CHARACTERIZATION AND WASTE TO ENERGY TECHNIQUES FOR IMPROVING MUNICIPAL SOLID WASTE MANAGEMENT IN UNA TOWN, HIMACHAL PRADESH, INDIA–A CASE STUDY

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ABSTRACT

In this study the characterisation of municipal solid waste (MSW) and the potential energy content is estimated for an agricultural town Una (Tier-IV city) of Himachal Pradesh located in Northern region of India. The MSW samples from the dump site were collected seasonally to analyse the physical and chemical (proximate, ultimate and heavy metal analysis) characteristics. The average waste generation in the study area is 6 tonnes /day with per capita generation waste of 0.29-0.32 kg/day. The physical characterisation revealed that the waste generated in the study location is rich in organic content (56%) followed by the plastic (10.3%) and inert materials (10.5%). It was observed from the results that average MSW composition varies with respect to time and seasons. The presence of heavy metals in waste was found to be in lower concentrations but could be a cause of concern in the future. The average calorific value for the study location was determined to be 2263 kcal/kg which is sufficient enough to be utilised for energy recovery from waste. The energy content (calorific value) in MSW is high due to presence of food waste, paper, plastic which makes it suitable for installation of energy recovery and waste to energy units. Further the average C/N ratio was determined to be 22.72 which are indicative that the MSW generated is suitable for treatment of organics including composting and energy generation. On the basis of waste characterisation and energy content results; suitable alternative options for utilization of energy value of waste for entire Una city and district were compared and appropriate Waste to Energy (WTE) techniques were suggested.

Keywords: Characterisation, Municipal solid waste, Proximate Analysis, Ultimate Analysis, Energy Content, Calorific Value

INTRODUCTION

Waste management is an integral part of the society and its proper management falls under the purview of urban local bodies (ULB) or municipalities of different cities in developing country. Solid waste generation and composition and thereby selected treatment measures varies within countries and are influenced by prevailing waste management systems, economic conditions, rate of urbanisation, habits and life style of the people (Thitame et al., 2010; Shekdar, 2009). Further, due to the increased urbanization, migration from village to cities has rapidly increased leading to additional increase in generation of the MSW (Sharholy et al., 2007; 2008).

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The waste generation across the globe is estimated to be 1.3 billion tonnes per year and is expected to increase approximately 2.59 billion tonnes annually by 2030 (World Bank, 2012;2018). The municipal solid waste (MSW) generation accounts for about 13.3% of the total waste generated across the globe and are expected to increase at a much higher rate (TERI 2015; Joshi and Ahmed, 2016). The total waste generated comprises of waste from agriculture, waste from the industries and mining sectors and hazardous waste (Khajuria et al., 2010).

In this context, generation of waste in developing countries is of significant concern due to increased population, burgeoning economy and rise in living standards (Singh et al., 2011a; Al-Khatib et al., 2010). The overall generation of Municipal Solid Waste (MSW) in India is about 1, 45,626 metric tons per day (Mtpd) (CPCB 2016) The growth rate of population for India in last decade was 17.6% (Census 2011) with an average waste generation rate of 0.3-0.6 kg/day with an increasing rate varying between 1-3% per year (Rana et al., 2015). The waste generated in different parts of country has been reported to show a high fraction of organic matter varying between 35-60% followed by about 6-10% other materials like paper, plastic, metal etc. (Khajuria et al., 2010). The waste generation rate in India for projected year 2001 to 2051 is shown in Figure 1 and was estimated to be increased by 146% with increase in population (CPCB 2012; TERI 2015). The total urban population in India is about 377 million accounting 31% of total population, generates about 1,43,449 Mtpd (Khajuria et al., 2010; Census 2011; Joshi and Ahmed, 2016).

The trend of urbanisation and composition of MSW in urban India is given in Figure 2 and Table 1, respectively. The waste generated in developing countries have higher fraction of organic waste containing high moisture content and density than developed countries because of food and related cultural habits (Joshi and Ahmed, 2016; Hoornweg et al., 2013; Srivastava et al., 2014a). About 90% of waste collected in India is directly disposed in the open dumps without any prior treatment (Sharholy et al., 2008; Joshi and Ahmed, 2016). The mismanagement of existing MSW generated in India is due to multifarious reasons including lack of data pertaining to accurate generation rate which in turn affects the allotment of resources for proper management of waste. Further, a reduced budgetary provision associated with MSW management also reduces the efficiency of the system (Srivastava et al., 2014b; Rana et al., 2017). Further, non-segregation of waste and improper practises of composting leads to poor quality of compost and improper utilization of waste to energy (WTE) facilities, like refuse derived fuel (RDF) units and bio-methanation plants, which suffer significant problems (Rawat et al., 2013; Lohri et al., 2014). MSW management systems function best in metro and Tier-I cities in India, albeit their efficiency being significantly less than other developed cities of the world. However, the Reserve bank of India (RBI) has classified the Indian cities into different tier (I to VI) based upon the population. Further, in this context, several characterisation studies have been carried out for important tier II cities in India like tricity of Chandigarh, Mohali, Panchkula (Rana et al., 2018), Jalandhar (Sethi et al., 2013) and for some other study locations in Himachal Pradesh (Sharma et al., 2019).

Hence, characterization of waste is important for selecting the appropriate methods for proper treatment of waste and management practises to be employed for waste management. The waste characterisation studies have already been conducted at different household levels (Rawat et al., 2013; Rana et al., 2018; Gomez et al., 2009) and thus provide a waste stream and waste management program is enabled for local needs (Rawat et al., 2013; Sethi et al., 2013; Chandrappa and Das, 2012; Pattnaik and Reddy, 2010; Saha et al., 2010). Also, for considering the sustainable waste management, reduction in the amount of biodegradable waste being disposed in landfill needs to be done as followed by western countries (Abu Qudais M and Abu Qudais HA, 2000; Khan and Ali, 1991). It also requires the consideration of energy recovery, economic value of MSW through various processes like recycling, combustion, pyrolysis, refused derived fuel (RDF) (Akkaya and Demir, 2009; Korzun EA, 1990). The waste to energy technologies (like biological treatment, landfill gas utilization, thermal treatment etc.) especially for developing nations are efficient techniques to turn waste into energy (Moya et al., 2017). The designing and operation of energy conservation systems requires estimation of energy content of MSW (Akkaya and Demir, 2009; Peavy et al., 1985) in order to save time and decrease the cost in designing and operation of engineering applications. In this context, the characterisation of waste is important to analyse nature of the waste. The characterisation of waste depends on various factors as food habits, different seasons, commercial status of the city, living standards of the people and other associated factors (Rana et al., 2018). The policy

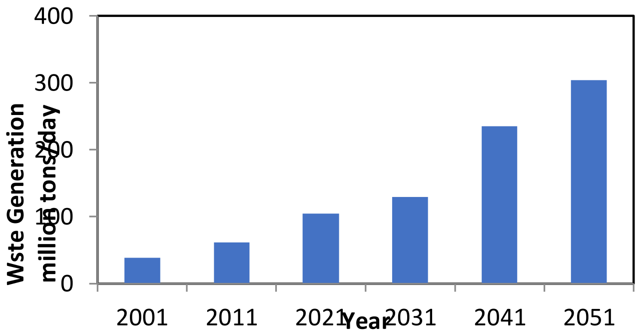

FIGURE 1
Estimation of waste generation in India in projected years (2001-51) (CPCB 2012; TREI 2015)

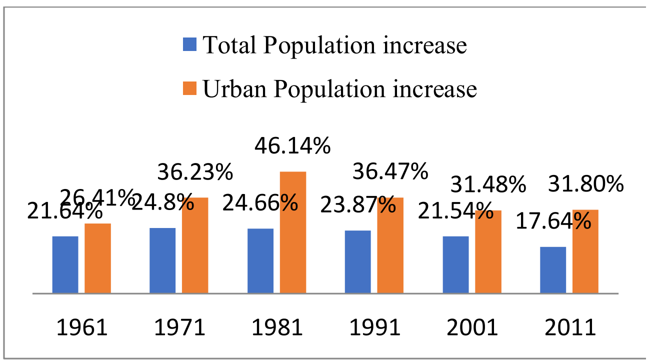

FIGURE 2
Trend of Urbanisation in India (TREI 2015)

TABLE 1
Composition of MSW in Urban India (CPCB 2012, 2016; Joshi and Ahmed, 2016)

Region/City	MSW (TPD)	Compostable (%)	Recyclables (%)	Inert (%)	Moisture (%)	Cal. Value (kcal/kg)
Metros	51402	50.89	16.28	32.82	46	1523
Other cities	2723	51.91	19.23	28.86	49	2084
East India	380	50.41	21.44	28.15	46	2341
North India	6835	52.38	16.78	30.85	49	1623
South India	2343	53.41	17.02	29.57	51	1827
West India	380	50.41	21.44	28.15	46	2341
Overall Urban India	130000	51.3	17.48	31.21	47	1751

for waste management is based upon public- private partnership which ensures the proper and regular collection of waste (Rana et al., 2015, 2017).

The waste generation rate in Himachal Pradesh located in the northern region of India, was reported to be 360 tonnes per day (TPD) with average per capita waste generation of 0.413 kg/day (TERI 2015). The waste generation rate in the state is expected to be increased 1-1.33% annually. The estimated projection for waste generation in year 2011, 2021, 2031 and 2041 is given in Figure 3. It is important to note that our present study location of Una Town lies in Himachal Pradesh which has certain distinctive patterns including very scattered populations leading to generation of scattered dumpsites. Further, our study location is a transit destination for other tourist hotspots in the state, thereby further skewing the data of the total waste generated and the character of the waste generated.

In this context, we have already undertaken a study regarding the existing MSW management practices in the study area and were analysed using the waste-aware benchmark analysis and matrix method (Thakur et al., 2017). The matrix method indicated that the overall performance of existing MSW management practises for the study site was 38% indicative of poor administrative system. Similarly, the analysis done for cities Solan, Mandi, Baddi (Sharma et al., 2018) also indicated the poor waste management practices in Himachal Pradesh. Further, waste generated in our study location is a mixed waste with no distinction of different socio-economic groups or other

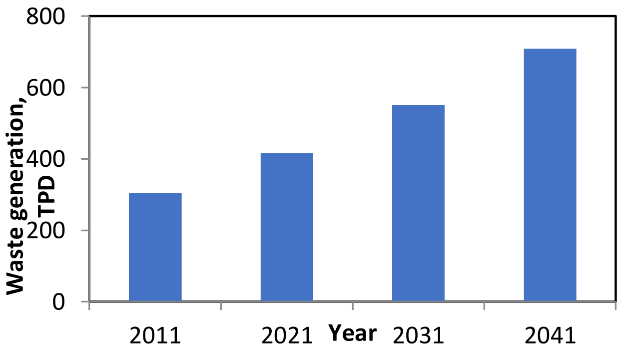

FIGURE 3
Estimation of waste generation in Himachal Pradesh from 2011 to 2041 (TREI 2015)

such classifications as has been the case determined for other study locations in Himachal Pradesh (Sharma et al., 2018; 2019).

The present study focuses on characterization and energy generation potential of municipal solid waste determined over three seasons (summer, monsoon and winter) to eliminate any seasonal biasness for Una town, a Tier-IV city of Himachal Pradesh. The characterization study was conducted to determine the physico-chemical composition and estimating the energy content of the MSW. Additionally, suitable recommendations in the context of appropriate Waste to Energy (WTE) techniques have been discussed.

Further, it is observed from reported scientific literature that majority of such characterization analysis have been carried out for Metropolitan cities (like Kolkata, Mumbai, Delhi) other significant Tier-II cities (Dhanbad, Surat, tricity region of Chandigarh etc.) in India but almost no literature exists for category III and category IV (tier III and IV) towns which are more representative of the selected study locations. The results of the study show that such analysis should be carried at all categories of cities as there exist potential energy benefits that can be derived from the MSW generated at such sites leading to economic benefits. Further, the present Government of India is promoting the '*Swachh Bharat Abhiyan*', i.e. clean the Nation, and the present study is expected to be a small contributor in this aspect. The Swachh Bharat Mission is a nation-wide campaign for period 2014-2019, that aims to clean up the streets, roads, infrastructures of Indian cities, towns, urban and rural areas. Therefore, the characterization study is an attempt to create a baseline information details and the results will be shared with the Government authorities including the Municipal Corporations and in some cases with other higher government officials for creating a database of such studies within the State of Himachal Pradesh in India.

DESCRIPTION OF STUDY AREA

Una town has population of about 18,722 as per census 2011 with growth rate of 16.26% during 2001-2011 and estimated population of town in 2020 is approximately about 21766. The disposal site in Una town is located within the coordinates (31.47°N, 76.27°E) and management of the dumpsite falls under the purview of the municipal council of Una. The total area of the disposal site is 0.20 hectare and open dumping is practises. Survey of area was done to know the status of generation and collection of MSW. It was reported that collection of waste was done on daily basis except on holidays and Sundays (Personal communication with MC Officers and workers). The waste generation in Una is about 6 tonnes/day with per capita generation is 0.29- 0.32 kg/day (Thakur et al., 2017) which is slightly less than the per capita generation rate prevalent in Himachal Pradesh (Thakur et al., 2017). Location of study area is shown in Figure 4.

MATERIALS AND METHODS

Sample Collection

The sampling of municipal solid waste was done from the dump site as per the procedure outlined in ASTM D-5231-92 (ASTM 2008; 2004a). The samples (n=10, for each season) from the site were collected randomly for ten days sampling period to obtain a representative sample. Separate sets of the sampling were carried out during different seasons for analysing the seasonal variation in the physical characterization of the waste. Collection of the waste was done on plastic sheets during unloading of trucks to prevent mixing of soil, dust particles with MSW. The quartile method was used to determine the composition of waste (Tchobanoglous and Kreith, 2002) Approximately 1000 kg of waste was unloaded from the vehicle and further reduced to 100 kg for obtaining a representative sample for physical characterisation.

Physical Characterisation

The segregation of waste was done manually with help of rag pickers. The physical characterisation of the waste was done for the different components like organic matter, paper, plastic, glass, metals, inert and other miscellaneous materials. Inert materials are those which are non-reactive chemically and cannot be degraded, mainly composed construction material, material from street sweeping (Rana et al., 2018). Segregation of the waste was done on wet basis without drying of samples and the weight of individual component was taken to determine the percentage of each component in total waste. Moisture content was determined immediately in laboratory after collection of samples.

Chemical Characterisation of MSW

During physical characterisation in each season using quartile method, a representative sample of 5 kg of waste was taken from 10 days sampling to the laboratory for chemical characterisation. The sample obtained is mixed sample and were tested for proximate, ultimate and heavy metal analysis. The samples for chemical characterisation were prepared as per ASTM- D5231-92 (ASTM 2008). The proximate analysis was done as per the procedure laid down in the ASTM standards including ASTM E790, E830 and E897, ASTM 2004(a, b, c). Proximate analysis of sample was done for determining fraction of crustal elements, ash content, volatile matter, fixed carbon in sample at different temperatures (Tchobanoglous and Kreith, 2002). The calorific value was determined in laboratory using bomb calorimeter. Heavy metal analysis of the waste was carried out using flame *Atomic Absorption Spectrometer* (AAS) and lab SOP as per ASTM D5198-09 (ASTM 2003). For analysis each sample was digested with concentrated HNO_3 as per ASTM standard (ASTM 2003).

The elemental analysis includes determination of carbon, hydrogen, nitrogen, sulphur, oxygen along with the C/N ratio determination for the waste sample. The samples were oven dried at 75^{o}C, shredded into smaller pieces and sieved through 2 mm, 1 mm sieves (Tchobanoglous and Kreith, 2002). Analysis of the samples were carried out as per ASTM D 3176-09 (ASTM 2002) and CHNS elemental analyser (Make - Thermo Electron Corporation Flash EA 1112) was used to carry out the test.

Further, the two-way ANOVA test is applied to the physical and chemical characterization results of MSW generated in Una in comparison with Baddi and Solan. The statistical

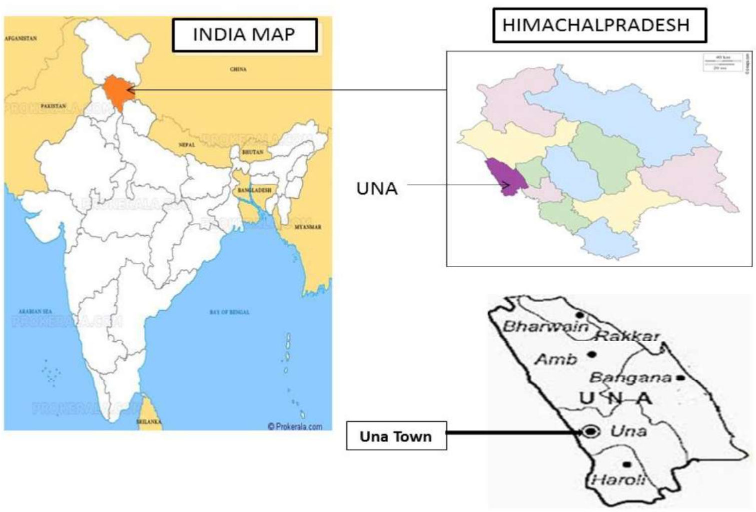

FIGURE4
Location of the study area

hypothesis testing of obtained experimental data for three different seasons was done. This test is helpful for determining the variance in the test results.

ENERGY POTENTIAL BASED ON CHARACTERISATION OF MUNICIPAL SOLID WASTE

The energy recovery of MSW is considered as a promising technique for sustainable waste management. Energy content was measured by bomb calorimeter in laboratory for chemical characterisation of waste and the results were validated using empirical methods as reported earlier (Abu-Qudais M, Abu-Qdais HA, 2000, Khan and Ali, 1991, Akkaya and Demir, 2009, Peavy et al., 1985, Liu et al., 1996, Wilson DG, 1977). The models used for empirically determining the potential energy generation is summarized in Table 2.

RESULTS AND DISCUSSION

Physical Characterisation

The components from physical characterisation along with the seasonal variation of the MSW in Una are shown in Table 3 and graphically represented in Figure 5. The density of the waste for the study area was determined to be 428 kg/m^3 which are due to the high percentage of compostable and inert fraction in the waste. The main component of MSW is organic in nature accounting for the majority (56.1%) of total waste generated in the city. The biodegradable matter includes mainly fruits, vegetables and papers generated in the town. The high fraction of biodegradables is supported by other studies mentioning high proportion of organic matter in the developing countries (40-70%) having higher moisture content (Khajuria et al., 2010; Sharma et al., 2019; Gomez et al., 2009; Khaiwal et al., 2015; NEERI 2010). The organic content in waste is mainly contributed by food remained from meals, plant trimming, rotten vegetables and fruits from the markets.

The fraction of organic content is higher in summer season (58.6±2.23%) because of greater abundance of vegetables and fruits in season and slightly lesser in winter season (53.4±3.44%) (Table 3). Further such seasonal variations are also caused due to change in climatic conditions and other cultural activities as has been similarly reported for other cities of Himachal Pradesh (Sharma et al., 2019). It has also been observed that Una being a transit town for more tourist destinations in Himachal Pradesh like Dharamshala, there is a higher flow of transient population (tourists) in summer months than in winter months which would also explain the slightly variation in the organic fraction in the summer season. The physical characterisation of MSW showed higher fraction of organic content comparable with other study locations in Himachal Pradesh (Sharma et al., 2018; 2019) than other Indian cities like Chandigarh, Mohali, Panchkula (42-53%), Varanasi (31%), (Jalandhar (33%) etc. (Srivastava et al., 2014a; Rana et al., 2018; Sethi et al., 2013).

TABLE 2

Empirical models used for predicting energy content of MSW
(Peavy et al, 1985; Liu et al, 1996; Khan and Abu- Ghararah, 1991)

Physical Composition Analysis	Ultimate analysis	Proximate analysis
Conventional Model	*Dulong's model*	*Traditional Model*
H_n = 88.2 R + 40.5 (G+P) - 6W	H_n= 81C +342.5 (H- O/8)+22.5S-6(9H+W)	H_n= 45B-6W
where	where	where
H_n= net calorific value (kcal/kg)	H_n= net calorific value (kcal/kg)	B = combustible volatile matter
R = plastic content (% wt. on dry basis)	C = carbon (wt.%)	W = water (% dry basis)
G = garbage content (% wt. on dry basis)	*H = Hydrogen (wt.%)*	
P = paper (%wt. on dry basis)	O =Oxygen (wt.%)	
W = water content (% wt. on dry basis)	S = Sulphur (wt.%)	
Eq. given by Khan and Abu Ghrahah	*Steuer's model*	*Bento's Model*
E = 23[F+3.6(PA)]+160(PL)	H_n= 81(C-3O/8)+57(3O/8)+345(H-O/16)+24S-6(9H+W)	H_n= 44.75B-5.85W+21.2
where PL = %age of plastic by weight	*Scheurer-Kestner's model*	
F= %age of food waste by weight *PA = %age of paper waste by weight*	H_n= 81(C-3O/4) + 342.5H + 22.5S + 57(3O/4)-6(9H+W)	

TABLE 3
Physical Composition of MSW at Una City

Sr. No.	Components	Summer	Monsoon	Winter	Average
1	Organic matter	58.6(±2.23)	56.3(±1.28)	53.4(±3.44)	56.1(±1.08)
2	Paper	10.6(±0.35)	13.9(±1.85)	12.12(±1.26)	12.2(±0.76)
3	Polythene/Plastic	10.3(±1.77)	10.1(±0.80)	10.61(±0.69)	10.3(±0.59)
4	Glass	0.9(±0.21)	1.1(±0.21)	1.09(±0.15)	1.0(±0.03)
5	Metal	1.4(±0.94)	0.9(±0.18)	1.13(±0.54)	1.2(±0.38)
6	Inert	10.0(±2.67)	10.0(±1.30)	11.2(±2.36)	10.5(±0.72)
7	Others	8.2(±1.44)	7.7(±1.07)	10.45(±1.23)	8.7(±0.19)

Note: All component values are in percentage (%). Number in the parentheses is standard deviation. Other includes leaves, wooden matter, thermocol, etc.

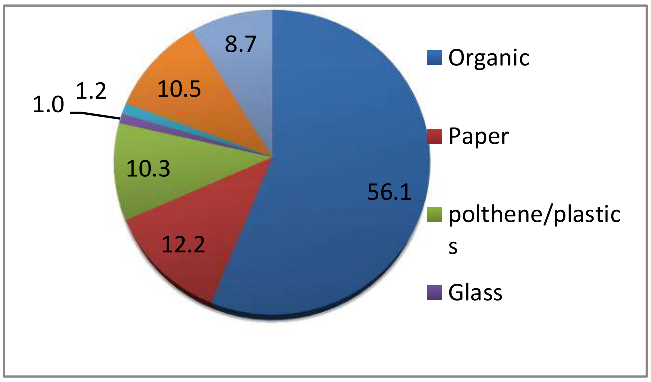

FIGURE 5
Percentage composition of physical component of Municipal Solid Waste

The dry fraction primarily consists of polythene/plastic, metals, glass and other miscellaneous materials (characterized as others' in Table 3). The characterisation results showed that the fraction of the dry waste matter in the study area was found to be 31.7%. Similar values were reported for cities of Himachal Pradesh (Sharma et al., 2019) with average dry waste material of 28.6% for Solan, 39% for Baddi region. One of the major components of the waste is plastic accounting for about 10.3% of the total waste generated. This is highly significant in the context that despite of fact that state of Himachal Pradesh has been declared as a 'plastic free' state since 2003; the study location still receives the plastic waste. The plastic waste comes in the different form as flexible plastics, bottles, plastic foam, plastic packaging of good and also the study area being in a border region with Punjab where such legislations are absent leads to increased plastic waste disposal in the study locations due to influx of tourists. Despite of fact that being a plastic free state the plastic content for other cities (Solan, Shimla, Mandi, Sundernagar) of state is comparatively less except Baddi (14.40%) (Sharma et al., 2019), which is also a border region to Haryana and thereby has reportedly higher fraction (6-8%) of plastics than the remaining major location in Himachal Pradesh. The possible reasons include its wide scale use by retailer, consumers for packing and carrying goods and transient populations from other nearby states. Glass and metal cover a small fraction of the dry waste generated (2%) primarily due to lack of any major industries producing such materials or wastes. Further, it was visually observed during the sampling period that very small informal recycling of these wastes was done (primarily by the rag pickers as an additional source of income for them) thereby further reducing its proportion to the total waste generated in study area (Thakur et al., 2017) The fraction of inert in waste (10.5%) is because of mixing waste from street sweeping, construction and demolition operations with municipal solid waste, thus increasing the density and reducing the calorific value of waste (Gomez et al., 2009; Sethi et al., 2013). Finally, the category 'others' (8.7%) include miscellaneous materials like thermocole wooden materials, which are generally generated from the commercial and institutional sectors of the study location. In particular, it was observed during seasonal analysis that there was a slight increase in this particular fraction due to its increased usage in winter seasons as they also serve for heating and insulation purposes. Also, major source of dry waste content in study area are institutions, commercial areas and surrounding industries.

The ANOVA test results depict that for parameters of physical characterisation there is significant difference ($p<0.001$) in the parameters for city which is in agreement with other similar study done for Himachal Pradesh (Sharma et al., 2019). However, for the study location the organic fraction was in greater proportion than other components and no significant variation ($p>0.05$) was observed in glass, metal and inert content for three cities.

Chemical Characterisation

The installation of good waste processing facilities in the area depends upon chemical characterisation of the waste which helps in deciding and setting up of treatment units. The results for the chemical characterisation are given in Table 4. The moisture content of the MSW were observed in the range of 40-61% for the three seasons, which is in range 20-65% for developing nations (Gomez et al., 2009; Srivastava et al., 2014a; Rana et al., 2018; Sharma et al., 2019; Thitame et al., 2010). It was observed that moisture content was lower during summer season in comparison to others because of higher temperature in the region which results in drying of waste, however no significant difference was observed for the seasonal analysis in Baddi, Solan, Mandi (Sharma et al., 2019). Consequently, the average calorific value of the waste was found to be 2263 kcal/kg with the highest value being reported for summer season (2543 kcal/kg), due to low moisture content. This also signifies that the MSW generated at the study location has suitable potential for energy generation. The variations in three seasons showed increase in calorific value of MSW from winter to summer seasons. However, the other reported studies carried out in metropolitan cities like Delhi, Mumbai and Chandigarh showed high calorific value as 4498 kcal/kg, 7477 kcal/kg and 1929 kcal/kg from waste generated in those locations (Sharholy et al., 2008; Lohri et al., 2014; Komilis et al., 2012). The comparison with average calorific values reported for similar cities of Himachal Pradesh (2327-2667 kcal/kg) and nearby Chandigarh (2208 kcal/kg) and Mohali (2508kcal/kg) cities (Sharma et al., 2019; Rana et al., 2018) suggest that the nature of the waste generated in Una city is almost similar to the cities of Himachal Pradesh and Chandigarh, Mohali thus having almost similar calorific values.

The ash content for the summer (27.34%) and winter (27.02%) seasons was found to be higher than monsoon season and also because of burning of waste on dump site during summer and burning of wood, coal for heating purpose during winter season also increased the ash content. Literature also showed similar range of ash content for Himachal Pradesh (23%-29%), tricity of Punjab (22%-35%) and 24.71%-31.69%) for Dhanbad city (Rana et al., 2018, Sharma et al.,

TABLE 4
Chemical Characterisation of MSW for Una Town, Himachal Pradesh

Parameters	Unit	Seasons *Summer*	*Monsoon*	*Winter*	Average
Proximate Analysis					
Moisture Content	% by wet weight	40.2±3.59	61.3±5.19	48.22±5.15	49.9±4.64
Ash content	% by dry weight	27.34±5.68	20.24±1.37	27.02±3.52	24.87±3.52
Volatile Matter	% by dry weight	29.57±5.50	16.43±3.25	20.60±1.18	22.2±3.31
Fixed carbon	% by dry weight	2.89±0.73	2.03±1.02	4.16±0.64	3.03±0.80
Calorific value	(kcal/kg)	2543±176.55	1953±104.73	2292±102.16	2263±127.82
Ultimate Analysis					
Carbon	% by dry weight	28.59±1.24	37.29± 2.20	31.51±1.29	32.46±1.58
Hydrogen	% by dry weight	4.90±0.10	2.66±0.55	3.97±0.29	3.84±0.31
Nitrogen	% by dry weight	1.36±0.11	1.56±0.51	1.39±0.13	1.44±0.25
Sulphur	% by dry weight	0.08±0.001	0.10±0.003	0.14±0.001	0.11±0.002
Oxygen	% by dry weight	16.55±4.02	11.62±2.11	13.83±1.03	13.99±2.39
Potassium	% by dry weight	0.67±0.08	0.63±0.08	0.52±0.04	0.62±0.07
Phosphorous	% by dry weight	0.45±0.06	0.37±0.05	0.39±0.06	0.40±0.06
Mineral Content	% by dry weight	47.40	45.77	48.28	47.15
C/N ratio	%	21.02	23.90	22.7	22.72

2019, Mboowa et al., 2017). The volatile fraction for the MSW varied within the ranges of 16-30% for three seasons, having highest percentage in summer (29.57%) and is due to high fraction of biodegradable matter present in MSW with an average value of 22.2%. The fixed carbon for the study area varied in range of 2.03% to 4.16% with reportedly higher values in winter season. The observed value of fixed carbon was lower for the monsoon season due to higher moisture content and comparison with reported literature showed higher value 1.68% to 4.86% for Himachal Pradesh, 6.7% to 8.3% for Jalandhar and 1.0% to 7.6% for tricity region of Punjab (Rana et al., 2018; Sethi et al., 2013; Sharma et al., 2019).

The average C/N ratio for waste was observed to be 22.72%, with seasonal variation ranging between 21-24% for the compostable fraction of waste. The variation of C/N ratio for Asian countries ranges between 17-52% (Khajuria et al., 2010; Al-Khatib et al., 2010; Rana et al., 2015; Sharma et al., 2019; Shekdar, 2009). Elemental compositions were observed to be highest for carbon(C) varying within the ranges of 28.59 to 37.29% followed by Oxygen (O) (11.62 to 16.55%), Hydrogen (H) (2.66 to 4.90%) and Nitrogen(N) (1.36 to 1.56%) for all the three seasons. The average carbon content (32.46%) was due to higher fraction of organic content in waste. Similar trend was observed for Indian cities and Himachal Pradesh (Rana et al., 2018; Sethi et al., 2013; Sharma et al., 2019, Srivastava et al., 2014a). The observed values of oxygen, nitrogen, hydrogen, sulphur, phosphorous, potassium was found to be within the range as observed for Chandigarh, Jalandhar, Baddi, Solan (Rana et al., 2018; Sethi et al., 2013; Sharma et al., 2019) with slightly higher fraction of nitrogen. The elemental composition of the waste is useful in determining the treatment potential of the municipal solid waste. The variation of moisture content, ash content, volatile matter and fixed carbon is shown in Figure 6 and the variation of elemental analysis is shown in Figure 7.

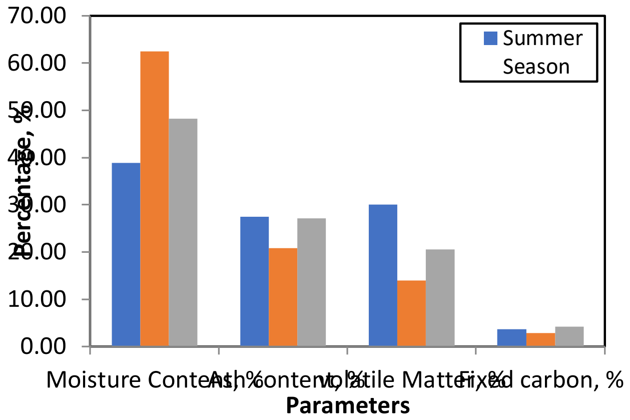

FIGURE 6
Proximate Analysis of MSW

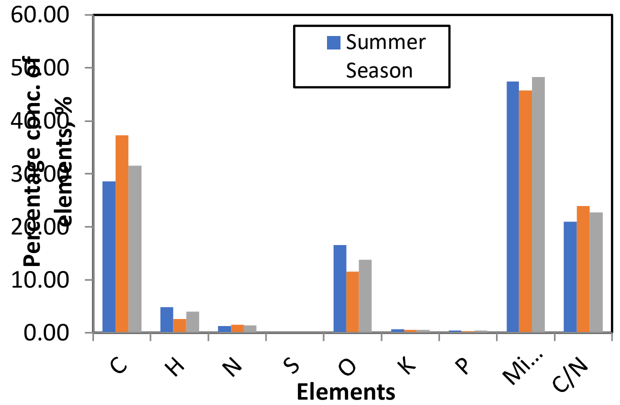

FIGURE 7
Ultimate Analysis of Municipal Solid Waste

Heavy Metal Characterization

The concentration of heavy metals Copper (Cu), Iron (Fe), Chromium (Cr), Zinc (Zn) and Manganese (Mn) were determined (Figure 8) and were found to within limits as prescribed by as per US Environmental Protection Agency Standard (US EPA 2000) and Municipal Solid Waste (Management and Handling) Rules for cities of India (MoEF 2000, Ministry of Urban Development 2016). Heavy metals like Lead (Pb), Copper (Cu), Cadmium (Cd) were found to be in very small fraction as shown in Table 5, but require consideration for their harmful effects, as even small concentrations could be significantly harmful. The presence of chromium, copper, zinc in waste is due to industrial water-cooling metal, paint, leather and gas industries. The results of chemical characterization thus can be utilized by authorities/researchers to set up waste processing units and disposal facilities. Many other options for waste management and handling can be adopted as properly segregated waste can be utilized for making compost and leachate recirculation system should be incorporated as this will lead to faster degradation of MSW.

The two-way ANOVA test revealed that for proximate analysis there is a significant difference ($p<0.001$) for ash content, moisture content, volatile matter and fixed carbon for cities of Himachal Pradesh and no significant difference ($p>0.05$) was observed for three different seasons. For ultimate analysis, no significant difference ($p>0.05$) was observed for elemental composition of three cities for different seasons.

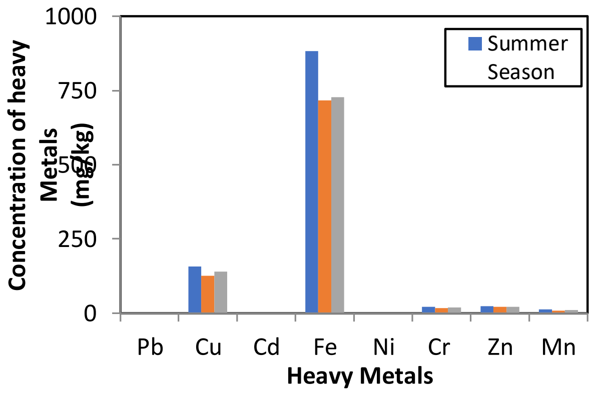

FIGURE 8
Variation of heavy metal concentration in MSW

ENERGY CONTENT OF MUNICIPAL SOLID WASTE – MATHEMATICAL VALIDATION

The calorific value observed in laboratory analysis having value of 2543 kcal/kg, 1953 kcal/kg and 2292 kcal/kg for summer, monsoon and winter seasons respectively. The energy content based upon the empirical models have been determined using the methods as described in Table 2. A summary of the energy content determined experimentally and by the different models for seasonal variations have been summarized in Table 6.

The different models predict the energy content based upon the physical and chemical characterisation of waste. The Dulong's model and model developed by Khan and Abu Ghrahah 1991 showed almost similar energy content as estimated experimentally and hence is best representative of the MSW generated in our study location. However, the conventional model overpredict the energy content followed by Steuer's model and Scheurer-Kestner model. The result from the models indicates that the contribution of paper, plastic and food waste (with low moisture content) for energy recovery is positive and considered for energy generation. However, the variation in calorific value in conventional models showed higher variation may be due to the moisture content consideration. The results depict that the measured and predicted values agree over a complete range of energy content. However, for proximate analysis (Traditional and Bento's Model) (i.e. moisture content and volatile matter) weak correlation exist between measured and predicted values which underestimates the energy content of MSW.

PROPOSALS FOR BETTER MANAGEMENT OF MUNICIPAL SOLID WASTE DEPENDING UPON ENERGY CONTENT

Different methods for management of MSW including segregation, collection and the energy recovery facilities need to be provided depending upon the energy content obtained for the study area. The energy recovery facilities require the installation of WTE plants and also the integrated solid waste management for minimization and reduction of the waste before finally disposing it to the landfill. However, the waste that comes to dumping site is mixed waste thus reducing the energy potential. Therefore, first step for better management of waste leads to the source segregation and collection which make it easier for further processing. The segregation of wet (organic) and dry components helps in utilizing the waste for various biological and thermo-chemical processes where it can be used as a source of energy. The provision of waste to energy facilities can also be provided in cluster formation with other cities of Himachal Pradesh or representative of the entire district. So, this section discusses the technologies for waste management including segregation, collection and WTE facilities that can be provided at the study location. The fraction of different components of MSW that could undergone different treatment processes at Una is shown in Figure 9.

TABLE 5
Heavy Metal Analysis of waste for three seasons (summer, monsoon and winter)

Parameters (mg/kg)	Seasons			Average
	Summer	*Winter*	*Monsoon*	
Pb	0.01	0.01	0.01	0.01
Cu	156.04(±7.88)	127.37(±9.18)	139.97(±1.74)	141.13(±0.58)
Cd	0.001	0.001	0.001	0.001
Fe	882.13(±65.49)	715.47(±41.09)	726.47(±75.32)	774.69(±25.11)
Ni	0.01	0.01	0.01	0.01
Cr	22(±1.41)	17.16(±4.15)	19.02(±2.85)	19.39(±0.95)
Zn	23.86(±5.1)	22.65(±5.27)	21.50(±7.44)	22.67(±2.48)
Mn	12.13(±1.82)	9.35(±4.73)	11.63(±1.33)	11.04(±0.44)

Note: Number in the parentheses is standard deviation. All values are in percentages (%).

TABLE 6
Estimated Energy content of MSW using empirical equations

Season	Physical Composition Analysis	Ultimate Analysis	Proximate Analysis	Experimental Analysis
	Conventional Model	*Dulong's model*	*Traditional Model*	
Summer	3308 kcal/kg	2619.5 kcal/kg	936.45 kcal/kg	
Monsoon	2786 kcal/kg	2452.5 kcal/kg	227.55 kcal/kg	
Winter	3031 kcal/kg	2550 kcal/kg	363.78 kcal/kg	Summer2543 kcal/kg
	Average = 3077 kcal/kg	Average = 2543 kcal/kg	Average = 401.4 kcal/kg	Monsoon 1953 kcal/kg
	Eq. given by Khan and Abu Ghrahah	*Steuer's model*	*Bento's Model*	Winter 2292 kcal/kg
Summer	2154 kcal/kg	2834 kcal/kg	960 kcal/kg	Average = 2263 kcal/kg
Monsoon	2259 kcal/kg	2494 kcal/kg	187 kcal/kg	
Winter	2185 kcal/kg	2928 kcal/kg	394 kcal/kg	
	Average= 2196 kcal/kg	Average= 2725 kcal/kg	Average= 432 kcal/kg	
		Scheurer-Kestner's Model		
Summer		*3030*		
Monsoon		*2654*		
Winter		*2893*		
		Average = 2890 kcal/kg		

Integrated Solid Waste Management (ISWM)

Generation of waste increases with population expansion and economic development. Improperly managed solid waste poses a risk to human health and the environment. Thus, a strategic approach for sustainable management of solid waste covering all aspects of its management in an integrated manner is necessary for maximizing the efficiency of the system. ISWM helps in achieving environmental objectives for sustainable system of region. For our study location, an integrated solid waste management system could involve management systems like segregation of waste, waste to energy facilities (applicable for the entire region), recycling and reuse of wastes and composting methods as shown in Figure 10.

The community participation in waste management is the present need. Involvement of private associations like NGO's plays an important role in guiding and encouraging the people appraising them on waste management issues. The awareness among people by organising programs based on education, communication, encouraging citizens for waste minimisation should be conducted with help of municipalities.

Source Segregation and Collection

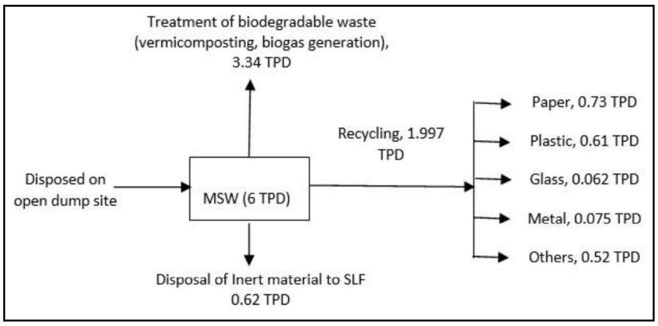

FIGURE 9
Treatment of different fraction of MSW in Una

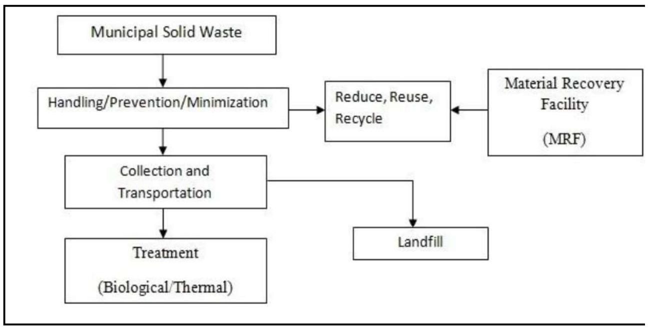

FIGURE 10
Integrated Solid Waste Management

Segregation and collection of waste is an effective way for MSW management. In practise, it could be initiated right from the households, thereby initiating '*segregation at source*'. This will significantly separate out the organic content of the MSW which accounts for about 55% of the total waste. Further, it should be ensured that construction and demolition wastes, which account 10% of the total waste generation, are separated from household wastes as they can significantly increase the 'load' on the dumpsite. To a certain extent, the segregation of recyclable and reusable material like paper, plastic, metal, glass is already being carried out by rag-pickers at source itself providing them an extra source of income. Segregation is also preferable as mixed fractions of waste leads to decrease in energy content and thus reducing the calorific value of the waste. The combustible material should be separated and used for the generation of refuse derived fuel in RDF plants. After segregation, a systematic approach needs to be provided for collection of waste using central bins, door to door collection, on regular basis. The roadside bins should be provided at distance of 80-100m from residential area for collection of waste. The installation of smart waste monitoring and collection system should also be incorporated to reduce the time and cost effects. The collected segregated waste should be transported to waste processing plants for energy generation and the inert material should be disposed on the dump sites.

Implementation of appropriate Waste to Energy (WTE) Facilities

Once the segregation of organic waste is completed it can be potentially harnessed to generate energy as methane by anaerobic digestion, installation of bio-methanation plant, producing RDF etc. and this has already been approved or is being currently used in other cities in India (Rana et al., 2018). However, if organic wastes from surrounding and nearby districts are collected, a single bio-methanation unit serving the entire area may seem like a viable proposition (Sharma et al., 2018; Rana et al., 2015; 2018). Installation of incineration plant for the state may not be possible because of higher organic content present in MSW. Depending upon the characterisation results for MSW of Una town, suitable methods for waste to energy facility are further discussed.

Biological Treatment Process. The biological treatment process involves aerobic and/or anaerobic digestion of organic waste and converts it into stabilized products. The characterisation results of study area showed that the waste collected from the study area comprises of 56.1% of organic waste which can be processed under aerobic and anaerobic processes also having high efficiency for generation of biogas.

The wet waste (food waste, agricultural waste) of MSW is converted into compost under aerobic digestion (Fricke et al., 2005). The aerobic process can be used for composting of waste in study area which involves the aeration and ventilation for micro-organisms growth to maintain effective decomposition (Arena and Di Gregorio, 2013; Petersson, 2013). Micro-organisms converts waste into stabilized product with good water holding capacity and used in agricultural activity as soil fertilizer or soil conditioner. Anaerobic digestion of MSW is the process to convert wet waste into biomass and digestate (Figure 11) in absence of oxygen (Fan et al., 2018) The biodegradable fraction of waste is converted into biogas using micro-organisms in bio-methanation plant which can be used as a fuel for producing heat and electricity. Biogas generated due to digestion of MSW having traces of different gases with higher concentration of methane (50-80%) (Fan et al., 2018) and CO_2. The anaerobic digestion of MSW requires maintenance of factors like pH, temperature which can affect degradation phase of waste. The variation in pH level of MSW (acidic phase) can reduce generation of methane leading to acetogenesis in MSW. However, the generation of biogas mainly methane is higher in mesophilic condition, so during winter months to sustain the methane production rate, heat blanket or other methods for maintaining the mesophilic condition needs to be provided.

For treating the waste anaerobically, it requires proper consideration for maintaining temperature and collection of biogases. However, this generated amount of waste is not enough for treating it anaerobically at a large scale for biogas generation as it may not be a cost-effective process. Thus, aerobic treatment of waste is feasible for the study area where waste converted into compost can be used as fertilizer for agricultural land.

Vermicomposting. Vermicomposting is the process of converting organic matters into compost (which is a humus like material) by using earthworms. It is a manure restoring microbial population which includes nitrogen fixers, phosphates etc. which make it suitable for crops. Vermicomposting of MSW is cost effective, economically viable process which accelerates the organic matter stabilization (Doble and Kumar, 2005). However, the vermicomposting facilities are not in practice in study area but in existence at some areas of Himachal Pradesh (Sharma et al., 2019) but not effectively in operation due to lack of skilled labour, mixed nature of waste and presence of

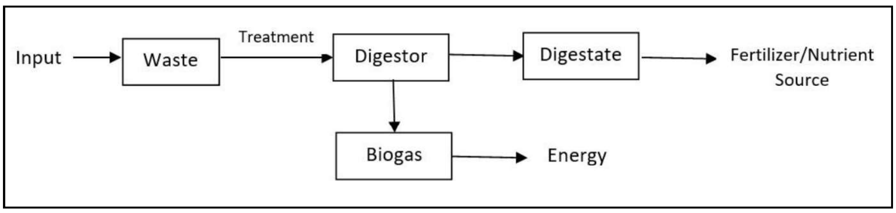

FIGURE 11
Anaerobic digestion of MSW

heavy metals. The presence of heavy metals in the waste is less at present but required to be removed from the waste prior to vermicomposting.

Thermal Treatment Process.

- RDF Facilities. The installation of refused derived fuel (RDF) plant in the study area is one of the optimal solutions for energy recovery for efficient waste management. The characterisation results showed that the presence of heavy metals in the waste is lower and higher proportion of paper, plastic, rags etc. showing better feasibility for installation of RDF plant in study area. The average calorific value (2263 kcal/kg) depict that the waste generated has enough energy content to be utilised for energy recovery. Presently one RDF plant exists in Northern region of India, located in Chandigarh (capacity - 500 TPD) (Rana et al., 2015) having capacity to generate RDF with calorific value 3100 kcal/kg is comparable to calorific value of study area. The RDF can be used to produce electricity and fed to plasma arc gasification and pyrolysis plants (Arena and Di Gregorio, 2013; Fan et al., 2018).
    - Pyrolysis. This process involves heating of waste in absence of oxygen at temperature of 300˚C-800˚C in a heating chamber. The segregation needs to be done to remove glass, metals and inert fraction from waste prior to pyrolysis (Moya et al., 2017). Pyrolysis process involves the conservation of biomass (organic waste) into solid, liquids (bio-fuels) and gaseous fraction by heating in absence of air (D'Alessandro et al., 2013; Sipra et al., 2018) having high energy recovery efficiency. The by-products of pyrolysis process can be re-used thus lowering the NO_x and SO_2 and increasing the efficiency and cost of process (Sipra et al., 2018; Chhabra et al., 2016; Klinghoffer and Castaldi, 2013). The product of pyrolysis '***syngas***' has high calorific value of 20 MJ/Nm^3, consists of methane (CH_4), carbon dioxide (CO_2), hydrogen (H), carbon mono-oxide (CO) (Zafar, 2018). Both the organic and plastic fraction of waste is utilised in pyrolysis process which convert plastic into fuel of high calorific value.

The comparison between different thermo-chemical processes is given in Table 7.

WASTE TO ENERGY FACILITIES-COMPARISON FOR UNA TOWN TO UNA DISTRICT

The above discussed WTE facilities require the sufficient amount of waste for efficient running of treatment plant. However, the study area (Una city) has a waste generation rate of only 6 TPD which is very less to be treated in WTE plant in comparison to its installation, running and maintenance costs. Hence, in the immediate context, implementation of WTE facility for the Una city seems a non-feasible option with the exception that composting technique may be employed as discussed earlier. However, the entire Una district has a waste generation 20.4 TPD (Personal Communication), which is suitable for implementation of appropriate WTE techniques. Additionally, the efficiencies of these WTE facilities may be improved by importing waste from nearby cities and other districts in collaboration also making it an economically efficient option.

TABLE 7
Thermochemical conversion technology: advantages and disadvantages
(Chhabra et al, 2016; Sipra et al, 2018; Srisaeng et al, 2017)

Thermochemical Conservation Process	Advantages	Disadvantages
Gasification	Reduction in volume of waste by 50-90%	High capital and operational cost.
	Uses all type of waste	Production of dioxins and other persistent organic pollutant (POPs) causing air pollution.
	No emission of greenhouse gases	Corrosion of metal tube during reaction.
RDF	High calorific value of RDF pellets (~4000 kcal/kg)	Needs safe disposal of produced fly ash.
	Alternative energy source for fossil fuels	High energy consumption.
	Lower pollutant emission	Coke formation from liquid products.
		Highly inefficient in higher moisture content.
Pyrolysis	Smaller emission of NO_x, SO_2	Greater capital cost.
	Less land requirement	Oily liquid product has high water
	Up to 80% energy recovery rate	content resulting due to moisture in
	High calorific value of product (~38MJ/kg)	feedstock.
	Washing of syngas before combustion	
	Lesser volume production of flue gas per kg of waste, reducing treatment capital cost	

In this context, based upon the characterization studies carried out in Himachal Pradesh and the proposed WTE facilities, it can be proposed that for the Una district a suitable anaerobic treatment method be used primarily for treatment of organics due to the increased volume of waste (20.4 TPD) generated in the entire district. However, in general for the winter months sufficient heating conditions should be enabled in the anaerobic system so as to enable the proper functioning of the WTE facility. Implemented WTE facility could be bio-methanation units or any other suitable WTE facility. This recommendation is in sharp contrast to the above proposed WTE facility for Una town (6 TPD) which has significantly less quantity of waste generation of and is more amenable for aerobic treatment system leading to composting techniques.

For treatment of dry waste, the thermal treatment facilities contribute in energy recovery from the waste to be used in various applications like generation of electricity and heat, fuel for industries, heavy power consuming machines as discussed in given section. In this context, the installation of RDF plant for waste collected from the Una town and districts is feasible option due to lower proportion of heavy metals and higher dry waste fraction including (~30-40%) paper, plastic, rags present. The present calorific value (2263 kcal/kg) of waste is enough for considering it as energy source. In general, the existing RDF plant in Chandigarh city has capacity for generating fuels of calorific value 3100 kcal/kg with daily waste intake of 500 TPD (Rana et al., 2015) and the same technology may be implemented with one unit covering the entire district of Una and its surrounding areas. This will also lead to economic efficiency in the operation of the system.

The last two paragraphs discuss the energy potential generation separately from wet and dry waste sources, but it implies setting up of two major WTE installation units, requirement of skilled labour, availability of land, suitable PPP arrangements with the government and private industries and other practical difficulties. In particular land requirement may be the biggest constraint in setting up two individual WTE facilities. In this context, Combined Treatment Systems (CTS) are often preferred which includes treatment of both wet and dry waste fraction in a single WTE unit. This is often achieved by use of biorefineries. In principle, the wet fraction is converted into biofuels and dry waste is treated to produce ***syngas***. Figure 12 showed the utilisation of biomass using biorefinery concept. In this context, a biorefinery WTE facility based on pyrolysis platform is also suitable for generating energy from the waste. The s***yngas*** produced in the processes from pyrolysis can be utilised for heat and electricity generation and for power sources for boilers and turbines in nearby industries.

Considering the practical location, the economy of the state and the district, land availability and the calorific value of the waste generated the utilization of biorefinery as a possible WTE proves to be best suited for study area as it utilises both wet and dry fraction of MSW to produce biofuels and syngas enhancing the value derived from biomass. Further, biological treatment processes could be used individually for wet waste and for dry waste RDF facilities could be provided.

ENGINEERED LANDFILL

One of the methods for effective disposal of the waste in the study location is the design of an engineered landfill site which can significantly reduce the harmful impact on environment. The engineered landfill for disposal of waste generated in Una district should be constructed for service period of about 20-25 years (CPHEEO, 2016 a,b). After the reutilization of recyclable, biodegradable fraction of waste, the remaining fraction (soil, inert and others) should be disposed into landfill. The waste disposed should be properly compacted to dry density and covered by a soil layer at end of each working day. The leachate collection system and liner system should be designed for the collection and to prevent migration of leachate into sub soil. To minimise the cost of construction alternative drainage materials (tire derived aggregates, C&D waste aggregates) may be used (Thakur et al., 2016). Finally, cover soil layer (0.5m depth) for vegetation growth should be provided on top, overlaying drainage layer, which could be used for recreational activities like gardens, parking area etc. Precaution needs to be taken after the final closure of landfill as degradation of MSW leads to settlement (Thakur et al., 2019).

CONCLUSION

For the management of MSW the first and foremost step is to understand type and character of waste generated for designing and suggesting the appropriated methods for collection and disposal of waste. Therefore, characterization of MSW and prediction of energy content plays an important role in energy recovery. The characterisation of MSW in Una, showed the presence of higher organic content of 56.1% and average moisture content 49.57%, which confirms the possibility of

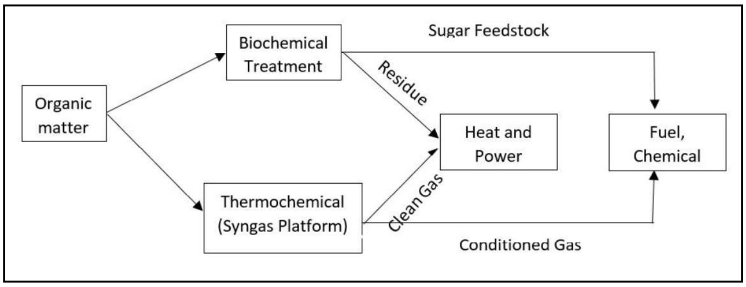

FIGURE 12
Utilization of Biomass in Bio-refinery platform

biological treatment of MSW. The chemical characterisation of waste specified the higher ash content because of presence of inert fraction. Inert coming to landfill from construction and demolition waste, street sweeping need to be restricted which affect processing of biodegradable and recyclable matter. The concentrations of heavy metals in waste were within the limit but need to consider in future as direct disposal of waste containing harmful chemicals may leads to increased concentration. However, the increased generation of MSW and shortage of land requires the strategies to manage the waste in future. In this context, the investigation of present study will be useful in adopting better management strategies and waste treatment and disposal options. The laboratory analysis revealed that average energy content of 2263 kcal/kg of MSW compared with empirical models resulted in agreement with the predicted values. The energy content determined using the models showed a correlation of physical composition and ultimate analysis with measured values. The calorific value of the waste can be utilised for the energy recovery and thus, estimation of energy content of MSW helps in achieving the optimal system performance. However, the waste segregation and recycling of waste is necessary and important for minimizing the quantity of waste that is disposed in landfill. Different techniques for energy generation have been discussed including energy generation separately from organic (wet) and inorganic (dry) waste fractions and combined treatment systems. The remaining fraction of MSW disposed in the landfill requires construction and designing of engineered landfill for minimizing the harmful effect on soil and environment. However, considering different practical factors including land requirement and other difficulties a single WTE unit is proposed. This can be based on designing a biorefinery wherein the entire waste can be treated and may be suitably designed on pyrolysis platforms.

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