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ORIGINAL ARTICLE

Integrated solid-waste management for Kabul city, Afghanistan

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Abstract
The increasing generation of solid waste and its improper management has imposed daunting impact on Kabul city. The city of 5 million people generated 3050 tonnes of solid waste every day in 2018. Data analysis shows that if an estimated 25% waste reduction is achieved gradually by 2023, then the total cost of the system will be reduced to 1505.9 million Afs/year, much lesser than the estimated cost at 2210 million Afs/year. This study was aimed at developing an integrated solid-waste management (ISWM) plan for Kabul city based on an overview of the existing system and practices, including the gaps in the entire value chain. The study recommends a paradigm shift from business-as-usual scenario to an ISWM approach. The proposed strategies, when implemented effectively, will increase the recycling rate and reduce the requirement for landfilling in Kabul city. Policy reforms to encourage waste reduction and segregation, and the establishment of facilities for recycling, treatment, and landfilling are proposed. Moreover, the willingness to pay of citizens indicates the total cost of waste management system, estimated at 111.53 million Afs/month, can be recovered effectively.

Keywords Integrated solid-waste management · Municipal waste · Cost recovery · Willingness to pay · Waste treatment

Introduction

While the world is rapidly racing towards urban future, the rate of generation of municipal solid waste (MSW) is faster than the rate of urbanization. The key issues of solid-waste management in Asia and Pacific Region may be attributed to increase in the amount of MSW associated with population and economic growth, difficulty in securing land for intermediate treatment and final disposal (due to 'not in my back yard' attitude), high but untapped potential for 3R, and other alternative treatments [1]. Kabul, the capital and largest city of Afghanistan, was the fifth fastest growing city in the world as of 2012 despite the prevalent political challenges. Kabul city has witnessed rapid urbanization rate which has resulted in the acute problems of MSW generation and its inadequate management at many levels [2]. Even though the national and international organizations in the country have tried their level best to properly manage the MSW, MSW management is still a concerning issue in the country due to lack of sufficient investments, poor human and machinery resource capacity, poor service delivery, and poor awareness of the residents about the impacts of solid-waste generation.

The total MSW generation in Kabul city in 2017 was about 2000 tonnes per day, with per capita generation of about 0.4 kg per day [3]. It is expected that in 2020, the MSW generation will rise to 2563 tonnes per day with per capita generation of 0.5 kg per day. It is further anticipated that the amount of MSW generated within the city will grow to 3300 tonnes per day with a per capita generation of 0.6 kg per day by 2025. Therefore, the amount of solid waste is projected to increase drastically in the few coming years, whilst the Kabul Municipality lacks a proper management system to deal with it. This poses serious social, environmental, and economic impact on the capital city of Afghanistan. No significant efforts have been made in the past to understand the composition and characterization of the waste generated that will help to identify the best 3R approaches for waste management in Kabul city.

Integrated solid-waste management (ISWM), the current SWM paradigm that has been widely accepted throughout the developed world, emerged from the policy shift away from landfilling and the push for a broader perspective that began in the 1990s [4]. The concept of ISWM

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strives to strike a balance between three dimensions of waste management: environmental effectiveness, social acceptability, and economic affordability. ISWM refers to all principals, activities, policies, and planning to control the generation, collection, on-site storage, transfer and transport, processing, and disposal of municipal solid waste. Over the years, it has been realized that it is necessary to design an integrated system as a whole rather than selecting individual component subsystems that may not work well together [5]. Integrated solid-waste management has also been defined as the selection and application of suitable techniques, technologies, and management approaches to achieve specific objectives and goals. ISWM includes the baseline study on characterization and quantification of waste for all waste generating sectors within a city, assessment of current waste-management systems and practices, target setting for ISWM, identification of issues of concern and suggestions from stakeholders, development of draft ISWM Plan, preparation of implementation strategy, and establishment of monitoring and feedback system. Resource conservation and resource recovery and 3R (reduce, reuse, and recycling) approach is becoming a guiding factor for SWM. 3R helps to minimize the amount of waste from generation to disposal; thus, it manages the waste more effectively and minimizes public health and environmental risks associated with it. This umbrella approach is useful to generate sufficient volumes of recycling materials required to make recycling industry (or eco-towns) feasible. The approach is also helpful for efficient re-allocation of resources [6].

The overall objective of this research work was to develop an ISWM approach for Kabul city in Afghanistan. Towards this goal, the existing SWM systems have been reviewed and the waste-management practices, both good and unsuitable, were identified. An attempt has also been made to characterize the solid waste generated in Kabul city. Furthermore, the possibilities of adopting 3R concepts in Kabul city have been investigated, along with the associated barriers and constraints.

Materials and methods

The ISWM plan was developed based on primary data collected through baseline information from field visits, interviews, questionnaire surveys, and waste audit analysis along with secondary data that includes literature review and information from the government departments. When stratification is adopted, fewer samples are required as it reduces the variation in the waste composition within each stratum vis-a-vis the entire population. Stratification also increases the accuracy of the composition estimates obtained for the same research resource [7].

For the characteristics and compositional analysis, a total of 606 samples were collected over the course of 2 weeks and the number of samples for each stratum is indicated in Table 1. The households and commercial units were randomly selected within each strata of sampling, to improve the accuracy of the results from the study. The number of sampling units of each stratum should exceed 6 for households, while it should be 15 for the commercial units [8]. Therefore, the number of samples for households and commercial units was adopted as 10 and 15, respectively, for this study. However, the number of samples for commercial units during the weekends was less than 15, since some of these commercial units were closed. Since the samples were taken from each stratum on daily basis, the daily waste production for both households and commercial units could be collected. The waste characteristics and composition analysis were carried out for both mixed waste and food waste. The moisture content and density analysis were carried out as part of the characterization along with the determination of pH for food waste. The analysis was done for two different periods, 1 week in the month of Holy Ramadan (5th June to 11th June, 2018) and 1 week after the month of Holy Ramadan (24th June–30th June, 2018) to assess the waste flows during these periods. In each of the 1-week period of study, the samples were collected for a duration of 7 days which allowed the sampling to be spread over each working day covering the full collection cycle. The collection bags were distributed to participants and collected back, every day.

Table 1 Description of sample collection

Strata code	Strata classification	Strata description	Total samples collected
A 1	High income	Households with income more than 50,000 Afs/month	140
A 2	Medium income	Households with income between 20,000 and 50,000 Afs/month	140
A 3	Low income	Households with income less than 20,000 Afs/month	140
B 1	Commercial units	Individual businesses	172
C 1	Health care facility	Hospital premises	14

Each household and commercial unit included in the study was assigned a special code based on the pre-investigation survey for effective sampling and collection. The samples collected were delivered to a designated secure facility at the Agriculture Faculty of Kabul University for sorting and analysis after which the wastes were disposed safely. One of the important aspects of ISWM plan is to clearly ascertain the waste generation in the study area to plan for a proper waste management system. Therefore, the per capita waste generation rate was calculated by weighing samples of waste from these households. Subsequently, the value was multiplied by the total population of the city to arrive at the total daily waste generation rate. In other words, the per capita waste generation rate is the quantity of solid waste (in kg/day) divided by the total population. Notably, the present study that was carried out during summer season could be extended for different seasonal durations so as to clearly understand the seasonal variation of waste characterization in Kabul city.

A questionnaire was also developed for conducting survey and was administered to collect information about the residents' attitude towards waste management, including their willingness to pay for collection services, along with the assessment of 3R concepts at stakeholders' level in Kabul city. For this questionnaire study, a total of hundred surveys were conducted at each stratum (high, middle, lower income households, commercial units, and healthcare facilities) for a confidence level of 90% at the Districts 3, 5, and 10 in Kabul city. After a random start at each stratum, every third household/commercial unit within the stratum was approached for inclusion in the survey. In case of no response from the selected household or commercial unit, it was substituted with the immediate next household or commercial unit. Door-to-door interviews were conducted and the respondents with age of more than 15 years were considered for the survey. Similarly, different sets of questions were designed that targeted solid-waste program operators. The targeted personnel for these sets of questionnaires included the staff of Directorate of Sanitation (DoS), sanitation officers of each district, dumping officers at landfill, private sector, rag pickers, and the owners of recycling facilities. These questionnaires were aimed at obtaining information on the type of MSW collected, collection equipment and vehicles, final disposal methods, location and type of dumping sites, assessment of the current 3R approaches, and the planned 3R concepts by the program operators. Face-to-face interviews were also held with personnel in charge of MSW management in the city. Finally, as part of the secondary data collection, information related to SWM in the study area in Kabul city was collected from government departments and NGOs. The literature was also reviewed for best practices of SWM from case studies of other countries. These data assisted greatly in the development of ISWM practices in Kabul city.

Results and discussion

Background information

Kabul city enjoys a strategic location at the center of Kabul province, which comprises of 22 city districts with an estimated total population of 5 million, where the number of households, commercial units, and administrative units are 694,756, 70,720, and 761, respectively [9]. A detailed map of Kabul city is provided in Fig. 1. The Directorate of Sanitation (DoS) in Kabul Municipality is the agency responsible for all the sanitation activities in the city including daily collection, transportation, and disposal of municipal solid waste, apart from street sweeping and drainage cleaning. As of 2018, the sanitation activities faced challenges with inadequate technical staff. The total number of officials for administration in DoS is 119. On the other hand, the total number of staff or workers is 3625, divided into three units, namely Central unit, Transportation unit, and District offices. DoS collects only MSW from municipal collection bins of all the districts except District 14. The DoS currently has no staff to design and operate landfills on international standards.

Characterization of waste in Kabul city

Municipal solid-waste generation, composition, and characterization

The average per capita generation was estimated to be 0.61 kg/capita/day in 2018 (Fig. 2). The average waste generation rate in Afghanistan was found to be 0.44 kg/capita/day in 2016 [10]. The reason in this increase is a result of recent economic growth in the city and the increased use of packaging materials. With an estimated 5 million population and an average per capita waste generation of 0.61 kg/day, the total municipal solid-waste generation is about 3050 tonnes/day. The per capita waste generation in Delhi and Bangkok was 0.41 kg/day and 0.82 kg/day, respectively [11, 12]. Noteworthy, Bangkok has more high and middle-income-level households, and therefore, the per capita generation was higher than Kabul city which mostly has middle- and low-income households. Interestingly, the high-income households of Kabul city generated waste at the same rate of the Bangkok city.

The average bulk density and moisture content of mixed waste was 221 kg/m^3 and 40%, respectively. The waste composed mainly of food, which was 45% for Ramadan period and 52.4% for non-Ramadan period. The food waste in the Middle East countries normally increases during the month of Ramadan, but the scenario was different in

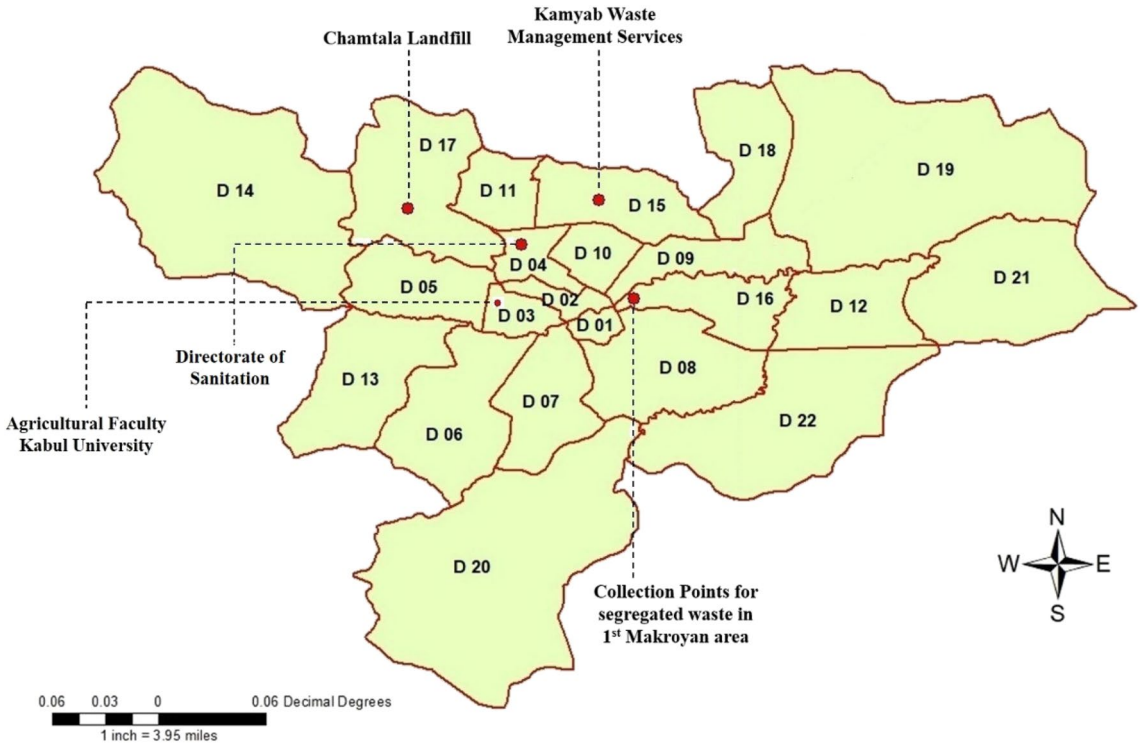

Fig. 1 Kabul city map with district boundaries and important sites of solid-waste management

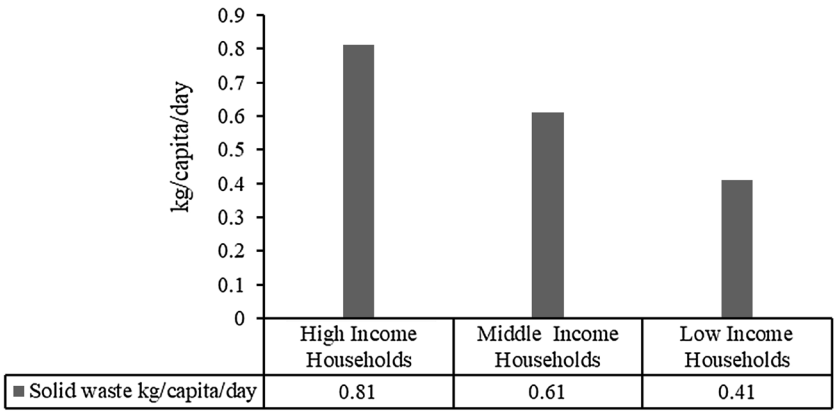

Fig. 2 Average per capita waste generation in Kabul city

case of Kabul city, compared to other Middle East countries. Since majority of the people in Kabul are in middle- and low-income group, Kabul city does not witness the extravagant *iftar* (the meal eaten by Muslims after sunset to break the fast during Ramadan) and humongous food charities. Therefore, most of the people use the leftover food rather than throwing it away unlike in the Middle East countries. One other major reason is that during Ramadan period, food is consumed only twice a day. The next highest component following food waste was Paper and Plastic, which were 20.3% and 17.4%, respectively, as shown in Fig. 3. Globally, municipal solid waste is composed of 44% food and green waste followed by 17% paper and cardboard and 12% plastics [10].

The results shown in Fig. 4 indicate that food waste has highest percentage compared to all other wastes. High- and middle-income households have high percentage of food waste (58%) compared to low-income households (47%), commercial units (44%), and healthcare facilities (38%). When the food waste composition for the commercial units was analyzed during the Ramadan and the non-Ramadan period, it was very low (28%) during Ramadan period compared with the non-Ramadan period (51%). This low percentage of food waste during Ramadan is basically because

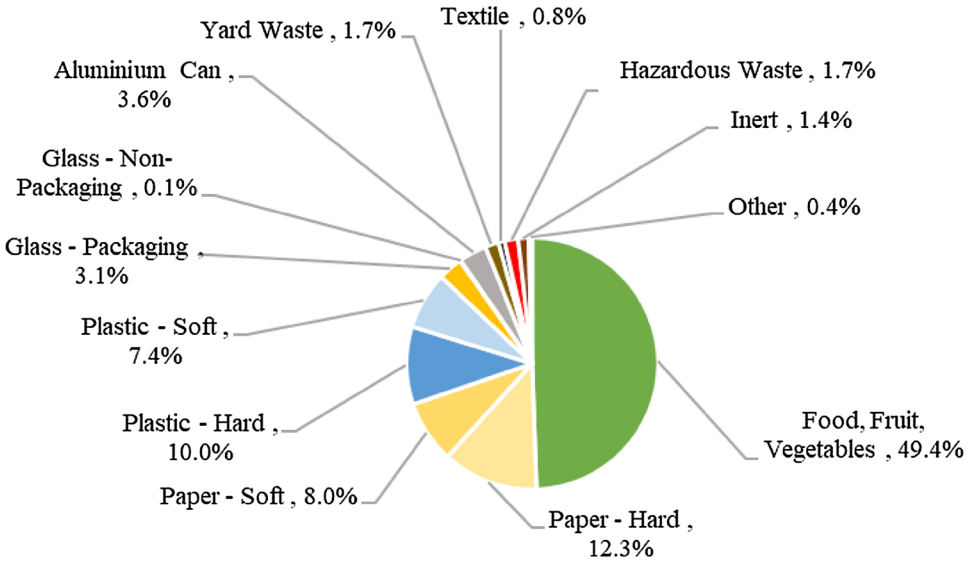

Fig. 3 Composition of mixed waste in Kabul city in 2018

almost all the restaurants (major food waste generators) are closed during Ramadan period. The commercial units have highest percentage of paper and plastic generation compared to households and healthcare facility. The composition of yard waste (9%) and inert (5%) in lower income households (mostly non-concrete buildings with yards) was much higher compared to high- and middle-income households (mostly concrete buildings with no yards). From the compositional analysis, it was also found that hazardous waste (27%) was generated only at healthcare facility.

Food waste generation, composition, and characterization

Food waste is currently one of the major concerns in Kabul city. As discussed earlier, 52.4% of total waste generated (non-Ramadan period) in Kabul city comprises of food waste. Therefore, with a total municipal solid-waste generation of 3050 tonnes/day, the contribution of daily food waste generation was 1598 tonnes. The average per capita food waste generation in Kabul city hence was 0.31 kg/day or 113.15 kg/year. The per capita food waste production in the developed countries is about 107 kg/year, while in the developing countries, it is about 56 kg/year, clearly indicating that the residents in Kabul city are generating food waste on par with the European and South Asian countries [13].

Food waste is composed of vegetables and vegetable products at highest percentage (25%) followed by fruits and fruits products at (22%). Rice waste (18%) is mainly generated at high-income households and commercial units. The overall composition of food waste shown in Fig. 5 indicates that the food waste is highly organic and suitable for composting facilities. This food waste can be a good feedstock for anaerobic digestion, as well. The average density of food waste was 320 kg/m^3, higher than that of mixed waste, which was 221 kg/m^3. The average moisture content of food waste was about 77.1% which can potentially lead to leachate generation after disposal in landfills. Since moisture content of Kabul city's food waste is high, the bioconversion technologies such as composting and anaerobic digestion are suitable.

Collection and transportation of MSW in Kabul city

As of May 2019, there were approximately 4273 collection bins in the city. From a total of 4273 collection bins, 857 are 7 m^3 bins, 1116 are 1 m^3 bins, and the remaining 2300 are 0.1 m^3 bins. The 0.1 m^3 bins were installed at public places like markets, parks, walkways, schools, universities, etc., to deal with the problems of waste littering. The data obtained from the weighing machine installed in 2017 at the landfill showed that during weekdays (Saturday–Wednesday), the average solid waste transferred to *Gazak* 2 landfill was 1738 tonnes/day, while during weekends (Thursdays and Fridays), the solid waste transferred was only 448 tonnes/day. The collection efficiency was much lower on weekends compared to weekdays, as the DoS does not allocate shift for workers on weekends and overtime remuneration for drivers. The DoS had a total of 477 vehicles by the end of 2018, out of which only 384 were active. Amongst the active vehicles, 374 were employed for sanitation purposes, while 10 were used for administrative purposes. It is worth mentioning here that in May 2019, 76 new vehicles were added to the fleet of DoS, and with these vehicles, it is expected that the waste transfer to *Gazak 2* landfill would increase to 2500 tonnes/day. Vehicles with capacity of 3 tonnes or less transferred waste to the transfer station, while vehicles of higher capacity transferred waste directly to *Gazak 2* landfill.

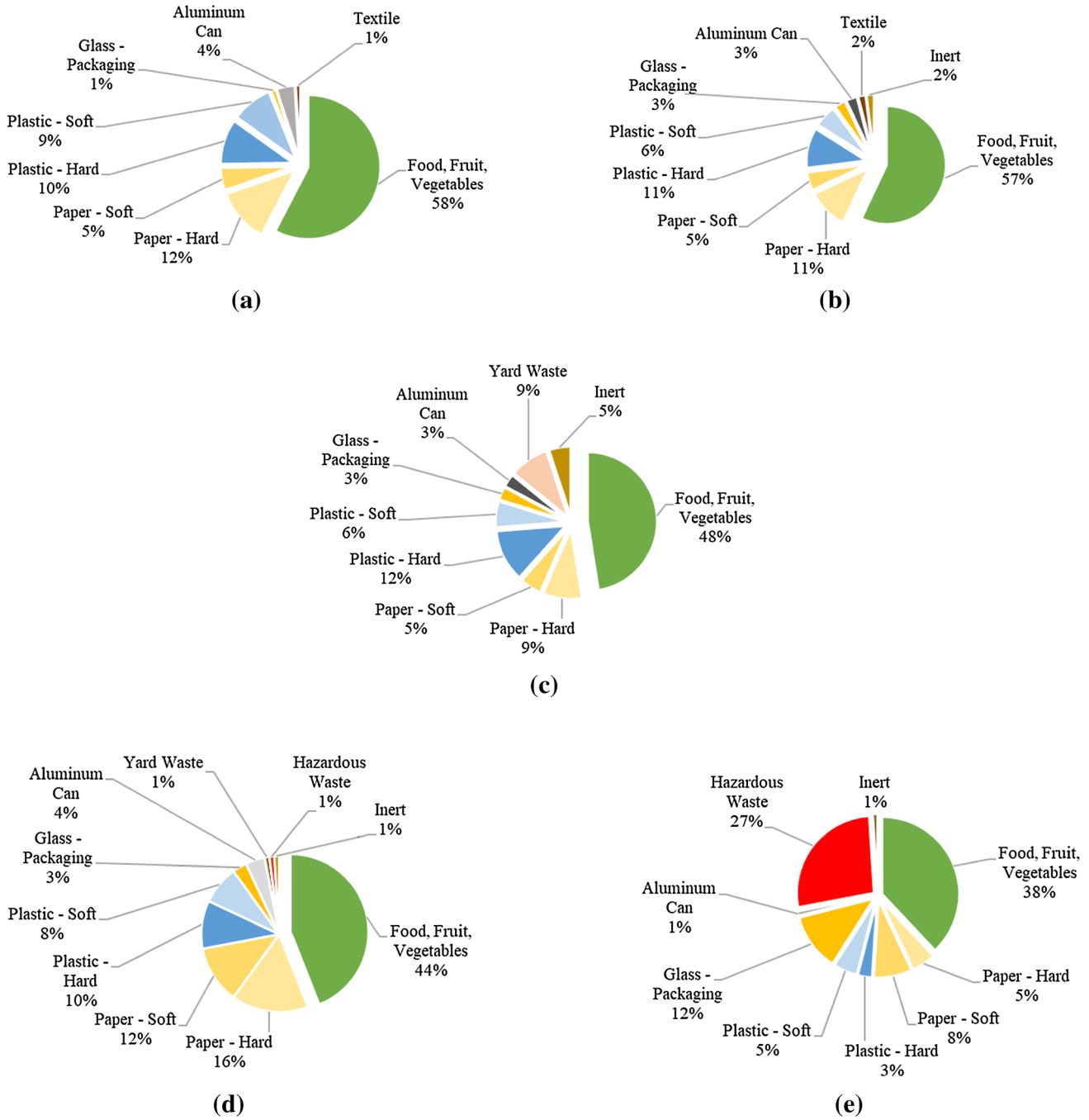

Fig. 4 **a** High-income households—mixed waste. **b** Middle-income households—mixed waste. **c** Low-income households—mixed waste. **d** Commercial units—mixed waste. **e** Healthcare facilities—mixed waste

Disposal of MSW in Kabul city

The municipal waste collected by DoS from all parts of the city is transferred to *Gazak 2* landfill for final disposal. The disposal of waste at *Gazak 2* landfill started in 2012 when the other two landfills (*Chamtala* and *Gazak 1* landfills) were closed. The *Gazak 2* landfill has an area of around 800 *jeribs* equivalent to 160 hectares (1 *jerib* = 0.2 hectare) and currently half of this is being used keeping room for expansion. All waste streams are disposed together in the landfill site and the soil cover is barely noticeable at some parts of the landfill. This landfill is operated like a dumpsite, where all the mixed waste stream is just placed without any major waste compaction nor is covered with soil on daily basis. The leachate penetrates to the underground waters whereas the gases are emitted into the atmosphere due to improper

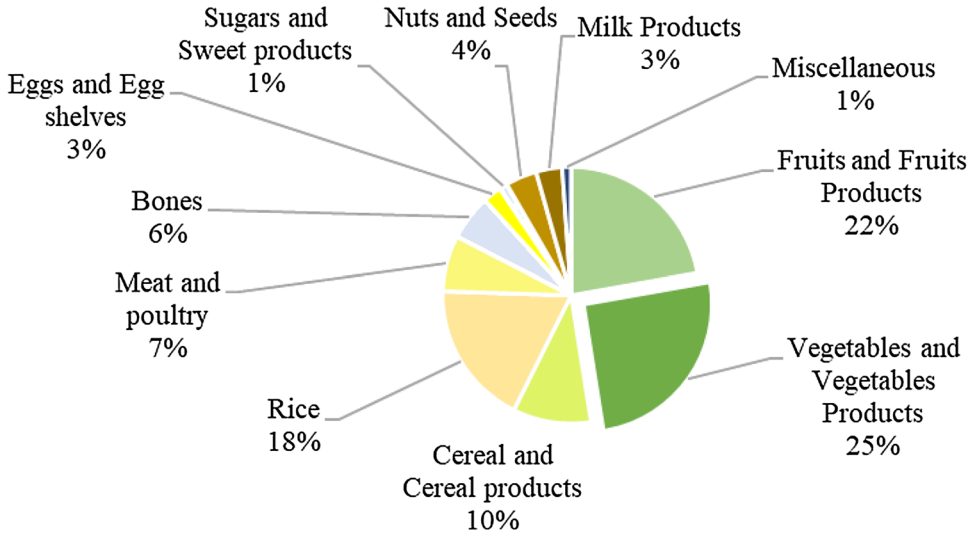

Fig. 5 Composition of food waste in Kabul city in 2018

treatment mechanism. Furthermore, the landfill (dumpsite) has turned into a good breeding site for the mosquitoes and stray dogs. Though there are no settlements near the *Gazak 2* up to 1 km radius, the citizens living beyond have been protesting over the years complaining about the foul odor, mosquitoes, and stray dogs. Other than these issues, the dumped waste often catches fire, especially during winter season, generating huge amount of smoke.

Current waste-management practices in Kabul city

Recycling of waste

The scavenging in the city is carried out for so many years by local scavengers, mainly children, old aged men, or drug addicts. These scavengers have their own four wheelers, three wheelers, or two-wheel carts to collect waste. DoS estimates that there might be around 2000–2500 scavengers in the city collecting about 200–305 tonnes of waste per day that accounts for 7–10% of total waste generated. Once the food waste is scavenged from around the city, it is then sold to livestock facilities. Even though this practice helps to reduce the chances of food waste accumulated in the landfill, it often leads to health complications in the livestock [14].

Recyclable waste like plastic, paper, glass bottles, aluminum can, etc., are sold by scavengers to the informal recycling facilities called locally as *Kabar Khana* (shops that buy waste from scavengers and pay them some amount of money). The different types of waste and their average prices that are obtained through field visits and interviews are given in Table 2. It can be observed that all waste types have a market value except the single-use plastic bags. All waste types, except glass, were sold to recycling facilities inside the city where these wastes were recycled into new products. Industries that manufacture toilet and tissue papers use paper waste as their raw material, whereas plastic waste was used in piping industry. Table 3 shows that if food waste, paper waste, PET and HDPE bottles, aluminum cans, and glass bottles are sold on daily basis to the recycling facilities instead of ending up in landfill, it can create an estimated profit of about USD 182,590/day.

Strategic implementation of reduction, reuse, and recycle of solid waste becomes an obligation through awareness and practice. This could achieve by reengineering current practice of solid-waste management from the conventional to integrated approaches, for a better cleaner environment and efficient cost effectiveness of the whole system [15]. The direction of 3R approach are developed also as an approach

Table 2 Types and average price of recyclable materials in Kabul city

Type of waste	Middle buyer/junk shops (price/tonne) (Afs)	End users/recyclers (price/tonne) (Afs)	Estimated profit (per tonne) (Afs)	Selling destination
Food, fruit and vegetables	5000	9000	4000	Livestock facilities
Paper	3000	6000	3000	Recycling facilities inside the city
PET and HDPE bottles	10,000	22,000	12,000	Recycling facilities inside the city
Aluminum cans	65,000	82,000	17,000	Recycling facilities inside the city
Glass bottles	25,000	40,000	15,000	Facilities outside the city

Table 3 Estimated profit for the total waste generated

Type of waste	Estimated profit (USD/tonne)	Weight (tonnes)	Total estimated profit/day (USD/day)
Food waste	53	1598	84,694
Paper	39.77	619	24,617
PET and HDPE bottles	98.99	305	30,191
Aluminum cans	225.1	94.5	21,271
Glass bottles	198.7	109.8	21,817
Total			182,590

to obtain synergistic effects with national strategies which aim at landfill prevention, procurement of resources, and reduction of GHG emissions [16]. Therefore, it is imperative that the proposed ISWM plan for Kabul city should be centered on 3R approaches. Hence, this study recommends that the promotion of 3R approaches should be prioritized over the conventional method of collection, treatment and disposal.

Biomedical waste management

There was no clear monitoring of medical waste disposal either by DoS or by the Ministry of Public Health (MoPH). Most of the government hospitals have their own incinerators where they burn all the biomedical waste that is generated. On the other hand, the private hospitals have contracted a private company named *Kamyab Waste Management Services,* which manages the health care waste generated from the private hospitals. Two private hospitals were also visited and both the hospitals claimed that they send their medical waste to the *Kamyab Company* for incineration. However, it was also observed during the survey, that huge amount of waste was stored mixed with other MSW components in the backyard of these hospitals. This indicates that these hospitals were disposing their medical waste along with MSW into the municipal bins.

Construction and demolition (C&D) waste

The rapid urbanization in Kabul city is resulting in drastic increase in the C&D waste. There is no proper management of the C&D waste. The pieces of steel bars are always sold to the factories where these pieces are melted down and recycled. The wood waste that is not reusable is sold to people for cooking or heating during winter season. The stone blocks, brick blocks, soil, and dirt waste are used for filling in buildings. Where they were not used for filling, the construction manager pays the private trucks to transfer the waste away from the city. These truck drivers transfer this waste to the rural areas and dump in the flood ways to protect agricultural fields from flood waters. However, this approach was not followed by all the construction owners. Most of the time, this type of waste is dumped into the municipal bins or it ends up in the drainage ways. The soil and dirt that ends up in the drainage ways blocks the water flow during heavy rains and results into urban floods.

Role of private sector in MSW management

In Kabul city, there are numerous small private companies that provide solid-waste collection services. For this study, four of these private companies were interviewed to assess their waste-management system. These companies mostly collect waste from households for a fee. The four companies that were interviewed charge around 150–200 Afs/month on average to each household. Door-to-door collection method is adopted by these companies. The total list of the private sector that provide door-to-door collection shows that currently, about 51,347 Households (HH) are provided with door-to-door collection. Out of the total 51,347 HH, about 25,982 HH (51%) pay 200 Afs/month, while 8585 HH (17%) willingly pay 150 Afs/month for waste collection.

Barriers and constraints for 3R

There are a number of barriers and constraints that create obstacles in the adaptation of 3R concepts. Based on the survey, it was found that the residents' willingness to actively participate in 3R programs was relatively low; it needs to be enhanced. Low price and high transportation cost of the recycled materials has restricted the recycling rate of waste in Kabul city. Lack of knowledge among people of not knowing which materials can be recycled and which can be sold to scavengers. Almost no attention has been paid to the legalization of scavengers from the government and non-government organizations. Lack of market demand for recycled products is also a major constraint to 3R. Lack of technical staff to operate and maintain recycling technologies is a major reason that the investors are not willing to invest in big recycling technologies. Out of the 400 respondents surveyed for this study, 63% admitted that they are aware of the 3R approaches and the potential paybacks

that these approaches possess, while 31% admitted that they have no knowledge of 3R approaches. This proves the main obstacle for adoption of 3R in the city that, even though most of the residents are aware of the benefits of 3R approaches, only a limited number of residents are willing to adopt it.

DoS has taken several good initiatives of waste management. The use of plastic bags in the bread shops has been banned and the vendors have been instructed to either use paper bags or cloth bags. DoS has also converted 655 open collection points with 7 m^3 and 1 m^3 collection bins by July 2018. DoS conducted an awareness program at *1st Makroyan* area in May 2018, where the DoS workers visited around 1801 households and briefed about 10,000 residents on dry and wet waste segregation. After the campaigns, eight collection points with separate bins for dry and wet waste were established in the *1st Makroyan area* to receive the segregated waste from these households. Earlier in 2015, the DoS installed GPS trackers in all its active vehicles to monitor the travelling routes of vehicles and to solve the fuel theft issues. This updated system was estimated to have saved 352 million Afs or USD 5.2 million per year, and the amount saved was used by DoS in capacity building programs. On the other hand, unsuitable practices of waste management included littering of waste by citizens onto roads and sewage lines resulted in heavy urban floods. In general, poor waste segregation practices were observed in the city. Biomedical, construction and demolition waste were dumped along with municipal solid waste. At most of the collection points, waste was not disposed properly into the collection bins. It was also found during the study that 1 DoS worker provides services for about 1380 people; however, most of the workers were old, weak and were not enthusiastic towards their work. At some points, burning of waste was found to pose huge threat to the air quality of the city.

Cost-recovery system and residents' willingness to pay

At present, all the Operations and Management costs of the DoS are financed by the national treasury of the central government. The DoS also receives international loans and grants for the SWM. For a well-developed solid-waste management system, one of the most important criteria is cost recovery. A cost-recovery system includes several steps, but the first and foremost step is the identification of actual cost of the total system. The total cost analysis for the current solid-waste-management system is given in Table 4. The cost of fuel consumed by the vehicles that collect and transfer the waste from collection points and the salaries of the sanitation staffs who were directly involved in waste collection and transportation were considered for the estimation of per tonne collection and transferring cost. The cost of fuel consumed by the vehicles like excavators and compactors that operates at the disposal site and the salaries of the sanitation staffs who work at the disposal sites (disposal officers, workers, guards, etc.) were included for calculation of per tonne disposal cost. On the other hand, the cost of fuel consumed by the vehicles that were used for administrative purposes, the salaries of the sanitation staffs who were involved in the administrative works, and the extra costs incurred from GPS, electricity bills, spare parts, maintenance, hydraulics, etc., were taken into account for the estimation of per tonne additional cost. As shown in Table 4, the cost of transferring one tonne of waste is 1219 Afs. Since currently only 1740 tonnes of waste are collected and transferred per month, the total transfer cost is 63.63 million Afs. For transferring the waste generated, which is 3050 tonnes per day, the total cost per month increases to 111.53 million Afs and per capita cost per month works out to 23 Afs.

For developing a cost-recovery system, it is essential to assess the increase in cost on a long-term basis. For this study, a future cost analysis for the next 10 years was calculated. For an urban growth rate of 3–3.5% per annum, the annual increase in waste quantities has been estimated at 5% per annum [17]. Therefore, in Kabul city, the waste increase for next 10 years is estimated at 5% per year. Table 5 shows that the waste generation in Kabul city will increase to 1.57 million tonnes in 2025 and 1.81 million tonnes in 2028. Furthermore, the per capita cost

Table 4 Cost of each component in SWM of Kabul city

Amount of waste	Component	Cost (in Afghanis)	Cost (in USD)
For 1740 tonnes of waste that is currently collected	Per tonne collection and transfer cost	687	9
	Per tonne disposal cost	10	0.13
	Per tonne additional cost	522	6.91
	Total cost per tonne	1219	16.14
	Total cost per month	63.63 million	0.84 million
	Total cost per year	774.18 million	10.25 million
For 100% collection efficiency (3050 tonnes of waste)	Total cost per month	111.53 million	1.47 million
	Per capita cost per month	23	0.3

Table 5 Estimated waste generation and costs for next 10 years

Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Percentage increase in waste	–	5	5	5	5	5	5	5	5	5	5
Waste generation (million tonnes/year)[a]	1.11	1.17	1.23	1.29	1.35	1.42	1.49	1.57	1.64	1.73	1.81
Inflation rate (%)[b]	–	5	5	5	5	5	5	5	5	5	5
Cost per tonne (Afs)[c]	1219	1280	1344	1411	1482	1556	1634	1715	1801	1891	1986
Total cost per year (million Afs)[d]	1353	1496	1650	1819	2005	2210	2437	2687	2962	3266	3601
Population growth rate (%)[e]	–	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36
Total population (million)[f]	5.00	5.12	5.24	5.36	5.49	5.62	5.75	5.89	6.03	6.17	6.31
Per capita cost per year[g]	271	292	315	339	365	393	424	456	492	529	570

[a]Waste generation in 2019 = (waste generation in 2018 × % increase in waste) + (waste generation in 2018)

[b]*Source*: World Bank's report on Afghanistan's Development Update (2018)

[c]Per tonne cost in 2019 = (per tonne cost in 2018 × inflation rate) + per tonne cost in 2018

[d]Total cost per year in 2019 = per tonne cost in 2019 × total waste generation per year

[e]*Source*: World Population Review (2018)

[f]Total population in 2019 = (total population in 2018 × population growth rate) + (total population in 2018)

[g]Per capita cost per year in 2019 = (total cost in 2019/total population in 2019)

will increase from 271 Afs in 2018 to 570 Afs in 2028, with the inflation and population growth rate of 5% and 2.36%, respectively.

Subsequent to the cost-recovery analysis, people's willingness to pay for the services was analyzed. 80% (320 respondents) agreed that municipality should introduce tax on solid-waste collection. 15% (60 respondents) disagreed on the implementation of tax. About 28% (113 respondents) agreed to pay 150–200 Afs, whereas 24% (95 respondents) responded that they were willing to pay more than 200 Afs for SWM services. Figure 6 shows that the ranges 50–100 Afs and 100–150 Afs were mostly selected by low-income households, while the higher range, which is 150–200 Afs and more than 200 Afs, was mostly chosen by high-income, middle-income households, and commercial units.

Integrated solid-waste management (ISWM) plan for Kabul city

The gaps and challenges in SWM in Kabul city observed during the study pose several threats to human health, environment, land use, climate, and esthetics, and hence call for an ISWM plan to adequately manage the solid waste of the city. The vision for this ISWM plan is to develop a step-by-step guide for the formulation and implementation of a strong, safe, and secure solid-waste-management system and to convert Kabul city into a sustainable and smart city, in times of growing resource scarcity. A schematic diagram of this vision is given in Fig. 7. Implementation of the integrated approach supported by trained manpower and the one that is led by political will improve the effectiveness of SWM and develops community participation for sustainable waste management [18]. At the core of the problems of waste management are the absence of adequate policies,

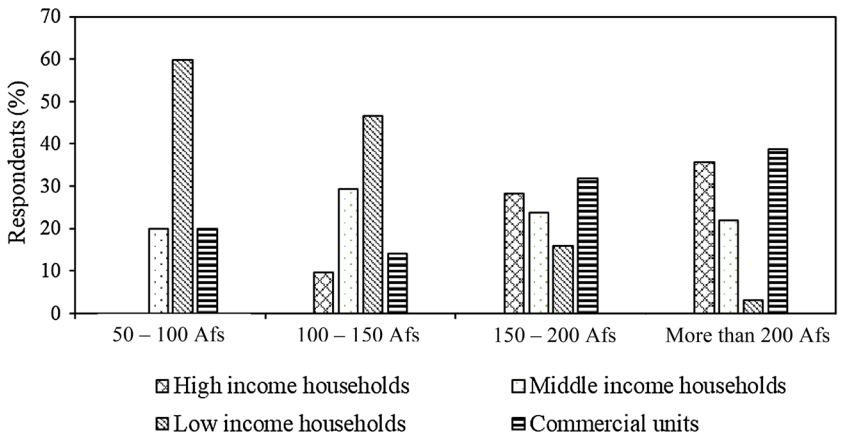

Fig. 6 Respondents willingness to pay (strata wise)

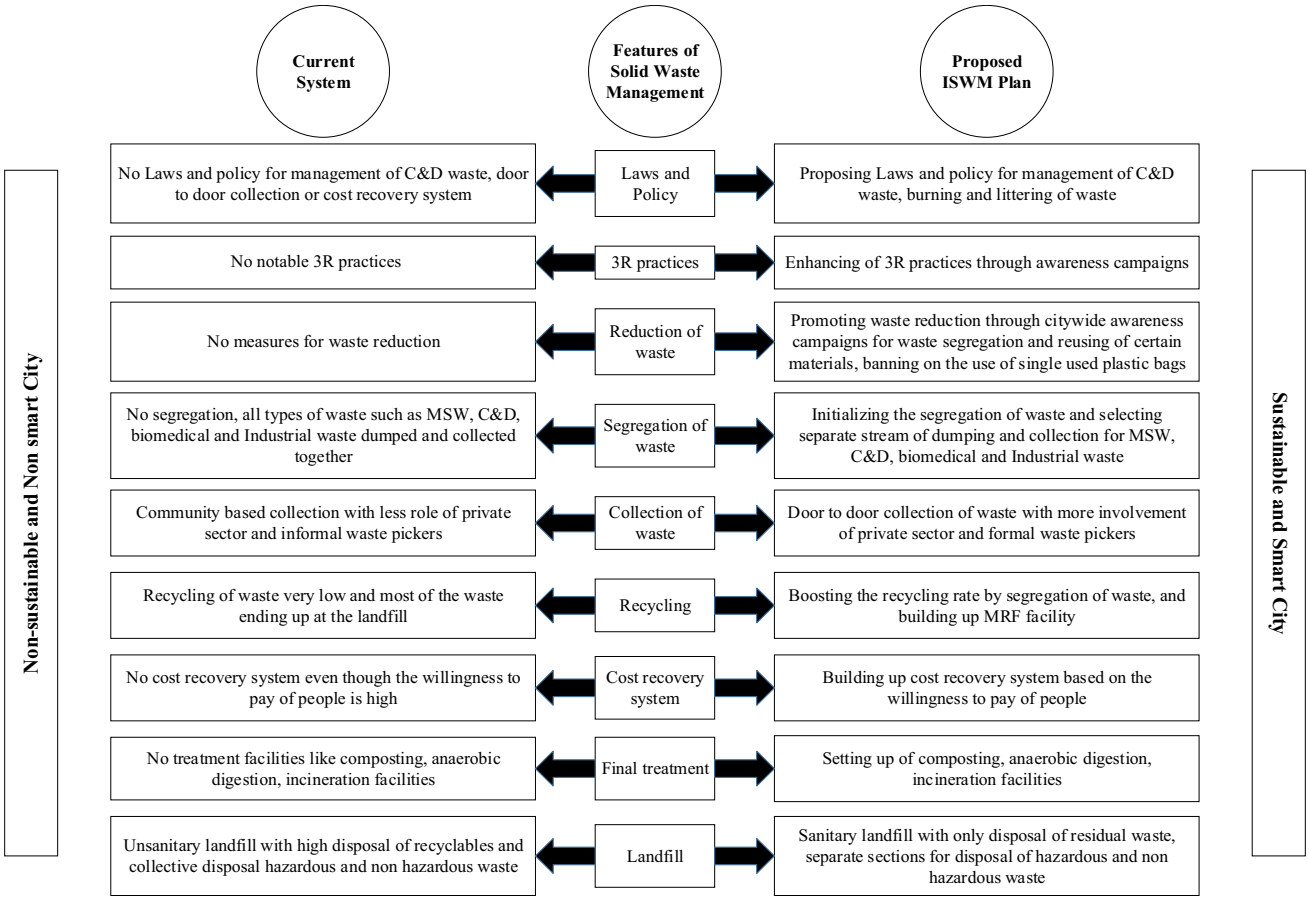

Fig. 7 Schematic diagram of ISWM plan's vision

enabling legislation, and an environmentally stimulated and enlightened public [19]. The waste-management law and policy of Afghanistan needs significant reforms. There have been no reforms made in the laws and policies since 2010 when they were prepared by the National Environmental Protection Agency (NEPA); on the other hand, the nature of waste, waste generators, and waste managers have changed to a vast extent. The ban on the use of single-use plastic bags should be extended to pharmacies and general stores. At the same time, focus needs to be directed to control the imported waste from other countries.

The current waste flow of Kabul city is presented in Fig. 8. The future cost analysis shown in Table 5 indicated that the waste generation in 2023 would increase to 1.42 million tonnes per year as compared to the 1.11 million tonnes per year in 2018. This increase in total generation advocates that in 2023, the total cost will increase to 2210 million Afs/year (from 1353 million Afs in 2018) and per capita cost to

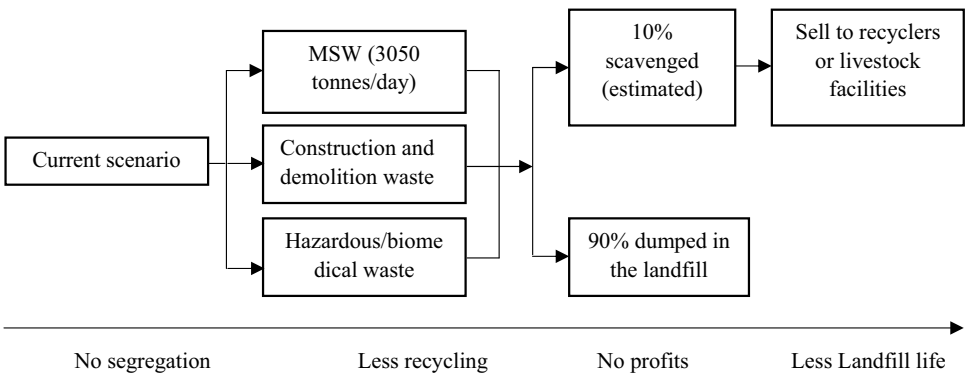

Fig. 8 Current waste flow of Kabul city

393 Afs (from 271 Afs in 2018). Therefore, a 25% waste reduction rate in per capita waste generation should be set as a goal as depicted in Table 6.

Lack of environmental concerns and awareness contribute to the failure of solid-waste-management plans in Asia [20]. The awareness campaigns should focus on behavioral changes of people towards good waste-management practices such as reuse of waste, segregation of waste, not burning or littering of waste in public places, adopting 3R concepts, paying for the solid-waste-management services, etc. Segregation of waste should be made compulsory for every premise in the city. Healthcare facilities should segregate their waste into three categories including dry waste, wet waste, and hazardous waste (biomedical waste). The implementation of door-to-door collection system of solid waste will help in increasing collection efficiency, recycling efficiency, and revenue. A specific private company should operate in a specific area or district, so that DoS could easily monitor effective waste-management services. Waste pickers should be registered and traceable. Trainings sessions should be arranged at regular intervals for capacity building. The dumping of healthcare waste with municipal waste should be banned and those not complying should be prosecuted. The C&D waste should be disposed separately from the municipal solid waste and should be handed over only to authorized processing facilities. Littering of C&D waste into roads or drains should also be prohibited. Those premises that generate C&D waste of more than 20 tonnes/day or 300 tonnes per project in a month should be made to submit waste-management plan and get appropriate approvals from the district authorities before construction or demolition work is started.

As a short-term plan, the waste could be collected from all three categories of waste generation, namely domestic bulk generators (less than 25 kg waste/day), mini bulk generators (25–100 kg waste/day), and bulk waste generators (more than 100 kg waste/day). The waste collectors should be asked to segregate the waste while collecting it from door-to-door. The hospital's biomedical hazardous waste should be collected separately by private companies for incineration. At least three transfer stations should be established for unloading of collecting vehicles, prescreening and segregation of waste, and reloading into high tonnage vehicles to transfer the same to final destination. The dry waste should be sent to a Material Recovery Facility (MRF) to effectively manage the recyclables. Kabul city's waste is composed of about 50% organic waste, suitable for composting. Therefore, composting becomes an important part of the ISWM plan. Since aerobic composting is cost-effective and easy to operate, the best choice of composting in Kabul can be aerobic composting. The *Gazak 2* landfill should be developed into a sanitary landfill. If Kabul city adopts ISWM plan, only about 4–10% (118–295 tonnes/day) of waste, mainly non-recyclable waste, would go to landfill compared to the current situation where about 90% of waste is dumped in the landfill, as shown in Fig. 9.

Based on the survey, the willingness to pay was found to be 150 Afs/month for households and 200 Afs/month for commercial units, which could cover the total cost of the system estimated as 111.53 Afs/month as indicated in Table 4. The profit from selling the recyclables, as mentioned in Table 3, could be used to cover the additional cost of the system. The most suitable practice of billing in Kabul city could be the indirect billing system. Internet of Things (IoT) for real-time monitoring could be employed in the ISWM plan. The weight measuring sensors, fullness-level sensors, and GPS-enabled collection trucks could be deployed. The mobile applications for the regulatory bodies, waste pickers, recyclers, and waste generators could lead to efficient waste management.

Long-term plan should start from sixth year of this ISWM plan. The violators of waste segregation should be penalized with fines. The mini bulk waste generators should have community-based compost pits or anaerobic digestion system. The bulk waste generators should have their individual transfer stations, and material recovery facility with composting or anaerobic digestion system. Since Kabul city has about 17 hospitals with more than 50 beds, these hospitals could be categorized as bulk waste generators of biomedical waste, generating more than 100 kgs of biomedical waste

Table 6 Comparison of cost before and after 25% reduction of waste

Year	2018	2019	2020	2021	2022	2023
% Targeted reduction in waste	–	5	5	5	5	5
Per capita waste generation	0.61	0.58	0.55	0.52	0.50	0.47
Population growth rate (%)	–	2.36	2.36	2.36	2.36	2.36
Total population (million)	5	5.12	5.24	5.36	5.49	5.62
Total waste generation million tonnes/year	1.11	1.08	1.05	1.02	1.00	0.97
Inflation rate (%)	–	5	5	5	5	5
Per tonnes cost (Afs)	1219	1280	1344	1411	1482	1556
Total cost per year (million Afs)	1353	1385.6	1414.7	1444.5	1474.9	1505.9
Total per capita cost per year	271	271	270	269	269	268

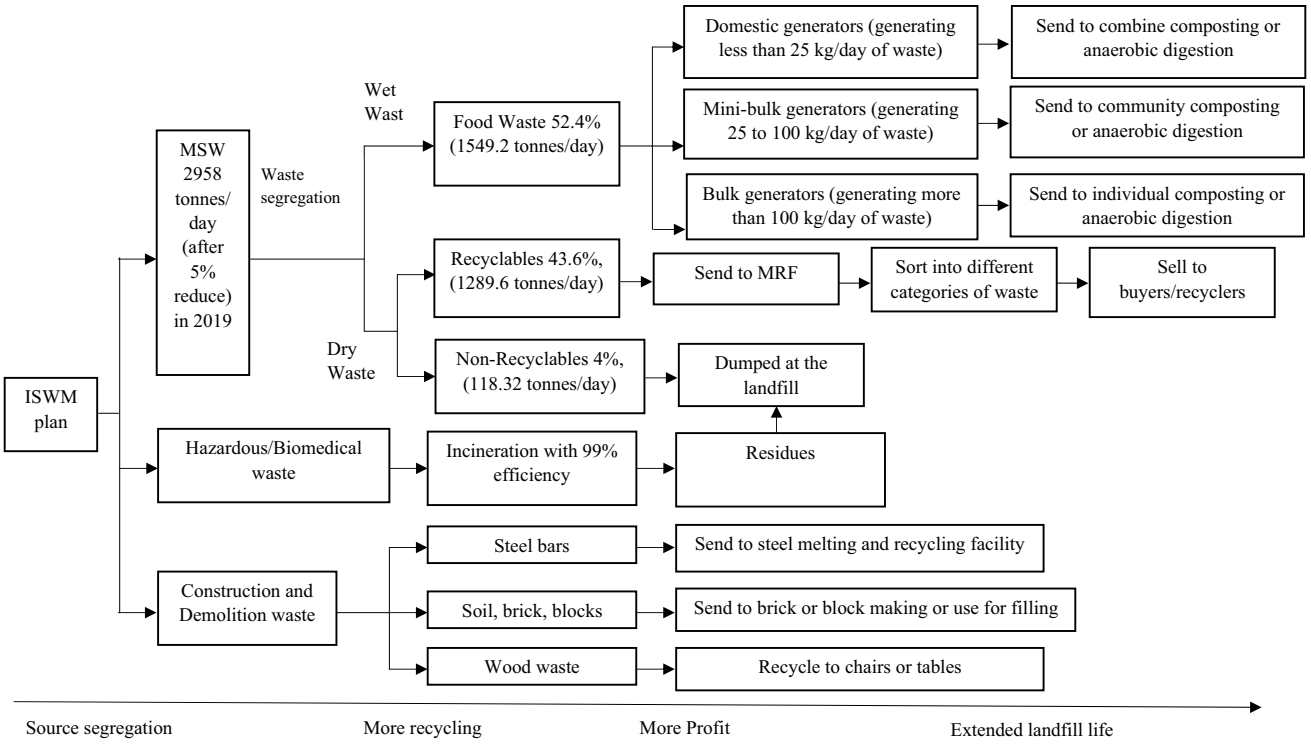

Fig. 9 Expected waste flow after ISWM plan implementation

per day. Therefore, these healthcare facilities should have their individual incineration facility. Each district should have its own collection zone where the initial transfer of waste should take place. For successful implementation, the proposed ISWM plan could be taken up as a pilot project and then expanded gradually throughout the city. DoS could seek external expertise in SWM, increasing the workforce. Incentives could be provided to waste generators to encourage their participation in accomplishment of ISWM plan.

Conclusions

This study has focused on developing an ISWM plan for Kabul city based on the baseline information collected through field visits, interviews, questionnaire surveys, and waste audit analysis. The generation, composition, and characterization of municipal solid waste and food waste for Kabul city in 2018 was established. With an average per capita generation of 0.61 kg/day, the total municipal solid-waste generation in Kabul city in 2018 was about 3050 tonnes/day. The existing waste-management practices in Kabul city have been thoroughly studied. Poor waste segregation practices were observed in the city, with the biomedical, construction, and demolition waste dumped along with the municipal solid waste. The study also included developing a novel cost-recovery system based on willingness to pay of the residents. The study recommends a paradigm shift from the business-as-usual scenario in SWM in Kabul city. The proposed Integrated Solid-Waste Management (ISWM) plan lays emphasis on promotion of 3R approaches over the conventional method of collection, treatment, and disposal. The proposed strategies, when implemented effectively, will increase the recycling rate and reduce the requirement for landfilling in Kabul city. Finally, the willingness to pay analysis concludes that a cost of 150 Afs/month on households and 200 Afs/month on commercial units could effectively recover the total waste-management cost of about 111.53 million Afs/month.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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