garbage collection, transportation and disposal from waste generators by the MCDs. The MCDs have been asked to evolve a mechanism for collection of user charges within three months of the notification of these bye-laws. Under the bye-laws, penalty shall also be imposed for non-segregation, dumping of solid waste in vacant plots and burning it in the open. The MCDs will take deposits from event-organisers and give refund on the completion of the event, after ensuring that the public place where the event was conducted was restored to a clean state and any waste that was generated has been collected and transported to the designated place. The SWM bye-laws, thus, provide legal teeth to ensure the status of solid WM in the capital improves. However, the MCDs need to take action on the ground and ensure that the details of the bye-laws are widely disseminated. The East Delhi and South Delhi Municipal Corporations also plan to distribute a set of two bins, for once, to push households towards segregation, as it is better that waste segregation has to start from the generator, and lot depends on their will to keep their city clean. On the other hand, the MCDs need to create systems to support end-to-end segregation, collection and transportation, processing and appropriate disposal of solid waste. It is only then that it is possible to witness a Clean Delhi. Else, this would just be a good policy with no action on the ground[17].

It may be added that the mountain of garbage in the capital is gaining an enormous size, as solid waste management becomes an acute problem, especially with the handling of plastic waste. Since everything is dumped together at the landfills, the dumps in Delhi have become to be identified as the largest, least regulated and most hazardous in the world, and it occurs, despite a huge workforce of waste collectors, scrap dealers and recyclers and, a rigorous campaign in operation by various municipal authorities to segregate

waste at the source. Legacy waste at the dumpsites of Bhalswa, Ghazipur and Okhla are already overloaded, with no space for dumping more waste in these landfill sites. The master plan should allocate localised water management centres for the people to treat waste within their locality. Delhi is a very small city and it cannot spare any more space for landfills, therefore, decentralised waste management has to encourage by municipal authorities. The Delhi 2021 master plan identifies the problem of solid waste management that is assuming serious proportions due to increase in population, urbanisation, changing lifestyles and consumption patterns. The environmental degradation has been accelerated from the garbage from unauthorised developments, slums, settlements etc., which is not collected by the authorities concerned. The projected average garbage generation up to the year 2021 is @ 0.68 kg per capita per day and total quantum of solid waste is 15,750 tons/day. Out of 24 landfill sites, 16 are already filled up. The management of solid waste has become a very big issue, if Delhi master plan fails to address it, then the waste will end up on roads across the city. The authorities concerned should, therefore, resort to alternative and decentralised methods of waste treatment, reduction, recycle and reuse, which include vermiculture, fossilisation and composting. Pilot projects in this regard have been taken up by the MCD with the consultants. For effective waste management, its segregation at the community and neighbourhood level is imperative. The waste shall be segregated and collected, in separate chambers. For this, involvement of rag-pickers is to be encouraged as per the 2021 master plan. The Citizens' Alliance society has requested the government to implement the solid waste management rules notified in 2016, especially with the plastic waste that is choking the city drains and lies untreated in the landfills[18].

2.2.3. WM in Bengaluru[19]: Bengaluru (12.98°N. Lat.:77.58° E. Long.), the state capital of Karnataka, is located at an elevation of 900 m above MSL and is one of the fastest growing cities in Asia. The city ranks on the top of the Indian cities with > 1million population in both the 2020 "Ease of Living" index and "economic ability" list, released on March 04, 2021 by the Housing and Urban Affairs Ministry of the Govt. of India. The Bruhat Bengaluru Mahanagara Palike (BBMP) with an area of 2190 sq. km and a population of about 10.18 million generates around 5000 Mt of waste per day. It is the agency vested with responsibility for effective solid waste management system for the Bengaluru city. Presently, the city is facing significant problems due to existing disposal practices of generated waste, incurring high cost due to lack of proper infrastructural facilities; also, the open dumping in the expanding zone of the city poses severe problems to the structures constructed on these old dumps. In the meantime, groundwater quality is deteriorating due to improper leachate management. As per the BBMP, the composition of municipal solid waste of Bengaluru in 2013 is as follows: vegetable waste - 35%, organic - 26%, plastic - 12%, paper - 8%, debris - 5%, textiles - 4%, cardboard - 4%, glass - 3% and bio-medical - 2%. The BBMP handles about 30% of solid waste and the remaining waste activity is outsourced (starting from primary collection to disposal). Solid waste collection is carried out in two phases. The first phase is a primary collection (door-to-door collection, street sweeping etc.) in which the solid waste is collected on auto tipper and pushcarts, and transported to a common point, i.e., secondary locations from where the waste is transferred to landfill sites/treatment plants through tipper lorries and compactors. At present, Bengaluru does not have any appropriate scientific treatment techniques for waste generated by the municipality and industries around the city. The solid waste is being directly collected and transported to the eight treatment/disposal facilities that have been developed around the city. For making effective solid WM, many decentralised waste processing facilities have been established by the BBMP. These include: (i) 185 functional dry waste collection centres (DWCC) for re-use/recycle of the items, such as batteries, tin cans, plastic-coated milk cartons, nylon, cigarette butts and leather; in these many self-help groups, NGOs, waste-pickers and contractors are involved; and (ii) sanitary landfill (the cheapest, simplest and most cost-effective method for disposing of waste) facilities to handle ~ 2100 TPD and for achieving 100% processing of solid waste, the government has identified seven new landfill sites. After the collection of waste at the above facilities, the next step is its safe and efficient disposal, for which the following have been adopted: (i) aerobic-/windrow-/community-/vermin-/bio-mechanical-composting; and (ii) waste-to-energy (WTE) projects, involving anaerobic processing for biogas production, refuse-derived fuel (RDF) and plasma gasification. For WTE, bio-mechanisation plants have been established for treating wet solid waste at 16 locations, out of which 8 are functional with each generating 400 units of power per day. The biogas produced from the bio-mechanisation plants has been utilised to light the street lights in that locality and the by-product of solid residue is used as high-grade manure. The other options of incineration and pyrolysis are under consideration to adopt. As the city is growing due to rapid urbanisation

and migration of the rural people nearby to the city for employment, the waste sites such as MSW landfills that were earlier in the periphery of the corporation limits are now in the development zone and such sites are under the reclamation process[19].

***2.2.4. WM in Hyderabad**:* The metro city of Hyderabad (17.3850º N. Lat.:78.4867º E. Long.; including its twin city of Secunderabad), situated at an altitude of 536 m above MSL with an area of 7,257 sq. km, about 10 million populations and a tropical wet and dry climate, is the capital of the state of Telangana in southern India. It is well known as the "Pearly City", "Pharmaceutical Capital of India" and is an IT hub. It is cosmopolitan and multi-lingual with people speaking the four languages of Telugu, Urdu, Hindi and English. It is a growing city, producing daily millions of tonnes of waste with much of it finds its way to landfills, polluting air, water and soil. The municipal solid waste (MSW) consists of domestic and commercial waste generated within different areas of the city. Owing to rapid urbanisation and a growing population, the city has seen tremendous growth in its MSW in recent times. At present, the per capita waste generated in the city is 0.62 kg/day. Gearing up for a comprehensive WM policy and decentralised WM in the city, the state government of Telangana has developed the following infrastructure: (i) development of 17 waste transfer stations in different zones, with each zone getting 25 autos (each with a carrying capacity of 4.5 tonnes of MSW) deployed in commercial stretches; (ii) pressing into service 650 *swachh* (clean) auto-tippers, 50 compact transportation points (CTPs), expanding the capacity of effluent treatment plant located at Patancheru, making 10,000 public washrooms operational and building pre-fabricated *basti dawakhanas* (neighbourhood clinics); (iii) the CTPs are the collection points where the garbage collected from the city is dumped into compactors, and from CTPs the garbage is transported to the Jawaharnagar dump yard; (iv) shortly, to make operational the Fathullaguda debris recycling plant (500 metric tonnes of waste per day capacity); (v) building another 25 pre-fabricated *basti dawakahanas* (neighbourhood clinics); (v) to further improve the sanitation standards, *Pattana Pragati Puraskaram* (city development/sanitation awards) would be given for urban local bodies (ULBs); (vi) seven transfer stations have already been developed; and (vii) expansion of the zero liquid discharge common effluent treatment plant, which can treat 480 kilo litres per day (KLD) of the industrial waste, to a million litres per day[20]. With the idea of having the advanced MSW management system, presently adopted in some global cities, the following infrastructure is recently added in Hyderabad: (i) for the first time in India, introduction of advanced garbage collection, transport and treatment system, including the fleet of 55 vehicles of advanced compactors for garbage collection and transportation; (ii) launching of a modern transfer station at *Sanjeevaiah Park*; (ii) replacement shortly of all the old and rickety garbage trucks with advanced compactors; (iii) introduction of modern waste transfer stations in closed sheds across the city to avoid inconvenience to residents in the neighbouring areas; (iv) inauguration of Waste-to-Energy (WtE) plant in the city; (v) commencement of the "MSW Collection & Transport Project" comprising (a) a network of fully mechanised secondary collection and transport points (SCTPs), located across the city, (b) introduction of strategically located waste transfer stations to serve large catchment areas; (c) deployment of modern, technology-enabled fleet of high-capacity waste collection, containment and transport vehicles, which include smart 35 GVW capacity Benz vehicles with fully integrated IOT sensors, telemetry and advanced safety systems, such as driver awareness system and other many safety and efficient innovations, coupled with Portable Self Compactors (PSCs) of 20 cu. m capacity; (d) introduction of hermetically sealed waste containers of 24 cu. m capacity; and (e) replacement of the old and rickety garbage trucks with advanced compactors in the city for secured waste conveyance. A dedicated "Command & Control Centre" remotely tracks and reports the performance of this smart "Waste Collection & Transport System" on a 24x7 basis. As decentralisation of transfer stations aid in more effective collection and transportation of municipal waste, the Greater Hyderabad Municipal Corporation (GHMC) is setting up 90 mini collections and transfer points (CTPs). This will make the *Swachh* (clean) auto-tippers to collect the waste from the colonies and dump the same at the mini CTPs doing away with the earlier practice of dumping the waste at 17 transfer stations across the city. The advanced compactors are launched to collect the waste from secondary collections and transport points[21]. Furthermore, some private companies, including a few startup ventures, have been working for WM in Hyderabad by their following activities: (i) Ramky Enviro, in association with GHMS, commissioned in November, 2020 a recycling plant for construction & demonstration (C & W) waste[22]; (ii) Ramky Enviro inaugurated in November 2020 a 19.8 Mw waste-to-energy plant[23]; (iiii) Ramky Enviro Engineers Ltd. (REEL) has set up the India's first

integrated industrial hazardous WM facility at Hyderabad in 1998, which handles more than a million tonnes of hazardous waste annually, which is ~ 65% of such waste treated in India. The industrial WM (IWM) facilities of Ramky are guided by international standards – they support double composite liner landfills with leachate collection arrangement, following USEPA's RCRA Subtitle C requirements for landfills. Waste received at these facilities is disposed off by three modes, viz., direct landfilling, stabilisation of waste and incineration of waste. Ramky operates hazardous waste incinerators at Chennai, Haldia, Kanpur Dehat and Indore, besides Hyderabad[24]; (iv) A start-up, founded by Nisar Ahmad and his brothers, was launched in November 2018 − an online doorstep waste-collection service to households, communities and industries for dry and recyclable waste such as books, newspapers, paper, magazines, cardboard, glass bottles, soft plastic, plastic, steel, iron, aluminium, copper, tin, brass and electronic items against cash payment. All the collected scrap is taken to the company's waste yard where the staff segregates it. The company has tied up with some local WM firms engaged in recycling; in this way, the startup recycles 470 tons of waste in 8 months[25]; and (v) In a first of its kind in the country, a floating trash barrier (FTB) was installed recently by Desmi Co., and WRI India Ross Centre at the inlet of Picket *nala* (drainage channel; one of the four *nalas* having their inlets into the Hussainsagar lake, located almost in the centre of the city) to catch a large amount of muck comprising plastic waste, glass, rexine, thermocol and other waste material entering the lake. The floating waste in the *nala* chokes drains and inlets, resulting in urban flooding. Apart from water getting polluted, garbage dumped in the Picket *nala* is causing harm to bio-diversity. Within three days, one tonne of waste was collected at the inlet and 200−300 kg of floating solid waste per day was taken out. The FTB (i) arrests the flowing solid waste entering into the lake and (ii) pushes waste towards wire-mesh conveyor, from which the waste is dumped into a land-conveyor and the garbage is dumped into dustbins on the lake-bank, from where excavators remove it. After collection, the waste gets segregated, followed by sending its glass bottles and plastic to vendors for recycling, bio-degradable items for composting and the remaining waste to transfer stations daily. Following its useful role in the urban WM, six more FTBs will be set up[26].

3. Recycling of Waste for Value-Added Products (VAPs) and Employment Generation

Recycling is the process of converting waste products into new products to prevent energy usage and consumption of fresh raw materials. It is the third component of "Reduce-Reuse-Recycle" waste hierarchy[27]. It involves some form of reprocessing of waste material to generate another useful product. The types of waste that can be recycled include organic-/plastic-/e-/agricultural-/construction and demolition (C & D)-waste, paper, glass, metals etc. Composting and worm farms are the methods of recycling organic waste. Buying products that are made from recycled materials is termed as "Closing the Loop", an important aspect of WM. By recycling the above cited types of waste, many VAPs can be produced resulting in an improved economy and employment generation, which will be a big boost to a developing country like India. Salient aspects of the recycling of a few of the above types of waste for production of VAPs are presented in the following, with some examples.

3.1. Waste to Energy (W-t-E): The W-t-E generation has been increasingly looked at as a potential energy diversification strategy, particularly in Sweden that has been a leader in W-t-E production over the past 20 y. The typical range of net electrical energy that can be produced is 500-600 kWh of electricity per ton of incinerated waste. The W-t-E plants are similar in their design and equipment with other steam-electric power plants, particularly biomass plants. After bringing the waste to the plant, it is sorted to remove recyclable and hazardous material, and is stored until it is time for burning. A few plants use gasification, but most combust the waste directly because it is a mature, efficient technology. The waste can be added to the boiler continuously or in batches, as per the design of the plant. In terms of volume, the W-t-E plants incinerate 80-90% of waste. Sometimes, the residue ash may be used as raw material for manufacturing cinder blocks or for road construction. In addition, the metals that may be burned are collected from the bottom of the furnace and sold to foundries. Some W-t-E plants convert salt-water to potable water as a byproduct of cooling processes[28]. As an example of W-t-E, at the Bowenpally vegetable and fruits market in Hyderabad, where from about 10 tonnnes of organic waste per day produced, 500 units of electricity and 30 kg of biofuel are generated, with the former used to light up over 100 streetlights, 170 stalls, an administrative building and the water-supply network, and the latter is pumped into the canteen kitchen of the market, besides organic manure for use in farming. For this, the process followed is bio-methanation, in which the vegetable waste is first put on conveyor belts that carry the waste to a shredder. The shredded waste is then converted into slurry that is put into large containers or pits to start the process of anaerobic digestion, when the organic waste is

converted into biofuel containing the major components of methane and carbon dioxide[29].

3.2. Agro-waste to VAPs: Over 400 million tons of agro-forest residues per year are generated in India. Rice straw can be used as a source of biomass and lignin that has many new economic applications, such as bio-fuel, binder, dispersant or emulsifier, phenolic resins, carbon fibers, automotive brakes, wood panel products, polyurethane foams, epoxy resins for printed circuit boards etc. Various methods, such as chemical, biological, photochemical and electro-chemical methods have been explored for the oxidation of lignin to obtain VAPs. The cost of production of chemicals will also be reduced due to involvement of micro-organisms and biochemical processes involved therein, whereby farmers will be benefited economically as their agro-byproducts will provide better cost-sharing[30]. Furthermore, from *stubble,* a major post-harvesting agriculture-waste generated in NW India, high-grade organic fertilisers can be prepared by mixing it with cow-dung and a few natural enzymes so as to substitute costly and carcinogenic inorganic or chemical fertilisers. This method has been successfully operated in the state of Chhattisgarh by setting up 2,000 "*gauthans"*, which are collecting centres in a dedicated 5-acre plot held in community by each village, where all the unused stubble is collected through "*Parali daan*" (People's donation). Furthermore, to solve the stubble-burning, which is causing much pollution, microbial spray is an effective long term solution that is economically viable for the farmers. With stubble as a raw material, a USA-based company, "New Generation Power International" has proposed to set up a 1000 MW biomass energy generating plants (200 plants each of 5 MW) in Punjab to address the polluting stubble burning[31].

3.3. Plastic Waste to diverse VAPs: About 300 million tonnes of plastic is globally produced every year, with most of it in the form of disposable products and half of all plastic produced ends up in a bin within a year. There are dozens of types of plastic, but of the 7 main types, five, viz., polyvinyl chloride, low-density polyethylene polypropylene, polystyrene and polycarbonates hardly ever get recycled as it's not worth the effort, since they contain toxins, carcinogens and other pollutants. The two types of plastic that it can make sense to recycle are polyethylene terephthalate (PET), used for things like single-use water bottles, and high-density polyethylene (HDPE) which is used to make some types of plastic bags and detergent bottles. PET can be recycled to make new bottles or textiles like fleece garments, while HDPE is recycled into garden furniture and plastic lumber[32]. India's per capita consumption of plastic is 11 kg, as compared to 109 kg in the US and world's average of ~ 28 kg. In India, around 5.6 million tonnes of plastic waste per year is generated with about 60% being recycled by about 7,500 plastic recyclers (registered and unregistered)[33]. Though recycling is one of the possible solutions to address the issue of mounting plastic waste, accurate identification of its type is crucial to achieve efficiency. In this direction, two researchers at the University of Hyderabad, India have come up with a low-cost solution for sorting plastic waste, offering 97% average accuracy in identification of the type and grade of plastic samples, employing a Laser-Induced Breakdown Spectroscopy (LIBS) combining with machine learning[34]. In India, many startups have been recycling plastic waste to produce diverse VAPs, e.g., (i) manufacture of water pipes for use in agriculture by M.R. Plastics Company at the village, Udemarri in the state of Telangana[35]; (ii) production of 45-90% diesel, kerosene and petrol as per an invented method (applied for patent) by three technocrats, using activated carbon and without burning plastic, by converting plastic to gaseous state using electricity to heat close to 700ºC, followed by condensing and distilling it into the above fuels in a plant at Guntur in the state of Andhra Pradesh[36]; and (iii) construction by a group of four friends, based on a French architecture, of an eco-friendly resort comprising 8 jungle-view luxury rooms and a 60-seater café, by name "Outback Havelock" in the Havelock island of the Andaman group of islands by using 500,000 plastic waste bottles, filled with sand and dust, as construction material that is > 10 times stronger than brick and also water-resistant, and waste rubber for footpaths[37]. It may be added that the Government of India has taken steps to ban single-use plastic in India. In this context, it was announced by Mr. Narendra Modi, the Prime Minister, that India would eliminate single-use plastic by the year, 2022. Notices of plastic-free zones and media on the reduction in plastic use are very prevalent. For example, to avoid plastic, in the state of Tamil Nadu only paper or metal straws in juices and lassies, and cloth bags for shopping have been extensively used.

3.4. E-waste to diverse VAPs: Electronic waste (e-waste) includes discarded computer monitors, motherboards, mobile phones and chargers, compact discs (CDs), headphones, television sets, air conditioners and refrigerators. According to the Global E-waste Monitor 2017, India generates ~ 2 million tonnes ((Mte) of e-waste annually and ranks fifth among the e-waste producing countries, after the US, P.R. China, Japan and Germany. About 95% of India's e-

waste is recycled in a crude manner in the informal sector. Laws to manage the e-waste have been in place since 2011, mandating that only authorisd dismantlers and recyclers collect e-waste. The E-waste (Management) Rules, 2016 were enacted on October 01, 2017, with over 21 products (Schedule-I) included under the purview of the rule[38]. In India, there are 312 registered e-waste recyclers/dismantlers. Recycling e-waste means separating materials, molecules or chemical elements so that they can be sold as raw materials for the manufacture of new materials. This involves dismantling the materials and components, their sorting and grinding, and finally separation of the materials, usually by incineration and then by solution-based chemical processes. As the e-waste is complex in nature, it is difficult to automate this step and, hence, disassembly is mainly carried out by costly manual methods. Sorting aims to minimise the chemical complexity of the mixture to be treated and its variability. The most common approach amongst recyclers, before chemical treatment, is grinding at the scale of the device or module, followed by the steps of separation by physical methods using the differences in density and magnetic properties. Magnets, eddy currents and trommel screens are employed to separate glass, plastic and ferrous and non-ferrous metals, which can be separated by a smelter[39]. Cu, Au, Pd, Ag and Sn are some of the metals sold to smelters for recycling that is the most effective solution to the growing e-waste problem, Furthermore, recycling reduces greenhouse gas emissions, caused by the production of new products[40]. In India, there are many companies located in all major cities, such as Hyderabad (Ramky e-waste processing plant), Bengaluru (e.g., Saahas Zero Waste), Chennai, Mumbai and Delhi as also smaller cities like Faridabad, Bhopal, Goa and Noida involved in the collection of e-waste at source after some payment to the owner, its transportation and recycling to generate VAPs, such as retrieved-plastic to make insulators, trays and fencing posts, recovered metals are segregated, melted and recycled into new products, extraction of mercury at specialised facilities for recovery and other non-recyclable or non-recoverable substances sent to authorised treatment, storage and disposal facilities (TSDF)[41].

3.5. Processing of Construction & Demolition (C & D) Waste: The rapid increase in population and urbanisation has led to a boom in the construction industry over the last two decades. As per the study by the Centre of Science & Environment (CSE), New Delhi, India was estimated to generating 50 million tons of C & D waste in 2013 and it is assumed that the number will go up to 287 million tons per annum by 2020. There are 5 registered (C & D) waste recycling units in India. For example, the Saahas Zero Waste (SZW) in Bengaluru has taken a proactive step towards adopting the C & D Waste Management Rules, 2016 under WM solutions, such as partnering with authorised vendors and certified recyclers for handling different streams of waste generated at construction projects. It keeps in-line with its zero-waste philosophy by extending its services to clients looking for solutions for a sustainable construction project while complying with all the regulations[41]. In the city of Hyderabad, nearly 2,000 tonnes of C & D waste per day has been generated The processing and recycling plant at Jeedimetla, set up in association with Ramky Enviro Engineers Ltd., has a capacity to recycle 500 tonnes of waste a day. The recycled waste, bricks, sand, paver blocks and other materials, which are useful in the construction-work, have been manufactured by a company. Buoyed by the success of this plant, the state government of Telangana is planning to set up six more similar plants, each with a capacity to handle at least 100 tonnes C & D waste per day, at different locations by grouping 65 Urban Local Bodies (ULBs) into six clusters, under the public private partnership (PPP) mode. The concessionaire will have to deploy GPS-equipped vehicles for collection and transportation of C & D waste with a provision for online monitoring, for which fee will be paid. The authorities are planning to make the project an economically viable and environmentally sustainable system[42]. Construction companies may have tons of steel beams for structures, electricians could have old wires and electrical equipment, or plumbers might have old or broken copper piping and brass fixtures they need to dispose of. While the scrap yards see a large quantity metal from the trade industry, they also welcome homeowners and other individuals. Recycling scrap metals involves first the separation of scrap into ferrous (iron, steel) and non-ferrous (copper, aluminium, brass, stainless steel and bronze) metals by magnetic separation. Compared to the ferrous scrap, the non-ferrous scrap is more valuable for recycling. For example, recycled aluminium saves 80% of the energy that was used to make it originally[43]. Recycling of these metals from the waste dumps in landfills is termed as "urban mining", which partially supplies the above metals at a much lower cost than those extracted from natural ore deposits, thereby saving and extending the life span of the ore deposits.

4. DISCUSSION

Considering the hitherto presented account on diverse methods of waste management (WM), which have been adopted in some clean cities, states and metros of India,

and the examples of recycling different major types of waste for VAPs to generate both wealth and employment, the following aspects are discussed aiming at zero-waste and better WM for a healthy, hygienic and sustainable society.

4.1. Complementary Role of Decentralised and Centralised WM: Decentralised methods of WM comprise (i) collection, at source, separately of the wet, dry and hazardous waste in GPS-monitored closed vehicles; (ii) segregation of different types of waste, such as paper, plastic, electronic, metallic, C & D etc., from *dry-waste* in the selected areas for such segregation at the village-level in rural areas and within or nearby to gated colonies, residential wards, hotels and restaurants in urban areas; and (iii) small-scale, in situ, *wet-waste* processing plants, either at or close by to the above selected areas, for generating bio-energy/fuel and manure, useful for farming, as exemplified in the vegetable-fruit market at Bowenpalli in Hyderabad. This type of decentralised WM at local level under the monitoring of village panchayats in the rural areas and ward-level bodies under municipal corporations in urban areas, both under the jurisdiction of state governments, helps in reducing much of the voluminous waste collected, incurs low transportation cost, ensures proper monitoring and generates some power, which can be used for lighting the streets, thereby saving some expenditure on power. Diverse types of waste segregated from dry-waste and hazardous waste cited above can then be sent in GPS-monitored vehicles to the processing and recycling plants, working under the centralised WM programme at mandal/district-level for the rural areas and in specified areas identified for medium-/large-scale waste treatment in urban areas. This pattern of employing decentralized methods of WM in small areas (e.g., WM at Amritapuri in Kerala [see sub-section 2.2.2.3] and "advanced local management" of waste in Mumbai [sub-section 2.3.1.3]) and centralised WM for processing recyclables and hazardous waste for large areas at district or city level may ensure better WM.

4.2. Need for Efficient Effluent and Sewage Treatment Plants: In India, the management of effluent and sewage in both the urban and rural areas is usually in a poor state of affairs, as these waste materials have been released, mostly as such, from the households, commercial establishments, such as hotels and restaurants, and even many industries into numerous *nalas* (drainage channels), lakes, rivers and their tributaries, and even into seas, thereby resulting in their choking, flooding of water, increased pollution that is badly affecting the bio-diversity and even occasional urban flooding, as has happened in Hyderabad in the year, 2020 during heavy rains due to little space for free-flow of rainy water. Though there are pollution control boards (PCBs) and healthcare sections (HSs) in all the urban bodies with a mandatory supervision for proper cleaning of drains and other water bodies, control of air pollution due to excessive release of both the particulate matter of 2.5 and 10 microns size, and the greenhouse gases, released from numerous fossil-fuel using vehicles and industries, and removal/filtering of toxic materials before releasing the industrial waste, their proper functioning is not taking place due to the laxity of the staff and officers of PCBs and HSs, corruption and undue influence of and interference in their work by powerful politicians, rogue elements etc., leading to poor maintenance of the water-bodies, unhygienic conditions and creation of health problems to the people. As an example, many pharmaceutical and other industries in Hyderabad have been releasing their waste, with little or no prior removal of toxic material, into the four major *nalas* joining the Hussainsagar Lake, thereby affecting the health of the people living close-by to the *nalas* as well as increasing the pollution levels causing much harm to fish in the lake. To reduce the effects of these problems, the municipal authorities have recently introduced a floating trash barrier (FTB) at the inlet of one major *nala* (Picket *nala*) into the lake and a proposal to introduce more such units at the inlets of other major *nalas* joining the lake[26] (see section 2.2.4). For better WM, it is, therefore, of much importance to continuously monitor, preferably by unmanned drone-based surveys, of diverse water-bodies, such as drains, *nalas*, rivers, tributaries etc., for their proper up-keeping as well as introducing new waste-removal and segregation measures like the FTBs so as to avoid the release of effluent and sewage into them for better hygiene and keeping good health of the people. Furthermore, care should be taken to keep proper distance between the sewage pipes and drainage *nalas* to avoid the mixing of their waters.

4.3. Integration of WM with PC, GW and CC: As it was demonstrated by some earlier studies that there is an inter-relationship between WM on one side and pollution control (PC)[44], global warming (GW) and climate change (CC)[45] on the other leading to an inter-linking of these four major problems[46], it is desirable that all the aspects related to these global problems should be addressed to, including proper monitoring and evaluation of each, under a single ministry at the levels of both the central and state/union-territory governments so as to make things easier for better management and implementation of required measures for mitigating

their disastrous effects on the society from the point of health and environment.

4.4. Importance of public awareness-commitment-participation in WM: In a gigantic area of WM, encompassing widespread, small, less-populated rural areas to a few, large to very large, highly dense, millions-populated metros in the world's second most populated country and a sub-continent, namely India, proper WM aiming for a healthy, hygienic and sustainable society with a benign environment is possible only by public awareness and their participation with a commitment. For this, it is important to inculcate from the childhood onwards the noble ideas of cleanliness with proper arrangement of things at home, personal hygiene, discipline, worship of the nature, respect for the environment and inculcating a sense of commitment for the society's well-being, both by parents and other elders at home, and teachers in the educational institutions. It is no exaggeration to have a commendable WM for hygienic and healthy environment by a few *properly planned*, *committed* and *service-oriented people* in the society, be at the level of a village, gated community or ward to city/metro level, as exemplified by Ms. Mahita dealing with waste on the frontline at Amritapuri in Kerala (see sub-section, 2.2.2.3.) and Mrs. Maria D'Souza's mission for zero-waste by 100% waste segregation under the "Advanced Locality Management" in Mumbai (see sub-section, 2.3.1.3**.**). Similar type of proper planning, commitment and adopting the health-care measures, such as wearing masks, maintaining social distance and avoiding mass gatherings during the Covid-19 pandemic period has helped countries, such as New Zealand, South Korea, Taiwan and Vietnam with less of covid-related infections and cases of death, as compared to the large-scale infections and/or high death-rate in some countries, such as the US, Brazil, India, Italy etc., due to lack of proper planning, carelessness in taking safe and health-care measures, and movement of people in large gatherings leading to serious health problems, even loss of life.

4.5. Reduce as an important tool for WM: Of the 5 R's of WM − reduce, reuse, recycle, recover and residual management − , the first one, namely *reduce* is an important, effective and easy to implement tool for proper waste management, especially in the case of food-wastage. It is estimated that 931 million tonnes of food, or 17% of the total food available globally to consumers in 2019 went into the waste bins of households, followed by food services and retail outlets, vide the "Food Waste Index Report – 2021", released by the United Nations Environment Programme (UNEP) on March 04, 2021. The weight of the global food waste approximately equals India's total production of food-grains, oil seeds, sugarcane and horticultural produce in 2019−20. On a global per capita level, 121 kg of food is wasted each year, out of which 74 kg is happening in the households. In South Asia, estimates at household level show a waste of 50 kg of food per person per year in India compared to 82 kg in Afghanistan, 79 kg in Nepal, 76 kg in Sri Lanka, 74 kg in Pakistan and 65 kg in Bangladesh. Compared to these figures, the per capita food wastage is much higher in west Asian and sub-Saharan African countries, and most of the European and North American countries, challenging earlier narratives of higher consumer food waste in developed countries, and food production, storage and transportation losses in developing countries. Referring to the Food and Agricultural Organisation (FAO) of the UN, which estimates that 690 million people were hungry in 2019, the food waste index report pointed out that the number was expected to rise sharply during and post-Covid-19. With a staggering 3 billion people who cannot afford a healthy diet (FAO, 2020) the message of the report is clear: "citizens need help to *reduce* food waste at home". In this grim paradox, it is high time that awareness campaigns on the food wastage, both by the government and civil society should be undertaken with emphasis to reduce such colossal food wastage[46]. In this context, it is relevant to adopt the Indian concept of *Aparigraha* − meaning "take only what one *needs*", but not to fulfill one's greed, which is recommended for an effective WM for a sustainable society with India's message of "*Vasudhaika Kutumbam*", meaning the whole world is one family; it is the responsibility of one and all living on the earth to consider all others as belonging to his/her own family with no exploitation − of course, an ideal proposition indeed.

4.6. WM as an Industry: The overview of WM in India − diverse methods, which have been adopted in the whole gamut of WM, starting from the collection of waste at source to final disposal of the least, non-recyclable waste in a landfill through various stages of monitored transportation− segregation, composting of wet waste for generation of bio-fuel/energy and organic fertiliser, and diverse types of dry waste for recycling, such as paper, plastic, C & D, metallic e-waste, etc., to produce various VAPs together with employment generation − points out that WM in India is truly an industry that is widely distributed, in both the decentralized and centralized modes, with large-scale employment in numerous micro- to small-scale

industries and startups, located in different parts of the country.

5. CONCLUSIONS

In an overview on waste management (WM) in India, different methods and results of WM that have been adopted in some of the clean cities and states as well as in a few metros of the country together with the processing/recycling of major types of waste, such agro, plastic, construction & development (C & D) and electronic-waste to generate energy, diverse types of value-added products, with examples, and employment are presented. The information and data accrued, thus, are discussed in terms of the role of decentralized and centralized WM; integration of WM with pollution control, global warming and climate change; need for more effluent and sewage treatment plants for better WM; importance of public awareness-commitment-participation in WM; *reduce* as an important tool for WM and WM as an industry in the country, all aiming a zero-waste based, healthy, hygienic and sustainable society.

Acknowledgements: My sincere thanks are due to (i) the authors of papers and other publications, cited in the text and listed under "References", for the data and information, much of which was accrued through "Google Search", which helped me in drafting this article and (ii) the management of UIJRT for inviting me to contribute a paper.

Author's Declaration*:* The author hereby declares that there is no financial contribution from any external agency as well as no conflict of interest in preparing this article.

REFERENCES

[1] 5 types of waste: Do you know them? – DTM Skip s Blog, https://www/dtmskps.co.uk/blog/types of waste, Aug. 27. 2020.

[2] Waste disposal methods – Types of waste disposal/ Solutions. https://byjus.com/biology/waste-disposal. Aug. 2020.

[3] The 5 R's of Waste Management. LEARNZ navig ation, http://www.learnz.org.nz/redvale181/bg-standard-f/the-5-r%27s-of-waste-management, August, 2020.

[4] Waste management industry in India – StartYo /w ww.startupyo.com. https://www.youtube.com/watch?v=T9YiaVregBk

[5] Subhadra (2020). Top 20 cleanest cities in India (2 020 list)/Swach Surveskshan. www.treebo.com > blog > clean… August 31, 2020.

[6] Anisha Bhatia (2020). Swachh Survekshan 2020: Chhattisgarh is India's cleanest state… Swachhindia.ndtv.com > swachh-survey.. August 21, 2020.

[7] Weber, Loren (2020). Zero-Waste in India. American India Foundation. https://aif.org/zero-waste-in-india, March 20, 2020.

[8] Solid Waste Management – Smart City Indore. www.smartcityindore.org > solid-waste.

[9] Approaches : Surat Municipal Corporation. 2020. https://www.suratmunicipal.gov.in/Departments/SolidWasteManagementApproaches

[10] Mysuru city corporation, Mysuru: Integrated solid waste management. ZYM_MYSORE.pdf.

[11] Bhatia, Anisha (2020). *Swatchh Survekshan* 2020: Chhattisgarh is India's cleanest city, Here's What It Did Right, August 21, 2020, 6:03 p.m.

[12] Ganesan, Prathibha (2017). Implementation of Decentralized Waste Management in Kerala. Public Policy Research Institute (PPRI) Working Paper 14, Thiruvanathapuram, Kerala, 44 p.

[13] Blacklaws, Katharine (2019). Meditations on waste management in India. April 26, 2019. https://www/isonomia.co.uk/meditations-on-waste-management-in-India/

[14] Davis, Bejoy. Solid waste management in Mumbai. The Bombay Community Public Trust (BCPT), 7 p. 0_solidwaste.pdf.

[15] Mumbai Waste Management Ltd. (MWML), Mumbai, India. State of the art disposal facility for industrial and non-industrial hazardous and bio-medical waste. Ramky Group. https://wwwmumbaiwastemanagement.com/

[16] Meet the 68-yo Mumbai woman behind 20 zero-waste societies. https://www.thebetterindia.com/209469/mumbai-woman-bandra-zero-waste-society-hero-inspiring-india-gop94/

[17] Sambyal, Swati Singh (2018). Delhi's solid waste management bye-laws focus on Individual accountability. January 24, 2018. https://www.downtoearth.org.in/news/governance/delhi-get-it-new-byelaws-on-solid-waste-management-59559.

[18] Solid waste management in Delhi, a giant problem: Experts/News. https://swatchhindia.ndtv.com/solid-waste-management-in-delhi-a-giant-problem-

Naveen, B.P. and Sivapullaiah, P.V. (2020). Solid waste management: Current scenario and challenges in Bengaluru. DOI: 10.5772/intechopen.90837.https://www.intechopen.com/books/sustainable-sewage-sludge-

management-and-resource-efficiency/solid-waste-management-current-scenario-and-challenges-in-bengaluru

[20] Nabinder, Bommala (2020). Telangana govt.'s big push to waste management in Hyderabad. Times of India, Dec. 16, 2020.

[21] Hyderabad now has India's advanced waste management system: KTR (2021). *Telangana Today*, February 16, 2021.

[22] Ramky Enviro, GHMC commission construction & demolition waste recycling plant in Hyderabad (2020). *The Hindu Business Lines*, November 08, 2020. https://www.thehindubusinesslines.com/companies/ramky-enviro-ghmc-commission-construction-demolition-waste-recycling-plant-in-hyderabad-article33051512.ece

[23] Ramky Enviro inaugurates 19.8 MW waste to energy plant (2020). *The Hindu Business Lines*, November 10, 2020. https://www.thehindubusinesslines.com/companies/ramky-enviro-inaugurates-198-mw-waste-to-energy-plant/article33068n.ece

[24] Hazardous waste management, common hazardous waste incineration in Ramky Tower, Hyderabad, Ramky Enviro Engg. Ltd., ID:189139 98397.https://m.indiamart.com./productall/hazardous-waste-management-18913998397.html

[25] Karelia, Gopi (2019). Waste Online/New Hyderabad Startup saves 45K trees, recycles 470 tons in 8 months. https://www.thebetterindia.com/190249/hyderabad-waste-pick-up-online-startup-collection-service-free-crapbin-green-india/

[26] Trash barrier at Picket nala cuts tonnes of waste, six more on anvil. Times of India, Hyderabad edition, January 24, 2021.

[27] What is waste management? ERG Environmental Services. https://ergenenvironment.com/what-is-waste-management/

[28] Waste-to-Energy plant. Wikepedia, https://en.m.wikipedia.org/wiki/Waste-to-energyplant.

[29] Hyderabad's Bowenpally market's vegetable waste generated electricity, biofuel (2021). The New Indian Express, Hyderabad edition, January 18, 2021.

[30] Barapatre, A., Aadil, K., Sahu, S. and Jha, H (2013). Value added products from agro-waste. Conf. on 'Recent Research in Science & Technology', v. 5 (2), pp. 7-12.

[31] Stubble burning.https://www.drishtiias.com/daily-updates/daily-news-editorials/stubble-burning-2. Indian Express, November 07, 2019.

Wilson, Simon (2020). Why it's not worth recycling plastic. MoneyWeek, October 03, 2020. https://moneyweek.com/economy/global-economy/602081/why-its-not-worth-recycling-plastic?amp

[33] Five things to know about plastic waste and recycling in India (2019). phys.org. Earth. Environment, October 02, 2019.

[34] Researchers at Hyderabad varsity develop low-cost model to sort plastic waste. The Indian Express – Cities News, Hyderabad ed., January 29, 2021. https://indianexpress.com/article/cities/hyderabad/researches-at-hyderabad-varsity-develop-low-cost-model-to-sort-plastic-waste-7165689

[35] Transforming waste plastic into water pipes//Waste Wealth//Udemarri Plastic Recycling Plant. https://youtu.be?hNEe86DCmp8

[36] Young technocrats set up world's first plastic-to-petrol plant in Guntur (2020). Times of India, Vijayawada ed., October 03, 2020. https://m.timesofindia.com/city/vijawayada/young-technocrats-set-up-worlds-first- plasstic-to-petrol-plant-in-guntur/amp_articleshow;78461260

[37] Santosh, Sanjana (2020). How we used 5 lakh plastic waste bottles to build a resort. December 30, 2020. https://www.thebetterindi.com/246182/recycle-plastic-bottles-rubber-waste-andaman-resort-hotel-san196/

[38] Lahiry, Samar (2019). Recycling of e-waste in India and its potential. (April 17, 2019) https://www.downtoearth.org.in/blog/waste/recycling-of-e-waste-in-india-and-its-potential-64034)

[39] WEE recycling resources (2015). Simsrecycling.co.uk (archived from the original on 6 January 2015; retrived on 6 June 2015).

[40] Benefits of recycling (2015). hardrawgathering.co.uk (archived from the original on 6 January 2015; retrived on 6 June 2015).

[41] Waste management in Bangalore/waste disposal management solutions/Saahas Zero Waste. https://saahaszerowaste.com/waste-management-services-bangalore.

[42] Telangana to set up six more construction and demolition processing plants (2021). https://telanganatoday.com/telangana-to-set-up-six-more-construction-and-demilition- processing-plants. February 23, 2021.

[43] Buechel, Virginia (2019). The basics of recycling scrap metal for money. iScrap App, May 15, 2019. https://earth911.com/eco-tech//basics-recycling-scrap-metal-money.

[44] Yang, H., Ma M., Thompson, J.R. and Flower, R.J. (2018). Waste management, informal recycling, environmental pollution and public health. Jour. Epidemol. Community Health, 72 (3), 237-243.

[45] Solid waste management and climate change – be Waste Wise. https://wastewise.be/2013/08/solidwaste-management-and-climate-change/#.X4Rj7EThU0M

[46] Dhana Raju, R. (2020). Waste management, pollution control, global warming and climate change. Intl. Jour. Sci. Tech. Res. Engg. (IJSTRE), 5 (5), Nov.-Dec., 10-19.

[47] 50kg food wasted per person per year in Indian homes: UNEP. The Times of India, Hyderabad edition, March 05, 2021.