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Utilization of organic fraction of municipal solid waste as waste to energy: A case study of Solan and Nahan, India

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Abstract
Municipal Solid Waste (MSW) has been considered as a major hazard in our society that creates an additional pressure on concerned municipalities with risks to public health and the environment. The decomposition of biodegradable material in the waste stream can lead to CH_4 and CO_2 emission from this sector. An attempt has been made to study the MSW generation, composition, characteristics and treatment options in growing towns i.e. Solan and Nahan of north hilly state (Himachal Pradesh) of India. It is estimated that the Solan is generated about 19,536.17 kg/day MSW while 4,406.50 kg/day in Nahan. Service Level Benchmark v/s Existing Situation shows a 41% performance level. Organic content was observed maximum (51.13-59.30%) in MSW followed by construction waste (16.27-17.17%), Plastic (3.68-11.27%), Paper (6.59-7.1%), Textile (4.22-5.87%), Rubber/Leather (3.97-4.18%), metal (2.72-3.34%) and Glass (1.42-1.54%). The moisture content was found between 29.15% and 63.15%. Carbon was found to be 50.10-50.18%, hydrogen 6.52%, nitrogen 2.23%, oxygen 33.66-34.53%, the C: N ratio was 21.63, ash was 6.15-5.12% and the empirical formula developed was $C_{26.3}H_{40.8}NO_{14.6}$ for Solan town, while $C_{25.5}H_{39.5}NO_{13.9}$ for Nahan town. The energy content for the Solan dumping site was estimated as 8742.95 KJ/tonne while, the energy content for the Nahan dumping site was 10607.72 KJ/tonne. The MSW of both these towns has enough energy content and Waste-to-energy can be a better option for the treatment of waste. The benefits include reduction of leachate production, reduction in methane generation which will automatically lead to reduction of greenhouse gases (GHG) emissions.

Keywords: Utilization, organic, waste as waste, MSW, GHG

1. Introduction
Municipal Solid Waste (MSW) become a major hazard in our society and generation of huge quantities of wastes not only exert an additional pressure on concerned municipalities of the many countries but also threaten public health and environment. Rapid population explosion has resulted in expansion of towns which leads high waste generation and poor management systems like disposal and treatment of waste (Greedy and Thrane, 2008) [8]. In developing countries, inadequate resources and inefficient Municipal Solid Waste Management (MSWM) system fail to manage the large quantities of wastes, therefore, open dumping or landfilling of waste is the most common management practice (Ali *et al*., 2014) [2]. In India, about 31% of the population lives in the towns which generate approximately 130,000 tonnes waste per day with a per capita waste generation rate of 500 grams/day (Annepu, 2012) [3]. In India, MSW management is constrained by institutional weakness, lack of proper funding, lack of proper management and operational systems, public apathy, lack of municipal will to become financially self-sufficient through municipal taxation, etc. MSW is dominated by strong or semisolid organic particles which are the active contributor of global greenhouse gas (GHG) emissions during its decomposition and combustion. The studies show that about 90% of the solid waste produced in India is dumped off directly in the landfills in an unsatisfactory manner, particularly in bigger towns and towns (Hazra and Goel, 2009) [10]. The decomposition of biodegradable material in the waste stream such as paper, food scraps, yard trimmings and garden waste can lead to CH_4 emission from this sector (Thorneloe *et al*., 2007) [15]. While burning of plastic waste is the major contributor of CO_2 emissions which can increase the ambient air temperature and prompt to warming and changing the climate.

Hence, an attempt has been made to study the MSW generation, composition, characteristics and treatment option in growing towns i.e. Solan and Nahan of north hilly state (Himachal Pradesh) of India where similar waste management issues exist due to local population and tourists. Here, we have carried out quantification of waste, physical and chemical characterization and estimation of energy content for appropriate treatment in selected towns during the period of January-December 2019. To the best of our knowledge, this is the first comprehensive study on quantification of waste, physical and chemical analysis and energy in these areas which will be of great importance for policy maker and treatment of waste in hilly areas.

2. Study Area and methodology

The study has been carried out at two municipal solid waste dumping sites of Solan and Nahan towns of Himachal Pradesh, India. Himachal Pradesh is a mountainous region, rich in its natural resources. The Solan Municipal Council is comprising into thirteen municipal wards and spread over an area of 33.43 km^2, which makes it the largest city in Himachal Pradesh by land area. According to the 2011 Indian census, Solan city has a population of 1,02,078 and has considered the second most populous city of Himachal Pradesh after Shimla. It has one MSW dumping site which is located at 30^0 56' 20.46''N and 77^0 08' 00.84''E as shown in Fig.1. While, Nahan Municipal Council has also comprised of thirteen municipal wards and has a population of 28,853 as per the 2011 census, which has been considered as fifth most populous city of Himachal Pradesh. It has one MSW dumping site located at 30^0 32' 53.01''N and 77^0 16' 39.40''E.

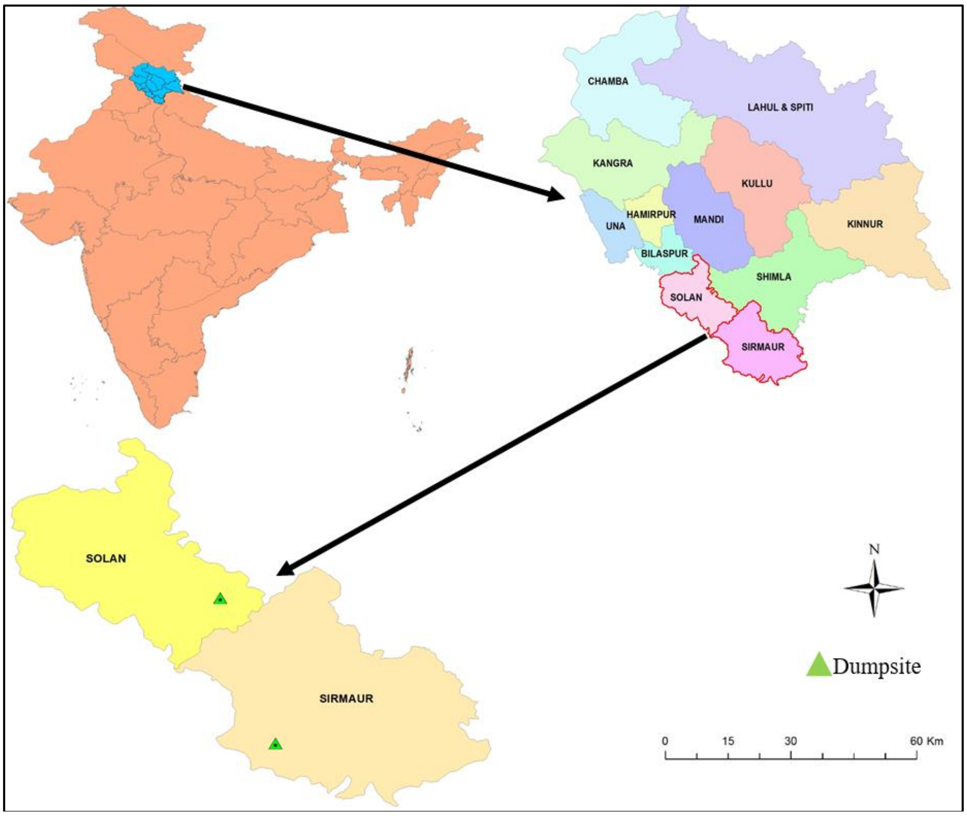

Fig 1: Study area, showing the locations of dumpsites of Solan and Nahan towns

2.1 Quantification, Composition and Characterization of MSW

An accurate assessment of the quantity and characteristics of solid waste generated is crucial for formulating solid waste management plans. Rational decisions on the municipal solid waste system are possible only if reliable data on the composition and quantity of solid waste are available. The method and capacity of storage, the correct type of collection vehicle, the optimum size of the crew and the frequency of collection depend mainly on the volume and density of wastes. The treatment and disposal method is dependent on the type of material recycled, organic content of waste, which could be composted, and the combustible material, which could be a source of energy. For collection of waste from the residential, commercial and dump site quartering procedure is followed as per CPHEEO manual (2000) [6] and as suggested by Hristovski *et al.,* (2007) [11]. and Tchobanoglous *et al*., (1993) [14]. The waste generated is quantified by means of taking the weights of waste laden vehicles for consecutive days. In order to assess the physico-chemical characteristics of the MSW, on-site physical analysis and lab testing for chemical parameters is carried out by collecting samples from representative collection points of dumping site as per procedures prescribed in Bureau of Indian Standards given below.

- IS: 9235-1979, Method of physical analysis and determination of moisture of solid waste
- IS: 9234-1979, Method for Preparation of Solid Waste Sample for Chemical and Microbiological Analysis. UDC 628.312.1: 543.05: 543.9-078 and
- IS: 10153-1982, Methods of analysis of solid waste, excluding industrial solid waste.
- IS: 8769-1978, Method of detecting ash and sulfated ash
- IS: 1350-1974, Method for Calorific Value

Based on the physical-chemical characteristics, the technical options were explored like Environmental Technology Assessment, Sustainable Assessment of Technologies and Technology appropriateness.

3. Results and Discussion

3.1 Quantification of Municipal Solid Waste

The amount of solid waste generated in Indian towns has augmented from 6 million tons in 1947 to 48 million tons in 1997 with an annual growth rate of 4.25%, and it is expected to increase to 300 million tons by 2047 (Sharholy *et al.*, 2008). [16] There are 54 Urban Local Bodies (ULBs) consisting of two Municipal Corporations, 31 Municipal Council, 21 Nagar Panchayats and 7 Cantonment Boards existing in the State of Himachal Pradesh. It is submitted that there is 7.13 Lakh Urban population (as per census 2011) and solid waste generation is approximately 389 Tonne per day (TPD), out of which 340 TPD is collected, 150 TPD is treated and 190 TPD is land-filled (CPCB, 2019) [7]. The amount of waste generated in the city was calculated on the dumping site on a daily basis. There was not the proper arrangement or well advanced system for weighing the vehicle completely entering the dumping site carrying solid waste and without solid waste. So the total waste carried by each vehicle entering the dumping site was weighted. The total amount of waste carried by the vehicle was weighted with the help of calibrated portable spring balance. The process was repeated for 7 days in all the three seasons.

It may be noted that the Solan Municipal Council (SMC) is largest city and second most populated town in Himachal Pradesh. It is estimated that the SMC is generated about 19,536.17 kg/day MSW with an average of 250g/day/person which is below the national average, i.e. 400g/day/person (Bhat *et al.*, 2018) [4, 5]. The daily, seasonal average amount of waste reached to the Solan's dumping site is given in Table 1, which receives about 7130700.83±879.08 kg waste/year. In Nahan Municipal Council (NMC), it is estimated that the daily waste is generated about 4,406.50 kg/day MSW with an average of 220g/day/person which is also below the national average i.e. 400g/day/person (Bhat *et al.*, 2018) [4, 5]. The daily, seasonal average amount of waste reached to the Nahan's dumping site is given in Table 1, which receives about 1608372.50±123.14 kg waste/year.

Table 1: Total amount of waste generated per capita wise in Solan and Nahan

Day	Solan			Nahan		
	Summer	**Rainy**	**Winter**	**Summer**	**Rainy**	**Winter**
Day 1	17968	19410	20762	4470	4504	4182
Day 2	18114	19109	21037	4911	4911	4256
Day 3	18981	17265	17651	4242	4245	4256
Day 4	18873	19941	20971	4390	4249	4404
Day 5	19486	19922	21169	4339	4250	4297
Day 6	19451	20045	21496	4799	4331	4281
Average Waste in Season Wise (Kg/day)	18812.17	19282.00	20514.33	4525.17	4415.00	4279.33
Standard Deviation	647.21	1052.68	1423.66	268.33	262.55	72.69
Daily Average waste Generation (kg/day)	19,536.17			4,406.50		
Total waste Generated in a Year (kg)	71,30,700.833 Or 7130. 70 Tons Per year			16,08,372.5 Or 1608.37 Tons per year		

3.2 Service Level Benchmarking for Solid Waste Management of Solan and Nahan towns

The Ministry of Urban Development (MoUD), GoI has introduced Service Level Benchmarking as one of the appropriate systems for information management, performance monitoring and benchmarking. This system aimed at improving not only the service provision but also the delivery of services to the consumers. MSWM is one of the four basic urban services which MoUD has identified as a performance parameter. These are indicators to measure the stepwise performance in MSWM at ULB level. Under the 13th Finance Commission, Service Level Benchmarking is a key criteria for performance grant of ULBs. Each ULB has to declare its current level of services as well as the target for improvements for the next year on the basis of defined criteria. Table 2 below shows the current status of Solan Municipal Council and Nahan Municipal Council against the required benchmarks set under the criteria and Fig. 2 shows the graphical representation of performance indicator.

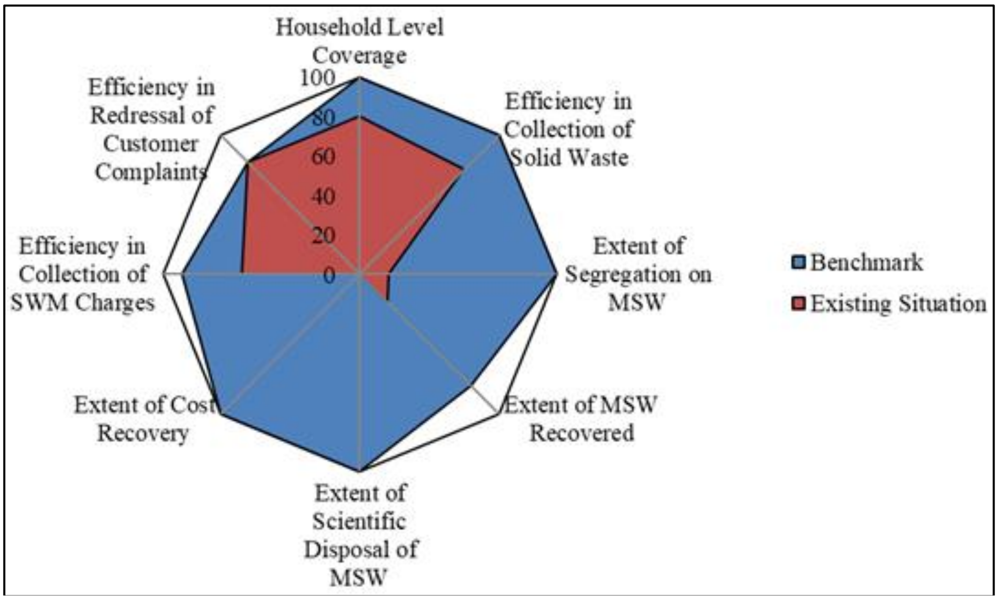

Fig. 2: Graphical representation of Service Level Benchmark

Table 2: Service Level Benchmark v/s Existing Situation (%)

S. No.	Indicators	Benchmark	Existing Situation
1	Household Level Coverage	100%	80
2	Efficiency in Collection of Solid Waste	100%	75
3	Extent of Segregation on MSW	100%	15
4	Extent of MSW Recovered	80%	20
5	Extent of Scientific Disposal of MSW	100%	0
6	Extent of Cost Recovery	100%	0
7	Efficiency in Collection of SWM Charges	90%	60
8	Efficiency in Redressal of Customer Complaints	80%	80

3.3 Waste Composition in the selected towns

The quality of waste and composition is very important factor for identification of treatment technology. However, the composition of MSW depends on a wide range of factors such as food habits (Agamuthu *et al*., 2007; Bhat *et al*., 2013) [1, 4, 5], cultural traditions, climate and income, etc. (Gupta *et al.*, 1998; Kumar *et al.*, 2009) [9, 12]. Vehicles entering the dumping sites were selected randomly for the characterization of waste for seven days in each season. The waste was segregated on a HDPE liner according its category and various categories of MSW were found such as commercial waste, food waste, institutional waste, street waste, industrial waste, construction and demolition waste, and sanitation waste at the dumpsites of selected towns. Fig. 3 shows the waste composition of Solan town which contains the highest percentage (59.30%) of organic content (Food, Garden, wood and straw waste) was observed, followed by Construction waste (17.17%), Paper (7.1%), Textile (4.22%), Rubber/Leather (4.18%), Plastic (3.68%), metal (2.72%) and Glass (1.42%). In Nahan, Organic content (Food, Garden, wood and straw waste) was estimated maximum (51.13%) followed by Construction waste (16.27%), Plastic (11.27%), Paper (6.59%), Textile (5.87%), Rubber/Leather (3.97%), metal (3.34%) and Glass (1.54%).

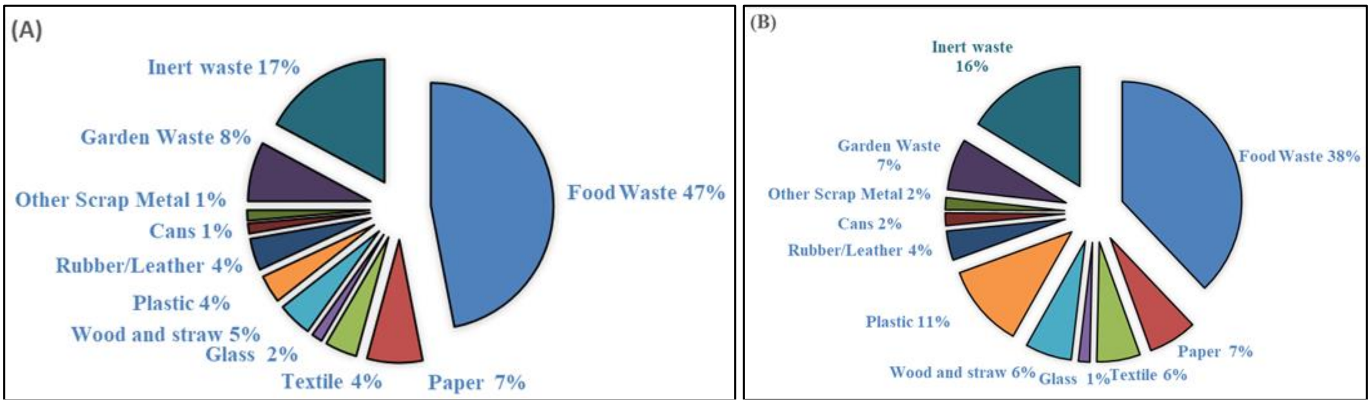

Fig 3: Waste Composition (a) at dumpsite of Solan Town and (b) at dumpsite of Nahan Town

3.4 Physical properties of Waste

3.4.1 Moisture content and pH

Environmental conditions in the landfill will have a significant impact on the rate of MSW decomposition. The moisture content and pH play a significant role in biodegradation of organic waste in the landfill and energy generation. The seasonal moisture content and pH of the waste was calculated at six locations of dumping sites (Fig. 4). The moisture content is found between 29.15% and 63.15%. The highest moisture (63.15%) was calculated at Solan dumping site during the rainy season while the lowest (29.15%) was measured at the Nahan dumping site during the summer season (Fig. 4a). The pH was measured by preparing a mixture of MSW and de-ionised water. The highest pH was recorded, *i.e.* 6.2 at the Solan dumping site during the summer season while the lowest (5.2) at Nahan dumping site during the winter season (Fig. 4b). It may be noted that the waste of both dumping sites is acidic in nature which play a significant role in decomposition of waste.

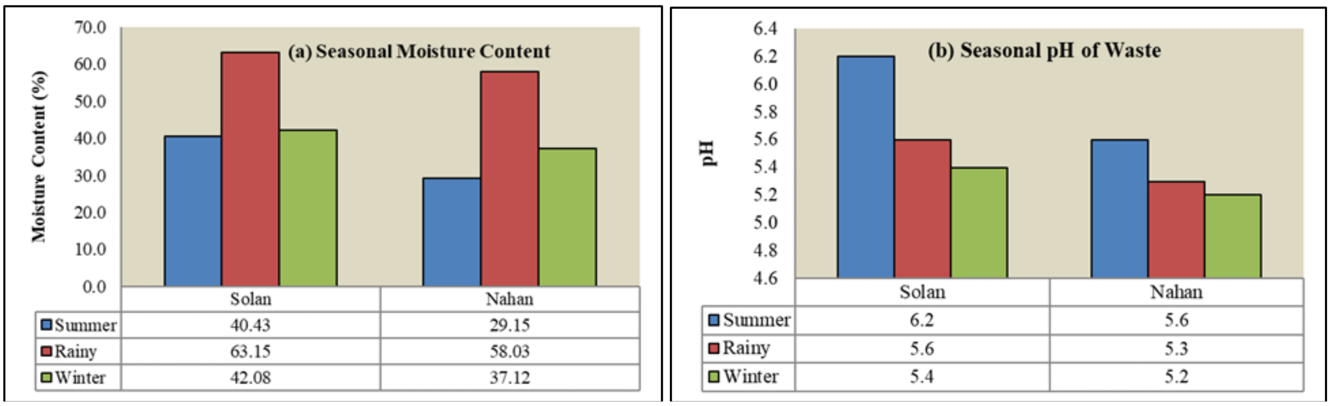

Fig 4: Seasonal average (a) moisture content and (b) pH level at dumpsite of Solan and Nahan Town

3.5 Chemical composition of Waste

The Chemical properties of MSW has a significant role in recovery options, disposal system and to release of GHGs in the environment. Availability of reliable data on waste composition and characterization is also important for policy makers for formulation of policy on proper waste management. However, limited information is available on the chemical composition of municipal solid waste of India as well as Solan and Nahan towns. Composting of MSW is one of the treatment method, diverting organic waste from the waste streams and thus eliminating the use of landfills in the study area. The objective of this paper is also to evaluate the physical composition of the various waste components and the chemical composition of the inorganic and organic fraction of municipal solid waste (OFMSW) that originate from Solan and Nahan towns that are disposed at the landfill site in order to make a proposition on the complete diversion of OFMSW from going to the landfill. Waste samples were taken from the landfill sites of the Solan and Nahan towns and was analyzed for elemental and proximate analysis. From the elemental analysis; carbon was found to be 50.10-50.18%, hydrogen 6.52%, nitrogen 2.23%, oxygen 33.66-34.53%, the C: N ratio was 21.63 and from the proximate analysis; ash was 6.15-5.12% and the empirical formula developed was $C_{26.3}H_{40.8}NO_{14.6}$ for Solan town, while $C_{25.5}H_{39.5}NO_{13.9}$ for Nahan town. The Chemical characteristics of both Solan and Nahan Cities are given in Table 3 and Table 4.

Table 3: Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, and Ash content in MSW of Solan town (dry weight basis)

Component	Wet Weight (kg)	Dry Weight (kg)	Composition (kg)					
			C	H	O	N	S	Ash
Food Waste	46.93	22	10.56	1.41	8.27	0.57	0.09	1.1
Paper	4.31	2.0	0.87	0.12	0.89	0.01	0	0.12
Cardboard	3.0	1.7	0.73	0.1	0.76	0.01	0	0.09
Plastic	2.21	3.68	2.21	0.26	0.84	0	0	0.37
Textiles	4.22	3.2	1.54	0.2	1.28	0.07	0.01	0.1
Rubber	2.0	2.0	1.39	0.17	0	0	0.03	0.4
Leather	2.18	2.18	1.31	0.17	0.25	0.22	0.01	0.22
Yard Waste	7.82	4.3	1.98	0.26	1.63	0.15	0.01	0.27
Wood	4.55	3.0	1.49	0.18	1.28	0.01	0.0	0.05
Total	78.69	44.06	22.07	2.88	15.21	1.02	0.16	2.71

Table 4: Molar Composition of the elements neglecting the Ash Content

Element	Component Weight	Atomic Weight (kg/moles)	Moles	Formula if Nitrogen (N) =1
Carbon	22.07	12.01	1.84	26.3
Hydrogen	2.88	1.01	2.85	40.8
Oxygen	15.21	16	0.95	13.6
Nitrogen	1.02	14.01	0.07	1
Sulphur	0.16	32.07	0	0.1

Table 5: Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, and Ash content in MSW of Nahan town (dry weight basis)

Component	Wet Weight (kg)	Dry Weight (kg)	Composition (kg)					
			C	H	O	N	S	Ash
Food Waste	52.4	23.6	11.33	1.51	8.87	0.61	0.09	1.18
Paper	14.5	6.9	2.99	0.4	3.06	0.02	0.01	0.41
Cardboard	5	3.3	1.42	0.19	1.48	0.01	0.01	0.17
Plastic	7	6.8	4.08	0.49	1.55	0	0	0.68
Textiles	4.5	4	1.92	`0.26	1.6	0.09	0.01	0.13
Rubber	3.4	3.4	2.3	0.29	0.0	0.0	0.05	0.66
Leather	5.7	5.7	3.24	0.43	0.63	0.54	0.02	0.54
Yard Waste	12.8	7	3.22	0.42	2.66	0.24	0.02	0.44
Wood	10.4	6.5	3.22	0.39	2.78	0.01	0.01	0.1
Total	115.7	67.2	33.72	4.38	22.62	1.52	0.22	4.31

Table 6: Molar Composition of the elements neglecting the Ash Content

Element	Component Weight	Atomic Weight (kg/moles)	Moles	Formula if Nitrogen (N) =1
Carbon	33.72	12.01	2.81	25.5
Hydrogen	4.38	1.01	4.34	39.5
Oxygen	22.62	16	1.41	12.9
Nitrogen	1.52	14.01	0.11	1.0
Sulphur	0.22	32.07	0.01	0.1

3.6 Current Treatment System and technological Option

Composting of MSW is one of the treatment method, diverting organic waste from the waste streams and thus eliminating the use of landfills in the study area. It may be noted that composting method is required maximum land for windrows. However, these landfill sites are located on a steep hilly slope and are also facing land availability issue for the treatment. So, there is a need of other sustainable treatment option for treatment of MSW. It is quite evident that the world is heading towards the renewable energy and the potential of producing renewable energy from waste quantities have been well recognized in front of the global community. This can lead to the use of local resources for producing renewable energy by reducing the quantity of overall waste generated and ultimately can contribute towards reducing the GHGs from waste sector. This conversion of Waste-to-energy (WtE), can help to promote the management of MSW by sustainable means and can help the municipalities to get a surplus of energy to overcome the gaps in terms of energy requirement and financial burdens.

Similarly, the possibilities for conversion of Waste-to-energy is also explored for the treatment of waste in Solan and Nahan towns. However, data on the energy content is required before any technological suggestion for treatment of waste in these towns. Hence, we examined and estimated the energy content for Solan and Nahan towns (Table 7 and 8). The Energy Content for Solan dumping site was estimated as 8742.95 KJ/tonne while, the Energy Content in for Nahan dumping site was 10607.72 KJ/tonne.

Table 7: Total energy content in the MSW of Solan Dumping Site (On Wet Weight basis)

Waste Category	Solid Waste (%age)	Standard Energy content Values (btu/lb) (Tchobanoglous *et al*., 1993)	Standard Energy content values in KJ/Kg	Total Energy Content KJ/tonne
Food Waste (mixed)	46.93	2000.00	4652.00	2183.1836
Paper Mixed	4.31	7200.00	16747.20	721.8043
Cardboard	3.00	7000.00	16282.00	488.46
Plastic	3.68	14000.00	32564.00	1198.3552
Textile	4.22	7500.00	17445.00	736.1790
Rubber	2.00	10000.00	23260.00	465.20
Leather	2.18	7500.00	17445.00	380.3010
Garden Waste	7.82	2800.00	6512.80	509.3010
Wood Waste	4.55	8000.00	18608.00	846.6640
Glass	1.42	60.00	139.56	1.9818
Tin Cans	1.42	300.00	697.80	9.9088
Aluminium	0.80	0.00	0.00	0.00
Metals (Mixed)	0.50	300.00	697.80	3.4890
Dirt/Ashes etc.	17.17	3000.00	6978.00	1198.1226
Total	100.00			8742.9502

Table 8: Total energy content in the MSW of Nahan Dumping Site (On Wet Weight basis)

Waste Category	Solid Waste (%age)	Standard Energy content Values (btu/lb) (Tchobanoglous *et al*., 1993)	Standard Energy content values in KJ/Kg	Total Energy Content KJ/tonne
Food Waste (mixed)	35.50	2000	4652	1651.46
Paper Mixed	11.50	7200	16747.2	1925.928
Cardboard	5.00	7000	16282	814.10
Plastic	5.00	14000	32564	1628.20
Textile	3.50	7500	17445	610.575
Rubber	3.40	10000	23260	790.84
Leather	5.60	7500	17445	976.92
Garden Waste	9.00	2800	6512.8	586.152
Wood Waste	7.00	8000	18608	1302.56
Glass	5.00	60	139.56	6.978
Tin Cans	3.00	300	697.8	20.934
Aluminium	0.50	0	0	0.0
Metals (Mixed)	2.00	300	697.8	13.956
Dirt/Ashes etc.	4.00	3000	6978	279.12
Total	100.00			10607.723

It is observed that the MSW of both these towns has enough energy content and conversion of Waste-to-energy can be a better option for the treatment of waste. The benefits include reduction of leachate production, reduction in methane generation which will automatically lead to reduction of greenhouse gases (GHG) emissions.

4. Conclusion

Municipal Solid Waste has been considered a major hazard in our society and creates an additional pressure on concerned municipalities with risks to public health and the environment. The decomposition of biodegradable material in the waste stream can lead to CH_4 and CO_2 emission from this sector which can increase the ambient air temperature and prompt to warming and changing the climate. Hence, an attempt has been made to study the MSW generation, composition, characteristics and treatment option in growing towns i.e. Solan and Nahan of north hilly state (Himachal Pradesh) of India. It is estimated that the Solan Municipal Council is generated about 19,536.17 kg/day MSW while 4,406.50 kg/day in Nahan Municipal Council.

Service Level Benchmark v/s Existing Situation shows a 41% performance level. Organic content was observed maximum (51.13-59.30%) in MSW followed by construction waste (16.27-17.17%), Plastic (3.68-11.27%), Paper (6.59-7.1%), Textile (4.22-5.87%), Rubber/Leather (3.97-4.18%), metal (2.72-3.34%) and Glass (1.42-1.54%). The moisture content is found between 29.15% and 63.15%. From the elemental analysis; carbon was found to be 50.10-50.18%, hydrogen 6.52%, nitrogen 2.23%, oxygen 33.66-34.53%, the C:N ratio was 21.63 and from the proximate analysis; ash was 6.15-5.12% and the empirical formula developed was $C_{26.3}H_{40.8}NO_{14.6}$ for Solan city, while $C_{25.5}H_{39.5}NO_{13.9}$ for Nahan city. The Energy Content for Solan dumping site was estimated as 8742.95 KJ/tonne while, the Energy Content in for Nahan dumping site was 10607.72 KJ/tonne. It is observed that the MSW of both these towns has enough energy content and conversion of Waste-to-energy can be a better option for the treatment of waste. The benefits include reduction of leachate production, reduction in methane generation which will automatically lead to reduction of greenhouse gases (GHG) emissions.

5. Acknowledgments

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