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REGIONAL CASE STUDY

Matrix method for evaluation of existing solid waste management system in Himachal Pradesh, India

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Abstract
Effective management of Municipal Solid Waste (MSW) is an essential function of the city municipal corporation. The present study reports on the existing solid waste management practices in four major cities of Himachal Pradesh (Sunder Nagar, Mandi, Baddi and Solan) in India, and suggests solutions for better management of the MSW generated at these locations. The overall generation of Municipal Solid Waste in Himachal Pradesh (HP) is 350 tons per day (TPD) of which the selected sites accounts for about 25% of the total MSW generated in the state. The collection efficiency of generated MSW in the study regions varies from 60 to 70%. Evaluation of the existing Solid Waste Management (SWM) practices at these study locations was determined using the '*wasteaware'* benchmark indicators, which incorporate parameters integrating both qualitative and quantitative indicators for comparing the efficiency of municipal solid waste management system. Further, a simple matrix method has been utilized for comparing the efficiency of the management of the MSW generated at these four selected sites in Himachal Pradesh. Using the matrix method, it was observed that Sunder Nagar and Mandi towns received an overall score of 36% and Solan and Baddi 32%, respectively. The overall results suggest that existing solid waste management practices in four study locations are very poor and need considerable improvement. Some key recommendations have been proposed for the better management MSW at the four study locations in HP.

Keywords Municipal solid waste management · Waste generation · '*Wasteaware*' benchmarks · Matrix method · Himachal Pradesh

Introduction

India is primarily an agrarian country with a population of 1.34 billion [1] with a large majority of the population living in urban areas. The latest report [2] mentions that about 50% of the population will reside in urban areas by 2030. Rapid development and formation of such urban areas has left the existing municipal corporations (and the new municipal corporations of developing cities) inadequately positioned for providing the basic sanitation facilities including effective management of the MSW generated [1]. The problem has been further compounded due to lack of adequate budgetary provision for effective management of solid waste generated at these locations [3–5].

The rate of generation of solid waste in urban areas in India is about 1.5×10^5 TPD [1] with a per capita generation rate of 0.2 to 0.87 kg/day depending upon the population and the economic potential of the city [6–8]. The rate of growth of increase in MSW generation with increase in population in India has been predicted and shown in Fig. 1. Generation rates of MSW in some of the major states in India have been shown in Fig. 2 [2]. It has been reported that the collection efficiencies of metropolitan and tier-I cities vary between 70 and 90% in and less than 50% in tier-II and tier-III cities of which 90% is open dumped [1, 3]. Open dumping of MSW leads to generation of landfill gas emissions which can lead to climate change [9, 10] and hence need to be disposed safely [11, 12]. In particular, MSW generated in India generally consist of high fraction of biodegradables (40–60%), inert materials (30–60%), paper (3–6%) with other components such as plastics, metals inerts contributing about 1% [5, 13], and hence such landfill gas emissions from open dumps needs to be suitably controlled. The composition of MSW in major Indian cities is shown in Table 1.

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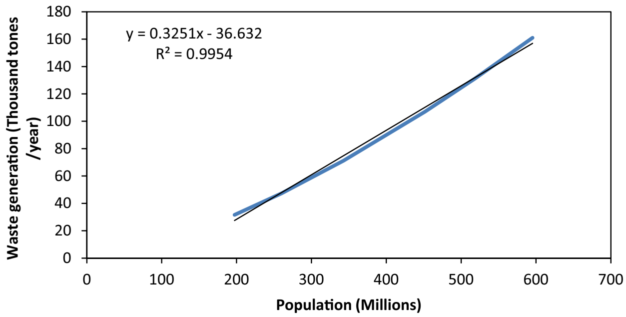

Fig. 1 Variation of MSW generated with an increase in population in India

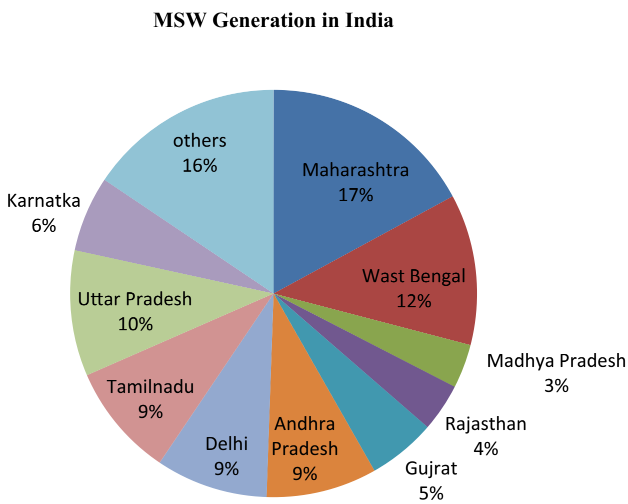

Fig. 2 Generation of MSW in India

In this context, an effective management of the MSW generated is an absolute necessity for maintaining the public health and also as a viable alternative for resource recovery [1]. However, the prevalence of open dumping and lack of suitable data regarding volume and characteristics of MSW generated combined with poor planning and inappropriate management practices are often the most significant drawbacks in designing an effective management system [14–17].

Effective system for proper management of MSW has always been of significant concern for developing countries [18]. In this context, several studies have carried out in an Indian perspective including existing generation, collection and disposal techniques [5, 19] prediction of solid waste generation in future depending on population increase [20], characterization of solid wastes [13], leachate properties generated from solid waste [21], life cycle assessment studies and design of engineered landfill sites.

Table 2 Estimated waste generation in HP [23]

Sr. No.	Year	Per capita waste generation	Urban population	Waste generated
1.	2011	0.413	736.3369	304.3
2.	2021	0.472	883.3212	416.6
3.	2031	0.538	1023.429	550.9
4.	2041	0.614	1155.249	709.6

Himachal Pradesh being a hilly terrain is the least urbanized state of India, which has only 59 urban agglomerations [22]. The fraction of total population of India residing in Himachal Pradesh is only about 0.5%. In this context, MSW generation in Himachal Pradesh (350 TPD) is significantly less than the daily generation in the country (100,000–120,000 TPD) with a per capita generation in Himachal Pradesh being 0.413 kg/day for 2011 [23]. However, there are certain distinctive features of the MSW generated in Himachal Pradesh, including many scattered small dumpsites due to scattered population, large variations in temperature making it difficult for collection, poor management practices followed primarily due to hilly terrain, and different types of waste generated during the tourist season needing specialized management [24]. Different studies carried out in Indian context suggest that the rate of increase of waste generation in India is 5% [7, 8, 22], however, the rate of increase in generation of MSW in Himachal Pradesh varies from 1 to 1.33% (Personal Communication with an official of Himachal Pradesh State Pollution Control Board (HPSPCB)) and future projections of population, and thereby waste generation using such rates are summarized in Table 2 and Fig. 3.

However, it is important to mention that the state Himachal Pradesh is home to diverse ecosystems and even such slight increase in MSW generation and without an

Table 1 Composition of MSW in Indian cities [2]

Sr. No.	Major cities	Paper	Metals	Glass	Textile	Plastic	Ash and dust	Organics	Others
1.	Chennai	5.90	0.70	–	7.07	–	16.35	56.24	13.74
2.	Delhi	5.88	0.59	0.31	3.56	1.46	22.95	57.71	17.52
3.	Kolkata	0.14	0.66	0.24	0.28	1.54	33.58	46.58	16.98
4.	Bangalore	1.50	0.10	0.20	3.10	0.90	12.00	75.00	7.20
5.	Ahmedabad	5.15	0.80	0.93	4.08	0.69	29.01	48.95	10.39
6.	Mumbai	3.20	0.13	0.52	3.26	–	15.45	59.37	18.07

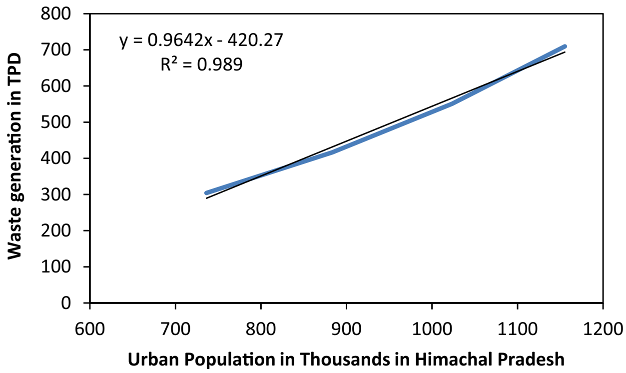

Fig. 3 Variation of MSW generated with an increase in urban population in Himachal Pradesh

effective management system is sufficient enough to make the existing ecosystem susceptible to changes. For example, forest regions in HP are being severely affected due to increase in generation of MSW making the growth of new saplings vulnerable [22]. Other associated problems in HP with increased MSW generation rates include choking of sewer pipelines primarily during monsoon seasons due to its hilly terrain, scavenging action by predatory animals and unaesthetic appearance which affects the livelihood of local people as the state is a tourist destination 'hotspot' (Personal Communication with an official of HPSPCB).

The present study focuses on the existing solid waste management systems practiced in four different sites in Himachal Pradesh, India. The study utilizes the 'wasteaware' techniques for categorizing the efficacy of the existing system. Furthermore, a matrix method has been utilized for inter-comparison of the study locations. The results obtained have also been compared with Chandigarh city which is one of the top tier-II cities in India due to its proximity to the study locations. The paper also proposes suitable remedial measures for improving the existing system of MSW management carried out at these sites. Further, no detailed evaluation studies of these locations have been reported in the literature earlier which adds to the novelty aspect of the research work carried out in the context of these locations.

Methodology

Site locations

Sunder Nagar lies in the coordinates of 31.5332°N and 76.8923°E with a population of 24,344 [25] with a MSW generation of 18–20 TPD with a collection efficiency of 60% which is open dumped in landfills.

Mandi town lies within 31.5892°N and 76.9182°E with a population of 26,422 [25] with a daily generation rate of 21 TPD of which 12.5 TPD (60% collection efficiency) is directly disposed in open landfills.

Solan town lies between 30.9045°N and 77.0967°E having a population of 39,256 [25] with a total MSW generation of 21–22 TPD of which 13 TPD (60% collection) is disposed in open landfills.

Baddi lies within the coordinates of 30.9578°N and 76.7914°E with population of 29,911 [25]. The total waste generation of the town is 18 TPD of which 11 TPD (60% collection) is disposed in non-engineered landfills.

Figure 4 shows location of respective study region of Himachal Pradesh.

The above study locations have been compared with Chandigarh city which covers an area of 114 Km^2 [5, 19] and has a population of 1.05 million as per census 2011 with a decadal growth rate of 17% [25]. The overall municipal solid waste generation in Chandigarh is 380 tons/day (TPD) [5, 19].

'*Wasteaware*' benchmark indicators

An effective management of MSW involves a 'cradle to grave' analysis. However, the major drawbacks involved in designing efficient MSW management systems are the absence of suitable and persistent data for design and evaluation of effectiveness of solid waste management system for comparative purposes. The '*wasteaware*' benchmark parameters provide a suitable platform incorporating both qualitative and quantitative indicators [26, 27] for comparing the efficiencies of different MSW management systems. The quantitative parameters includes Public Health-collection, Environmental controlled disposal and Resource Management—reuse, reduce and recycling and the qualitative indicators include governance parameters such as user and provider inclusivity; financial sustainability; and the national policy framework and local institutions [26, 27].

Evaluation using matrix method

The results obtained using the '*wasteaware*' benchmark parameters are primarily semi-theoretical. In this paper, a simple matrix quantification method has been utilized for a better understanding of the evaluation of the existing MSW management system [19]. Since the proposed grading system used in the 'wasteaware' benchmarks is low (*L*), low/medium (*L*/*M*), medium (*M*), medium/high (*M*/*H*) and high (*H*), a five-point classification has been assigned to each of these benchmarks. These are ($L=1$, $L/M=2$, $M=3$, $M/H=4$, $H=5$). Parameters excluded from assignment of such classifications include background information of the cities and the composition of the waste fraction; since they

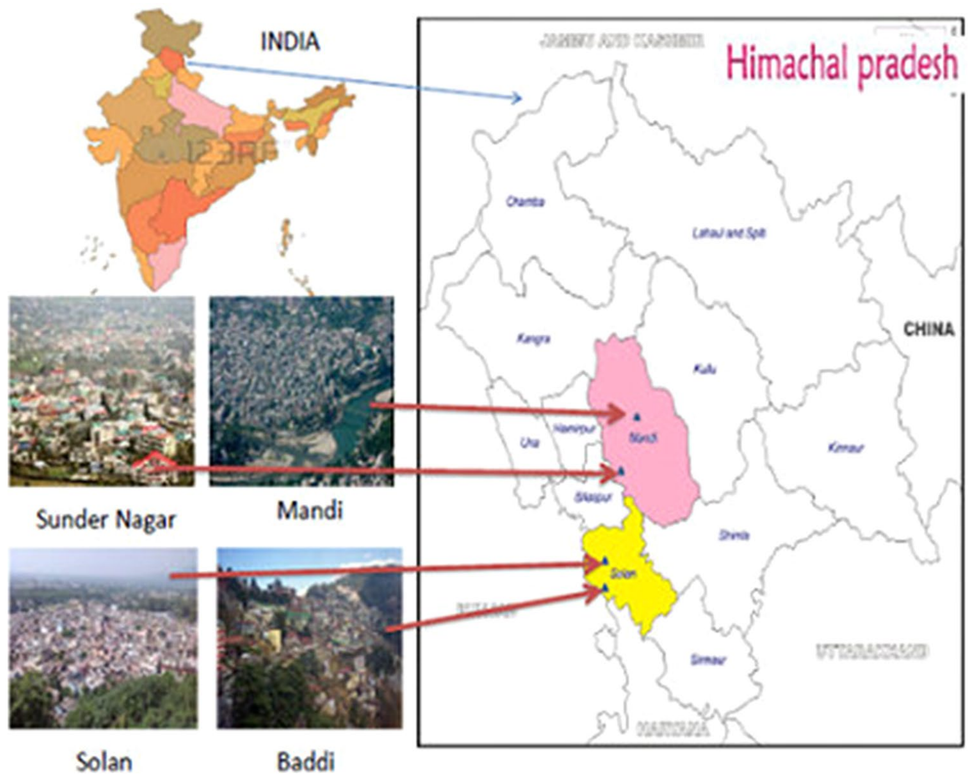

Fig. 4 Location map of study regions of Himachal Pradesh

are not utilized in the final evaluation scheme using the '*wasteaware*' benchmark parameters.

Results and discussion

Assessment of existing municipal solid waste (MSW) management at study locations

Budgetary provisions

The operating cost per ton of waste generated experienced by different districts in Himachal Pradesh has been summarized in Fig. 5. As observed from Fig. 5 the expenditure incurred by each district (and thereby each municipal corporation) in Himachal Pradesh varies greatly. From Fig. 5, it is observed that Kullu has the highest operational costs per waste generated while Paonta and Hamirpur have the lowest.. Generally, a limited budgetary provision is made each financial year for management of the MSW generated at these sites which are primarily used for payment of manpower resources with the remaining being utilized for collection purposes. As a consequence of this, there often exists a shortfall of adequate budgetary provisions which are replenished through revenue generating systems such as collection charges and implementation of adequate taxation systems [24].

Msw generation

A comparison with the reported literature shows that per capita generation of MSW in India (0.2–0.87 kg/day) is relatively low in context of other global countries such as USA (2.58 kg/day), Germany (2.11 kg/day), France (1.92 kg/day), UK (1.79 kg/day), Japan (1.71 kg/day), China (1.02 kg/day), Brazil (1.03 kg/day) and Russia (0.93 kg/day).

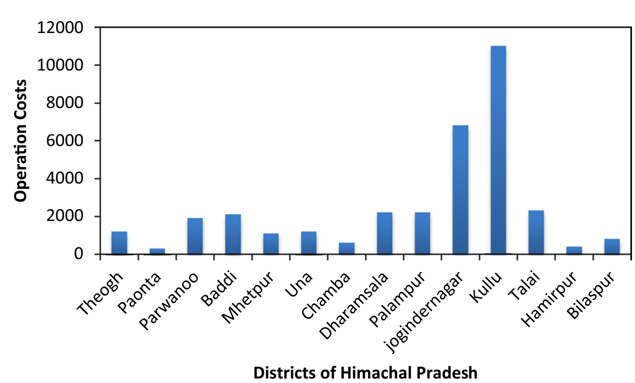

Fig. 5 Operation costs per ton of waste managed at different districts in Himachal Pradesh

The waste generation rates and the composition of the MSW of the study locations have been summarized in Table 3. It is observed from Table 3 that the per capita generation of MSW increases with increase in population in Solan and this is primarily due to slightly increased per capita generation in Solan, compared to Sunder Nagar and Mandi. In contrast, it is observed that even though Baddi has a less population than Solan its per capita generation of MSW is slightly more. This is because the Baddi study site is also the industrial hub of the state. As such, even though the population is comparatively less than Solan, the per capita generation of solid waste is slightly higher as it also includes a certain fraction of the hazardous wastes generated in the location (Personal Communication with official of HPSPCB and Baddi Municipal Corporation).

It is important to note that no detailed physico-chemical characterization of the municipal wastes generated at these four sites exists presently. However, on close inspection of waste at the dumpsites and discussion with different sweepers, rag pickers and municipal corporation officers, it was inferred that organic fraction was relatively high due to the close proximity of the dumpsites to the vegetable markets (locally known as '*Sabji Mandi*'), wherein the rotten and outdated fruits and vegetables are dumped. It is further observed that proportion of plastics in overall composition of MSW in Himachal Pradesh is relatively low with a slightly higher fraction in Sunder Nagar primarily being an education hub (schools, colleges, etc.) of Himachal Pradesh. This is because of the existing legislation in the state banning use of plastics. However, it was observed that high fraction of wood and other related materials is a major source of MSW primarily due to high fractions of agricultural land and forests within the state. It was further observed that metal and bottle waste found slightly higher in Sunder Nagar, because juice and beverage factories are installed in the town. However, a detailed physico-chemical characterization result is absolutely necessary to make an absolute conclusion regarding the waste characteristics. This is similar to other reported literature for different cities in the world, whereas a comparison with the reported literature showed less fraction of metal and bottle with studies reporting about 3% in Bhutan [28], 0.2% in Jalandhar city, Punjab [17], 0.12% in Ota, Nigeria [29] and 3% in Northern Ireland [30].

Table 3 Waste generation rate in study regions of HP

Sr. No.	City name	Population of towns	Waste generation (tones/day)	Per capita waste generation (Kg/capita/day)
1.	Solan	39,256	21.5–22	0.42
2.	Sunder Nagar	24,344	18–20	0.44
3.	Mandi	26,422	20–21	0.44
4.	Baddi	29,911	16–18	0.43

It was further observed that the practice of source segregation of the different types of MSW generated and disposed at the dumping sites were entirely absent. The entire unassorted waste generated from households and other sources were directly delivered to the respective dumpsites of the study locations. The absence of source separation techniques significantly increases the burden on the landfills, thereby effectively reducing their lifespan.

MSW collection and storage processes

An effective MSW management system can only be devised when the infrastructural setup is equally matched to handle the production of the MSW generated. However, in most of the developing countries, such as, India the existing infrastructure is ill—equipped to handle to the vast quantities of waste generated resulting in formation of open dumps [31]. In principle, the management of MSW to be handled by the municipal corporations is often under-predicted including the generation rate, and thereby in turn the finances, labour and infrastructure needed [31]. Similar such conditions were observed for our study regions.

It has been reported that door to door collection efficiency from Solan and Baddi is about 20% and from Mandi district (including Sunder Nagar town) is about 38% [24], however, further detailed investigations carried out during our study revealed that in practicality less than reported values for door to door collection existed for Solan and Baddi and almost none for Sunder Nagar and Mandi (Communication with the respective authorities of Municipal Council). Sanitation workers are assigned to each ward of the respective study locations and each of these locations have about 20–25 wards and the overall manpower involved in the collection process at all the four sites were 2.6/1000, 2.3/1000, 2.1/1000 and 3.3/1000 for Solan, Baddi, Sunder Nagar and Mandi, respectively. Hence, total manpower involved in the collection process is extremely low and highly insufficient. This is greater than about 0.9 labourers per thousand population reported for Kharagpur [31] but is less than the considered datum of 3.5 labourers per thousand for Indian conditions which are still exceedingly low [31]. Such low numbers make it almost impossible for the existing systems to operate efficiently. Further, with the collection system being entirely dependent upon the labourers it was often observed that a high percentage of absentee cases were reported primarily due to low salary, lack of motivation, and health issues. The absence of potential tie-ups of these municipal corporations with local NGO further compounds these problems. This is because local NGO often act as 'mentors' for such workers providing them training, protective equipments for safety to prevent direct contact with waste and management of salary and other benefits for such workers. Waste is generally collected by handcarts in all above said study regions.

In practice, each city has '*designates*' for official and unofficial sites for waste collection [31]. However, the absence of designated waste storages sites at these study locations lead to indiscriminate dumping of solid waste in the open dumpsite lead to major environmental concerns. The problem is further compounded by local residents in slum and low-economy areas due to less awareness environmental concerns arising from open dumping of solid waste, people thrown out waste improperly causing excessive littering which often chokes up the drainage conditions of the study areas. Further, it was observed that the total amount of waste generated at the study locations was more than that of the capacity of dustbins provided in some of the locations in the study area leading to overflow conditions. It was further observed that the municipal corporations of the study locations do not provide separate collection bins for wet and dry wastes, respectively. The problem is further compounded by insufficient number of collection bins and location of these bins in inaccessible areas, thereby reduced frequency of collections leading to an increased unsanitary condition in these regions. Further, it was observed that most of the bins utilized for the collection purposes are open bins with no cover leading to scavenging action by strays causing littering in the vicinity of these bins. The capacity of bins generally used for storage of waste at these locations is about 3 m^3. Figure 6 shows the different types of collection bins at the study locations. The overall collection efficiency of the MSW generated at the study sites was about 60%.

MSW transportation

The major problem associated with transportation of MSW is insufficient capacity and inadequate number of collection vehicles, non-maintenance, and thereby breakdown of such vehicles [31]. In practice, due to incorrect estimation of generation rates of MSW coupled with allocated budgetary provisions often maintenance and running costs of these transportation vehicles are not considered and the actual number of '*on-road*' vehicles for collection system may be considerable than the actual fleet of vehicles. Further, the absence of drivers for driving such vehicles also leads to reduced efficiency of the collection system. The total number of collection vehicles utilized at the four sites has been summarized in Table 4 along with the different types of vehicle fleets (Personal communication with Executive Officer of Municipal Committees). The density of waste reported at Sunder Nagar varies from 0.37 to 0.4 tons per cubic meter [24], and hence assuming a density of 350 kg/m^3 for all the other study locations the collection capacity per capita has been determined as shown in Table 5. Hence, the total numbers of vehicles are insufficient compared to the total volume of waste generated. Most of the collection vehicles are in dilapidated conditions with almost negligible maintenance and often almost no cleaning after dumping of the waste. Further, the tractors, trucks and dumpers utilized for the transportation systems are non-covered causing spillage on road, thereby littering them and also as a breeding ground for different disease spreading vectors. Figure 7 illustrates the transportation vehicles for the different study locations. Further, the transportation of the solid waste at the study locations was carried out in an unsystematic manner with no proper travel route management, thereby reducing the collection efficiency.

MSW disposal

Open dumping of solid waste is a severe health hazard and of environment concern due to percolation of contaminants through leachate into subsoil. All the wastes generated from the households are directly disposed off via open dumping, and no preventive measures are practiced for environmental contamination in the study regions. The different dumpsites located at the study locations have been shown in Fig. 8. For our study location in Solan and Baddi region, it is observed the total land available for the waste disposal is 5 acres with the operations at these landfill sites starting in 1998 (Personal communication with the authority of municipal council of respective study region). For the other two sites in Sunder Nagar and Mandi, the dumping operations started in 1994 and 1991 covering an area of 5 and 6 acres, respectively. Survey an inspection of the MSW dumpsites at all the four sites revealed that the dumped wastes were heterogeneous in nature. However, on discussion with several sweepers and municipal corporation officials it was inferred that some informal recycling takes place with about 5 to 10% of the disposed waste being recycled (Personal communication with the authority of municipal council). Hence, it can be safely reported that recycling and reclamation of wastes are almost negligible at all the study locations. The authority of municipal council of the respective towns should promote the formal recycling facilities in the town. Interestingly, at all the four dumpsite locations, the dumped waste is not covered by any protective layer (soil, silt) and is totally exposed to atmosphere, and thereby a environmental concern and breeding ground for disease spreading vectors. Moreover, no further treatment of waste is practiced including composting and incineration due to lack of infrastructure facilities available in the study regions (Sunder Nagar, Mandi, Baddi and Solan) of Himachal Pradesh.

In an overall sense, the prime cause for low efficiency in the management of MSW generated at the four study locations is due to insufficient manpower resources, lack of infrastructure including collection and storage lack of machines and collection equipment and no treatment procedures followed.

(a) Baddi **(b)** Solan

(c) Sundernagar **(d)** Mandi

Fig. 6 Collection bins at our study locations in HP

Table 4 Number of vehicles for transportation of waste in study regions of HP

Sr. No.	Type of vehicles	Solan	Mandi	Sunder Nagar	Baddi
1.	Trucks	2	2	2	2
2.	Dumper placer	3	2	1	1
3.	Compactor	1	1	1	1
4.	Tractor	2	2	2	1
5.	Three-wheeler	3	3	3	2
6.	Maruti Van	–	–	2	–
7.	Backhoe loader	2	2	–	1
8.	Twin lift	–	1	–	–

The following observations were further confirmed using the 'wasteaware' analysis results discussed below in the next section.

'*Wasteaware*' benchmark indicators for sustainable waste management in Himachal Pradesh

System analysis using 'wasteaware' benchmark indicators

It is observed from Table 6 that overall MSW generated at the four study locations are considerably much less than the overall MSW generated in Chandigarh. This is primarily because of the huge difference in population between Chandigarh and the study locations. (subsection B2 in Table 6). Though detailed physico-chemical characterization of MSW has not been carried out in Himachal Pradesh reported

Table 5 Collection capacity per capita of waste in study regions of HP

City name	Population of towns	Per capita waste generation (Kg/capita/day)	Collection capacity (m^3/day)	Collection capacity per capita (m^3/day)
Solan	39,256	0.42	47.11	0.0012
Sunder Nagar	24,344	0.44	30.60	0.0013
Mandi	26,422	0.44	33.22	0.0013
Baddi	29,911	0.43	36.75	0.0012

(a) Baddi **(b)** Solan

(c) Sundernagar **(d)** Mandi

Fig. 7 MSW transportation vehicles at our study locations in HP

(a) Baddi (b) Solan

(c) Sundernagar (d) Mandi

Fig. 8 Open dumpsite for MSW disposal at our study locations in HP

values mention that it consists of high fractions of organics similar to those of other cities in South East Asian country including India and as similarly observed in comparison to Chandigarh. Further, it was observed from 'wasteaware' benchmark parameter evaluation that our study locations have less waste collection efficiency and waste collection services (Public Health parameters) and can be categorized in low/medium index (L/M) as compared to Chandigarh city having collection efficiency lies in medium/high index (M/H) [5].

Interestingly, for rest of the quantitative parameters (Environmental control and 3R's) the study locations along with Chandigarh were categorized in low index. The wasteaware analysis also reveals that there exist almost no recycling provisions in the study locations.

Quantification of indicators using matrix method

Using the matrix method, the 'weights' have been assigned to both quantitative and qualitative parameters of '*wasteaware*' benchmarks for all the study locations which has been summarized in Table 7 and also has been compared with Chandigarh city. The overall results for Solan and Baddi sites were 32% and for Sunder Nagar and Mandi sites were 36%. These were significantly lower than Chandigarh (overall score of 46%) as observed from Table 8. The matrix analysis also reveals that overall management of MSW generated at our study location can be categorized as low and that for Chandigarh as L/M. Further analysis revealed that weightage obtained from quantitative parameters of 'wasteaware' analysis were same for all the study locations (30%), whereas it was slightly more Chandigarh (40%) as it is a planned city, and thereby has a slight advantage in comparison to other tier-II and tier-III cities [19]. Interestingly, it was observed that for governance

Table 6 'Wasteaware' benchmark parameters for selected study sites in HP

No.	Category	Indicator	Solan CityResults	MandiCity	SundernagarCity Results	Baddi Town Results	Chandigarh City Results
BackgroundInformationof the City							
B1	CountryIncome Level	WorldBank Indicator Level	Lower-Middle	Lower-Middle	Lower-Middle	Lower-Middle	Lower-Middle
		GNI per Capita	$1,420	$1,420	$1,140	$1,140	$1,140
B2	Population oftheCity	TotalPopulation oftheCity	39,256	26,422	24,344	29,911	1,055,450
B3	WasteGeneration	MSWGeneration (tons/year)	8030	7665	7300	6570	135050
W1	Waste perCapita	MSWper capita(kg peryear)	153.3	160.6	160.6	157	128
W2	Waste Comp	3keyfractions–as % wt.oftotalwaste generated					
W2.1	Organic	Organics (foodandgreen wastes)	56%	54%	52%	52%	52%
W2.2	Paper	Paper	18.2%	20%	18%	16%	6%
W2.3	Plastics	Plastics	14.50%	15%	12%	13.5	7%
1.1	Public health –Wastecollection	Wastecollectioncoverage	60% (L/M)	60% (L/M)	60% (L/M)	60% (L/M)	90% (M/H)
1C	-	Qualityof wastecollection service	81% (M)	79%(M)	77% (M)	74% (L/M)	90% (M/H)
2	Environmentalcontrol–	Controlledtreatment	30% (L)	30% (L)	20% (L)	17% (L)	30% (L)
2E	-	Degree	0% (L)	0% (L)	0% (L)	0% (L)	0% (L)
3	3Rs–reduce,reus	Recycling rate	0% (L)	0% (L)	0% (L)	0% (L)	0% (L)

Table 6 (continued)

3R	-	Qualityof 3Rsprovision	10% (L)	15% (L)		10% (L)	10% (L)		17% (L)	

Governance Factors

4U	Useri nclusi	Userinclusivity	69%		70%		55%	52%		75% (M)
4P	Provi der inclusi	Degree of provider inclusivity	65% (L/M)		66%(L/M)		60% (L/M)	61% (L/M)		78% (M)
6N	Sound instituti ons,pro	Adequacy of national SWM framework	55% (L)		58% (L)		55% (L/M)	52% (L/M)		60% (L/M)
6L		Degree of institutional	62% (L/M)		65% (L/M)		72% (M)	58% (L/M)		75% (M)

parameters both Mandi and Sunder Nagar scored 45%, whereas Solan and Baddi scored 35% but were significantly lower than Chandigarh (55%).

Key recommendations for improvement of municipal solid waste management at the selected study locations

It has been observed from the above matrix analysis that the overall waste management efficiency at all the study locations is extremely poor with the overall scores being less than 40% at all the selected study locations. The following are some of the key recommendations for improvement of existing MSW management system in HP. Some of these recommendations have already been suggested for implementation in the entire state of HP as per report prepared by Ministry of Urban development of Himachal Pradesh [24]. We have incorporated some few more suggestions based on our study.

Segregation at source

It was observed during the process of conducting the study that source segregation during the initial collection process from the different households in the study locations was completely absent. Source segregation is the first and most important procedure in designing an effective MSW management system. Importantly, it is neither a time consuming nor a costly process and can be effectively implemented at the household levels. Unsegregated wastes are highly undesirable as it affects the treatment process of the waste. For example, incineration of plastics can lead to emissions of dioxins.

Segregation of waste into two primary categories of waste (biodegradable and non-biodegradable) helps immensely in streamlining the treatment process. The non-biodegradables (also inert) can be further segregated into different types such as paper, plastic glass and metal, and thereby provide immense opportunity for rag pickers and waste traders for income generation by the 'informal recycling processes' as they become 'material supplier' to such existing industries. This leads to production and thereby use of such recycled products in the public mainstream, thereby leading to economic viability of the process.

As reported earlier, majority of the MSW generated in Indian conditions are organic in nature, and thereby highly amenable to biodegradation process for generation of energy. Anaerobic treatment of such waste can lead to generation of methane, and hence biomethanation plants should be installed for generation of biogas which can be utilized as an energy source. Further, the compost generated is a good source of nutrients and can be effectively used as a natural fertilizer.

As such, segregation of waste leads to diverse benefits including reduced consumption, increased economic potential for rag pickers and waste traders and economic investments. Further, they reduce the burden on landfill, thereby increasing the lifespan of the existing landfills and also reduce GHG emissions. In this context, due to such multifaceted advantages of segregation, it is highly recommended to be initiated at all the households within the purview of the study locations and also in all districts of HP as a whole

Table 7 Weightage assignment for evaluation using matrix method

No.	Category	Indicator	Solan town results	Mandi town results	Sunder Nagar town results	Baddi town results	Chandigarh city results
Quantitative indicators (public health, environmental control, 3R)							
1.1	Public health—waste collection	Waste collection coverage	60% (L/M) (2)	60% (L/M) (2)	60% (L/M) (2)	60% (L/M) (2)	90% (M/H) (4)
1C		Quality of waste collection service	81% (M) (3)	79% (M) (3)	77% (M) (3)	74% (M) (3)	90% (M/H) (4)
2	Environmental control—waste treatment and disposal	Controlled treatment and disposal	30% (L) (1)	30% (L) (1)	20% (L) (1)	17% (L) (1)	30% (L) (1)
2E		Degree of environmental protection in waste treatment and disposal	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)
3	3Rs—reduce, reuse and recycling	Recycling rate	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)
3R		Quality of 3Rs provision	10% (L) (1)	15% (L) (1)	10% (L) (1)	10% (L) (1)	17% (L) (1)
Qualitative indicators (Governance Factors)							
4U	User inclusivity	User inclusivity	69% (L/M) (2)	70% (M) (3)	55% (L/M) (2)	52% (L/M) (2)	75% (M) (3)
4P	Provider inclusivity	Degree of provider inclusivity	65% (L/M) (2)	66% (L/M) (2)	60% (L/M) (2)	61% (L/M) (2)	78% (M) (3)
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	52% (L) (1)	58% (L/M) (2)	55% (L/M) (2)	52% (L) (1)	60% (L/M) (2)
6L		Degree of institutional coherence	62% (L/M) (2)	65% (L/M) (2)	72% (M) (3)	58% (L/M) (2)	75% (M)

Table 8 Summary of scores obtained using matrix method

No.	Category	Indicator	Solan town results	Mandi town results	Sunder Nagar town results	Baddi town results	Chandigarh city results
Quantitative indicators (public health, environmental control, 3R)							
1.1	Public health—Waste collection	Waste collection coverage	2	2	2	2	4
1C		Quality of waste collection service	3	3	3	3	4
2	Environmental control—waste treatment and disposal	Controlled treatment and disposal	1	1	1	1	1
2E		Degree of environmental protection in waste treatment and disposal	1	1	1	1	1
3	3Rs—reduce, reuse and recycling	Recycling rate	1	1	1	1	1
3R		Quality of 3Rs provision	1	1	1	2	1
Total score (quantitative indicators)			9	9	9	9	12
Maximum score			30	30	30	30	30
Weightage (%)			30	30	30	30	40
Qualitative indicators (Governance Factors)							
4U	User inclusivity	User inclusivity	2	3	2	2	3
4P	Provider inclusivity	Degree of provider inclusivity	2	2	2	2	3
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	1	2	2	1	2
6L		Degree of institutional coherence	2	2	3	2	3
Total score (qualitative indicators)			7	9	9	7	11
Maximum score			20	20	20	20	20
Weightage (%)			35	45	45	35	55
Total score (Overall)			9 + 7 = 16	9 + 9 = 18	9 + 9 = 18	9 + 7 = 16	12 + 11 = 23
Total maximum score			30 + 20 = 50	30 + 20 = 50	30 + 20 = 50	30 + 20 = 50	30 + 20 = 50
Overall weightage (%)			32	36	36	32	46

for better management of MSW. This can be achieved by conducting training, workshops and awareness campaigns across the study locations and the entire state of HP.

The principle of segregation at source has already been successfully implemented in Tirunelveli municipality in Tamil Nadu, Pune municipality in Maharashtra, Alappuzha in Kerala and in Panjim city. Further, municipalities of major metropolitan and tier-I cities and top tier-II cities such as Chandigarh are already in preparation of draft guidelines of implementation of segregation of source at household levels which would enable these municipalities for a better and more effective system of waste management.

Installation of transfer stations

It has been observed in HP that there exists small scattered dumpsites along the entire state. Such increased scattered dumpsites are difficult to manage and hence there should be installations of transfer stations for waste sorting. They are also deemed necessary at the study locations due to hilly terrain conditions with road connectivity the major thoroughfare. Hence, if any problem arises after collecting of waste (such as vehicle breakdown) nearby transfer stations could be of immense help. The primary objective of these transfer stations should be to ensure that all recyclables (both organic and inorganic) are completely separated and only inerts are dumped in the landfill sites. This will substantially increase the lifespan of the landfill and will lead to 'zero waste'.

Transfer stations are already in existence at majority of the metropolitan and tier-I cities in India because majority of the dumpsites are located at considerable distances from city premises. For example, Pune city has been about seven transfer stations serving the entire waste generated in the city. The major problem is in having adequate number of transfer stations to handle the quantity of waste generated. For example, even though Indore city in Madhya Pradesh needs four number of transfer stations to effectively manage its waste; it presently has only one transfer station in operation. Further, often due to the absence of sufficient land to construct transfer stations; certain municipalities utilize mobile compactor trucks with primary collection vehicles for improving the systems until permanent transfer stations can be constructed. Such systems are in existence in Surat and Kanpur in Uttar Pradesh.

Waste collection from other sources

One significant observation made during the survey and interactions carried out during the study were that no wastes generated from other sources (such as hotel, agricultural) were included with MSW before dumping them in landfills. However, to achieve a 'zero waste' in the state it is necessary to take care of such wastes. Possibilities include treatment of such waste in biomethanation units as such wastes are rich in organic and nutrient contents.

In our study locations, the hotel and agricultural wastes are classified as '*side stream wastes*' (i.e. not a component of mainstream MSW) and there is lack of sufficient data detailing the generation rates of such wastes. In actual practice, the agricultural wastes are either disposed of by incineration or are recycled for nutrient to the farmland. The food wastes generated are often disposed by incineration (i.e. burning of biomass leading to causes of severe air pollution) or in some cases local composting or vermicomposting methods are followed. Even though both the methods of composting and vermicomposting are effective, the success of these methods in actual reality is unknown due to the lack of factual data on these 'side *stream*' generations.

Reduction of waste at source and implementation of practices of 4R's

The implementation of the principle of 4R is highly desirous for effective management of MSW primarily for developing countries such as India [31].

The first component involved in 4R is *Reduction*. The basic principle involved in this is utilization of lesser quantity of raw products for manufacturing without compromise on quality. As such, it should be promoted in the study locations along with the entire state of HP. This includes using rechargeable batteries instead of disposable ones, using refilling techniques for food and other such examples [31]. Further, it should be promoted that longer lifespan materials be used for manufacturing of products and promotion of such products should be promoted at the study locations to reduce the burdens on the landfill sites. This include promotion of plastic products for certain cases (such as plastic furniture) instead of using wooden material (even though it highly abundant in the state) and less utilization of any such material which could increase the burden on the landfill.

The municipal corporations located in the study locations should promote the concept of *reuse* in the public domain as it involves monetary benefits. This includes products made of cardboard, plastics, jute, glass and other recyclable materials.

The matrix method of evaluation of the existing system showed that only a very small fraction of 5–10% is recycled at the study locations. *Recycling* and *recovery* of components such as paper, plastic and glass presents in the MSW will considerably reduce the load on the landfills and can also be an 'income generator' for rag pickers. The efficiency of the recycling process depends on the efficiency of source segregation and further on the diligence of the rag pickers. As such, the municipal corporations in the study locations should ensure that such process should be carried out under strict supervision probably in association with local NGO. Combined recycling units for Solan and Baddi and Sunder Nagar and Mandi locations could be setup to serve these towns. Setting up of such recycling units at these locations would require an initial investment of 20–25 lakhs INR ($30,000 to $40,000) the cost of which can be recovered over the entire lifespan of the recycling unit as such processes are revenue generating, and hence also increase the life span of the waste dump. Finally, the lack of sufficient waste collection and transportation infrastructure could severely affect the efficiency of the process.

The concept of application of 4R's is still new in India. For example, it has been reported that the total amount of household waste recycled in India is only 15%. However, there exist certain stand alone achievements of recycling of wastes. For example, construction wastes (classified as inert waste) is an important component of the characterization of municipal solid waste in major cities often accounting for 20 to 30% of solid waste generated in major metropolitan and tier-I cities in India but only one single construction waste recycling facility at Burari exists in the country till date. Though, the government of India had notified that such facilities should be set up in all cities with population exceeding 10 lakhs, it has still not been implemented in such Indian cities. Another such success story of recycling activity is in Jamshedpur city in Jharkhand state, wherein recycled plastics have been utilized for road construction. The major advantage of this is: no maintenance costs are required for the first five years.

Waste audit

One major significant drawback in designing an effective MSW management system at these study locations is the absence of reliable data including the amount of waste generated, the physico-chemical properties of the waste and the different waste sources. Hence, conducting a waste audit by the municipal corporations is of immediate importance at these study locations (and the state of HP) to establish the potential benchmark (existing) data. Further, it is recommended that such annual audits should be carried out to check the variations in the data recorded and act accordingly as per the requirement.

It is important to note that our study locations in Himachal Pradesh are tourist '*hotspots*', and hence are subjected to transient populations leading to expected changes in consumption levels, and thereby waste generation and alteration in composition and types of waste generated. To account for this, the waste audit analysis should be carried out over different seasons in the year to record for any seasonal variations in waste generation rate and its characteristics taking place due to more influx of tourists. For example, during summer due to more influx of tourists, the generation rate and the characteristics of the waste could vary significantly from the winter due to lesser number of tourists. In this context, stratified random sampling methodology should be implemented to obtain bias free results. Further, the annual generation rate per capita can be computed from the seasonal generation rates. This in turn will give a more robust assessment and will be incorporative of the floating population.

Improvement in existing infrastructure and labour resources

The above study has shown that the existing infrastructure including manpower is completely insufficient for adequately managing the MSW generated at the study locations. Reported recommendations [24] suggest use of colour coded and well informed *underground bins* for collection of MSW with such bins located within 100 ms of each other. Separate bins are to be utilized for biodegradables and plastic waste and such bins will ensure convenience to general public to dump their wastes accordingly. The suggestion of using underground bins was given due to scarcity of sufficient manpower. However, it was observed at our study locations that the ground reality is very different and no such recommendations are currently being implemented nor is the timeframe known by which it will be truly working.

Hence, in this context for present situation it is suggested that the municipalities of the study locations should take appropriate steps to avoid littering of waste that cause environment pollution. It should be ensured that sufficient number of bins be appropriately located for waste collection so that no waste overflowing of these bins take place, thereby avoid littering on roads. Use of covered bins will significantly reduce littering and also prevent the scavenging action of animals and minimise breeding of disease spreading vectors.

Moreover, education about maintaining cleanliness in public areas must be made mandatory in these study locations.

The report [24] further recommends special collection vehicles for transportation of the organic components to the biomethanation plants. However, as mentioned earlier since none of these recommendations are currently in practice at ground levels at the study locations, to improve the existing system it is suggested that municipal council should take extreme care regarding timely and proper maintenance of the worn out and exhausted vehicles so that wear and tear losses of vehicle can be avoided. Further, it is suggested that sufficient number of vehicles, machines and manpower should be provide by the authority of municipal council so that work efficiency can be increased and in turn waste management system can be improved. Adequate training should be provided to the rag pickers to ensure increased efficiency of segregating the wet and dry waste (biodegradable) and dry waste (recyclable waste) that would help in improving the efficiency of solid waste management, and moreover, it would provide substantial job opportunities for the informal waste collectors or rag pickers. Further, proper protective equipment should be provided to such labourers to prevent direct contact with waste and motivational talks; income potential and salary should be negotiated properly utilizing local NGO's. Finally, it is suggested that engineered landfill sites be constructed at all the study sites with proper installation of leachate and gas collection systems.

Installation of biomethanation plant

It has been widely reported that the major constituents generated in domestic MSW in India primarily consist of biodegradable organics. Such biodegradable organics can be utilized to generate biogas which can be used as source for energy since methane is one of the major constituents of biogas. Utilization of biogas for energy purposes can significantly reduce power bills and the manure generated from running such plants can be utilized as a natural fertilizer.

However, it is important to note that production of biogas works under anaerobic process best under thermophilic and mesophilic ranges of bacterial reactivity even though it can still work in the psychrophilic range. However, temperatures in our study locations often fall below zero degree (i.e. less than psychrophilic range) during the winter periods reducing the reaction rate of anaerobic bacteria to almost become zero and non-production of biogas. As such, during such winter conditions sufficient heat insulation should be maintained in the digester to ensure biogas production.

Considering our study locations, two biomethanation plants can be installed. One biomethanation plant can serve the study locations of Solan and Baddi and other the regions of Sunder Nagar and Mandi. Further, waste streams from other sources (hotel wastes, agricultural wastes etc.) can be utilized for increasing the efficiency of the biomethanation plant as they are rich in organic content. This has also been recommended in a separate study [24].

Biomethanation plants installed in India generally use the Nisargruna technology developed by Bhabha Atomic Research Centre (BARC). Presently, there exist about 250 biomethanation units distributed all over India with different capacities ranging from 0.25 TPD to 20TPD, generating biogas as potential source of fuel and manure as natural fertilizer.

Installation of RDF units

An exact physico-chemical compositional analysis of the MSW generated at these four site locations is absent. However, depending upon the topography and the expected overall composition (consisting of inert and other miscellaneous materials) a refuse derived fuel (RDF) plant could be set up at the existing study locations. While one plant can be effectively set up for Sunder Nagar and Mandi regions (and wastes collected from other surrounding areas) another can be effectively set up for Solan and Baddi regions (and other surrounding areas) for treatment of such wastes for generation of RDF.

In principle, a wide scope exists in India for installation and use of RDF units. For example, RDF generated in India could be utilized as a suitable alternative to existing fuels in different industries including boiler and hot air generators (HAG). Further, the calorific values of RDF (about 3500 kcal/kg) are much better than the low quality coal (1750 kcal/kg) utilized in industry, thereby compensating the costs involved in its procurement (about Rs 2500 per ton) in comparison to coal (about Rs 1500 per ton) making it a more viable option. Only one RDF plant exists in the entire north India located in Chandigarh and functioning under the name 'Greentech Fuel Processing Plant'. The RDF generated from the plant has a calorific value of 3100 kcal/kg with moisture content less than 15%. It has the capacity to handle about 500 TPD of waste on a daily basis.

Utilization of plastic waste and inert material

Cities in India generally have a high content of inert and miscellaneous waste including plastic which is now finding use as aggregates for construction of pavements. In this case, we recommend utilization of waste plastics in two categories. It is important to note that HP state has been declared a non-plastic state. However, plastic is used for different packaging materials and maybe found in a slightly higher proportion in Sunder Nagar and Mandi due to burgeoning educational hub at these study locations.

As per the latest National Highway Authority Report of India, the state of HP is set to be upgraded and better connected by road networks and maintenance of existing road networks. In this context, the waste plastics, inert (non-suitable for RDF) and other non-biodegradable wastes could be used as possible binders for construction of road. Another possible use of such waste plastics is in the cement factory located in Barmana, wherein they can be transported in clusters (collected from different locations) and can be burned in the kilns and the incinerated wastes can be used as admixtures in the cement production.

Construction of engineered landfills

Finally, it is recommended that engineered landfill facilities with proper leachate collection system, liner system, gas collection system and final cover system should be incorporated in the towns of Himachal Pradesh for better management of solid waste system.

An engineered landfill site is highly effective in the management of municipal solid waste generated. The biggest engineered landfill site exists in Gyaspur in Ahmedabad having the capability to handle about 1.15 million tons of waste.

Sustainability of the proposed technologies

The sustainability of the above proposed technologies generally follows a hierarchical system for proper management of the generated waste. In practice, source reduction and reuse are the most sustainable approach. This in turn, is followed by sound recycling process systems as they are more economically viable than energy recovery processes of waste. However, with large volumes of waste being generated in both developing and developed countries, a sufficient quantity of waste materials are still left as residue after completion of recycling process, thereby making energy recovery processes more justified and economically feasible than dumping of these residual wastes to the open landfill sites. This is primarily because the residual waste after the recycling process has high calorific value content. Further, the waste to energy generation process (WTE) can be subdivided in two components; generation of methane gas from biomethanation plant using organic fraction of the residual waste and utilization of RDF facilities for energy generation from non-biodegradable fraction of the residual waste. Presently, determining the optimum conditions between recycling and implementation of waste to energy (WTE) techniques of the generated wastes are being researched. In essence, we should consider the generated MSW as a useable resource rather than a burden requiring disposal.

Implementation of key recommendations for improvement of municipal solid waste management at the selected study locations

Since it has been already established that the disposal sites in HP are scattered, the implementation of an integrated MSW management system in a cluster approach would be highly beneficial for the study locations [32]. The cluster approach would basically involve setting up of an integrated MSW plant, incorporating the key recommendations made in the above sections covering different locations. For example, for our study locations two clusters could be implemented, one covering the Sunder Nagar and Mandi regions and the second cluster covering the Baddi and Solan regions incorporate a comprehensive integrated MSW management system. Figure 9 shows a schematic diagram which can be effectively used for setting up of an integrated MSW management system at our study locations.

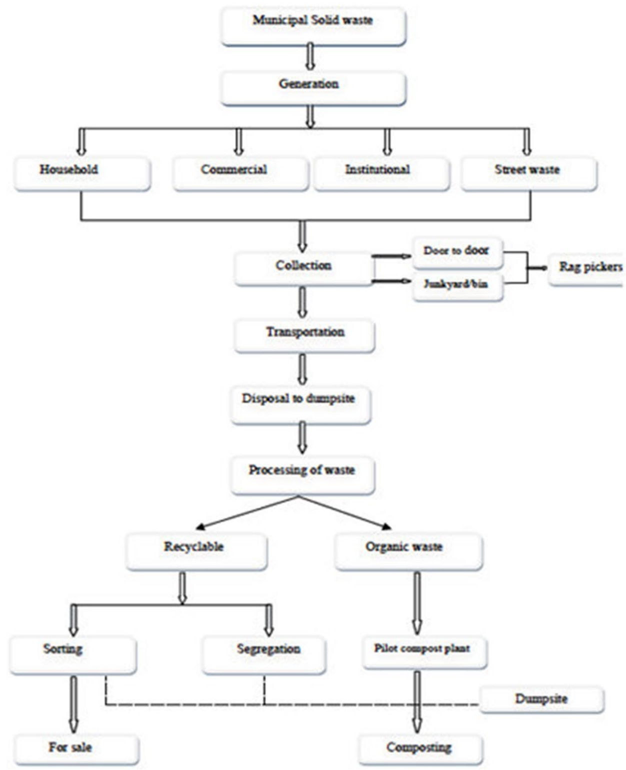

Fig. 9 Schematic diagram of proposed Integrated Solid Waste Management System at the study locations in HP

Further, it is proposed that the integrated MSW management system should be self sufficient in regards to operational and maintenance expenses. In this context, a detailed integrated cost benefit analysis should be carried out including financial modelling of the proposed system. This could be achieved through collection of user charges and implementation of proper recycling schemes resulting in financial sustainability. A separate contingency fund should be set aside separately to deal with any sudden implications. A portion of the excess fund generated should be set aside and a certain portion should be reinvested back for further upgradation or innovative applications. Finally, the integrated MSW management plant should have a "comprehensive integrated solid waste management plans" that includes financial mechanisms, monitoring, risk assessment, social development, research and development, education and training and even disaster management.

Conclusion

The overall study showed the daily waste generation rate in Himachal Pradesh is 350 tons/day, whereas on the other hand, daily waste generation rate in each study region of

Himachal Pradesh (Sunder Nagar, Mandi, Baddi and Solan) is reported in the range of approximately 18–22 tons/day. The collection efficiency of waste in the respective towns is reported 60–70% that proves inefficient for the proper waste management system. The study revealed that low collection efficiency of the waste in the study regions because of insufficient number of collection bins, inappropriate machines and equipment, lack of manpower, lack of transportation vehicles for waste disposal, etc. The paper also emphasized the 'wasteaware' benchmark indicators and matrix method for quantification analysis of system for each respective study region of Himachal Pradesh. The results clearly showed the poor performance of environmental control methods including collection and treatment of waste, disposal of waste, 3R's facilities, etc., in Himachal Pradesh. Further, the paper suggests some initiative and remedial steps that must be taken by municipalities of the study locations for the better enhancement of solid waste management including sufficient number of dustbins to avoid littering, timely and proper maintenance of worn out vehicles, start-up of latest machines and equipments for segregating and recycling facilities. Moreover, there is no such provision of lining system and leachate collection and removal system for better handling of leachate generation.

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