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RESEARCH ARTICLE

COMPARATIVE ANALYSIS OF SOLID WASTE MANAGEMENT IN DEVELOPING SMART CITIES OF INDIA BY AHP: A CASE STUDY.

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Abstract

In developing scenario of India, the concept of smart cities is playing a crucial role. The solid waste management is necessary not only in maintaining the hygienic environment but in reducing the probable health hazards. The current study deals in obtaining weightage of chief ingredient of solid waste management viz. chief criteria like waste collection, transportation, disposal, energy recovery etc. along with their respective sub criteria. Putting these weightage to reference, the data obtained in the survey study from Indore, Jabalpur and Nagpur city will be compared. This study will provide vital results to identify achievements as well as the lacuna in the solid waste management process of the respective cities.

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Introduction:-

In the current study, the data regarding the collection, transportation, disposal, energy recovery, financial issues and social awareness was collected from the officials as well as public. With the above given chief criteria and sub criteria of each particular criteria, a result with the help of pairwise comparison, was generated. This result achieved lead the study to build an ideal weightage of each element in the performance index.

AHP that is Analytic Hierarchy Process is a multi-criteria decision making method. AHP derives ratio scales from paired comparisons of criteria and allows for some small inconsistencies in judgments. Inputs can be actual measurements, but also subjective opinions. This method is theoretically sound for weighting and selecting individual indicators. In a hierarchical model of a decision problem, broad overall objective is the crown of the structure. The lower levels includes the criteria, sub criteria and also alternatives used for evaluation.

AHP consists of three main principles, including hierarchy frame work, priority analysis and consistency verification. Formulating the decision problem in the form of hierarchy framework is first step of AHP, while top level presents object, and later presents criteria and sub-criteria and alternatives. Once a hierarchy framework is constructed, a pair wise comparison matrix is setup at each levels and compare each other according to Saaty's scale. In this study, use of AHP was constructed considering SWM of cities and the criteria are considered. Mathematically the method is based on the solution of an Eigen value problem. The results of the pair-wise comparisons are arranged in a matrix. The first normalized Eigen vector of the matrix gives the ratio scale (weighting), the largest Eigen value determines the consistency ratio.

Mathematical Formulation for Identification of Weight of Indicator:-**Table 1:-Main Criteria**

	Collection & storage	transportation	Disposal	Energy recovery	Financial issue	Awareness
Collection & Storage	1	2.2	2.5	3	2.5	1.5
Transportation	0.45	1	2.4	3	0.38	2
Disposal	0.4	0.42	1	2	0.33	1.5
Energy recovery	0.333	0.33	0.5	1	0.41	0.43
Financial issue	0.4	2.6	3	2.4	1	2.5
Awareness	0.28	0.5	0.666	2.3	0.4	1
Total	2.863	7.05	10.066	13.7	5.02	8.93

Table 2:-Main Criteria Normalised Matrix

	Collection & storage	transportation	Disposal	Energy recovery	Financial issue	Awareness	Average	%
Collection & Storage	0.349	0.312	0.248	0.218	0.498	0.167	0.2986	29.86
transportation	0.157	0.141	0.238	0.218	0.075	0.223	0.1753	17.53
Disposal	0.139	0.059	0.099	0.145	0.065	0.167	0.1123	11.23
Energy recovery	0.116	0.046	0.049	0.072	0.081	0.048	0.0686	6.86
Financial issue	0.139	0.368	0.298	0.175	0.199	0.279	0.2469	24.69
Awareness	0.097	0.070	0.066	0.167	0.079	0.111	0.0983	9.83

Sub Criteria:-**Table 3:-Matrix for Collection and Storage**

	Separation	Dumping	Frequency	Method of collection	Amount	Convenience to segregate	Number of containers
Separation	1	3.5	2.5	3	4.75	3	4.25
Dumping	0.285	1	0.210	0.363	0.307	0.235	0.465
Frequency	0.4	4.75	1	4.15	2.65	2.85	3.55
Method of collection	0.333	2.75	0.240	1	0.980	3.444	0.680
Amount	0.210	3.25	0.377	1.02	1	0.2	0.350
Convenience to segregate	0.333	4.25	0.350	2.25	5	1	3.35
Number of containers	0.235	2.15	0.281	1.47	2.85	0.298	1
Total	2.796	21.65	4.958	13.253	17.537	8.027	13.645

Table 4:-Normalised Matrix for Collection and Storage

	Separation	Dumping	Frequency	Method of collection	Amount	Convenience to segregate	Number of containers	Average	%
Separation	0.357	0.161	0.504	0.226	0.270	0.373	0.311	0.314	31.4
Dumping	0.101	0.046	0.042	0.227	0.017	0.029	0.034	0.042	4.24
Frequency	0.143	0.219	0.201	0.313	0.151	0.355	0.260	0.238	23.8
Method of collection	0.199	0.127	0.048	0.075	0.055	0.055	0.049	0.0754	7.54
Amount	0.0751	0.150	0.076	0.076	0.057	0.024	0.025	0.069	6.9
Convenience	0.199	0.196	0.070	0.169	0.285	0.124	0.245	0.1725	17.25

to segregate									
Number of containers	0.084	0.099	0.056	0.110	0.162	0.037	0.073	0.0887	8.87

Table 5:-Matrix for Transportation

	Time of collection	Vehicles used for collection	Frequency of transportation
Time of collection	1	3	2.5
Vehicles used for collection	0.333	1	0.307
Frequency of transportation	0.4	3.25	1
Total	1.733	7.25	3.807

Table 6:-Normalised Matrix for Transportation

	Time of collection	Vehicles used for collection	Frequency of transportation	Average	%
Time of collection	0.577	0.413	0.656	0.547	54.7
Vehicles used for collection	0.192	0.137	0.080	0.136	13.6
Frequency of transportation	0.230	0.448	0.262	0.317	31.7

Table 7:-Matrix for Disposal

	Landfilling	Incineration	Recycling	Biological processing
Landfilling	1	2.5	0.210	0.1666
Incineration	0.4	1	0.181	0.275
Recycling	4.75	5.5	1	1.5
Biological processing	6	3.625	0.666	1
Total	12.15	12.625	2.057	2.9416

Table 8:-Normalised Matrix for Disposal

	Landfilling	Incineration	Recycling	Biological processing	Average	%
Landfilling	0.082	0.198	0.102	0.056	0.1095	10.95%
Incineration	0.032	0.079	0.087	0.093	0.0727	7.27%
Recycling	0.390	0.435	0.486	0.510	0.457	45.7%
Biological processing	0.493	0.287	0.323	0.340	0.3608	36.08%

Table 9:-Matrix for Energy Recovery

	Waste to energy	Efficiency	Segregation of waste
Waste to energy	1	1.2	0.2
Efficiency	0.833	1	0.333
Segregation of waste	5	3	1
Total	6.833	5.2	1.533

Table 10:-Normalised Matrix for Energy Recovery

	Waste to energy	Efficiency	Segregation of waste	Average	%
Waste to energy	0.146	0.230	0.130	0.168	16.80
Efficiency	0.121	0.192	0.217	0.176	17.60

Segregation of waste	0.731	0.576	0.652	0.656	65.60
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Table 11:-Matrix for Financial Issue

	Safety measure	monthly expenditure	Fine	Tax	Man power	Profit	Waste cultivation	Workers salary
Safety measure	1	4.5	3	3	2.5	2.85	3.5	2.65
monthly expenditure	0.222	1	3	2.64	1.85	1.75	3.8	1.2
Fine	0.333	0.333	1	2.75	2.64	1.25	0.222	0.666
Tax	0.333	0.378	0.363	1	0.333	1.2	0.222	2.5
Man power	0.4	0.540	0.378	3	1	2.5	0.4	1.25
Profit	0.350	0.571	0.8	0.833	0.4	1	0.333	0.952
Waste cultivation	0.285	0.263	4.5	4.5	2.5	3	1	3
Workers salary	0.377	0.833	1.5	0.4	0.8	1.05	0.333	1
total	3.3	8.418	14.541	18.123	12.023	14.6	9.81	13.218

Table 12:-Normalised Matrix for Financial Issue

	Safety measure	monthly expenditure	Fine	Tax	Man power	Profit	Waste cultivation	Workers salary	Average	%
Safety measure	0.303	0.534	0.206	0.165	0.207	0.195	0.356	0.200	0.2707	27.07
monthly expenditure	0.067	0.118	0.206	0.145	0.153	0.119	0.387	0.090	0.1606	16.06
Fine	0.100	0.0395	0.068	0.151	0.219	0.085	0.022	0.050	0.0917	9.67
Tax	0.100	0.044	0.024	0.055	0.027	0.082	0.022	0.189	0.0678	6.78
Man power	0.121	0.064	0.025	0.165	0.083	0.171	0.040	0.094	0.0953	9.53
Profit	0.106	0.067	0.055	0.045	0.033	0.068	0.033	0.072	0.0598	5.98
Waste cultivation	0.086	0.031	0.309	0.248	0.207	0.205	0.101	0.226	0.1760	17.64
Workers salary	0.114	0.098	0.103	0.022	0.066	0.071	0.033	0.075	0.0727	7.27

Table 13:-Matrix for Awareness

	Campaign	Mobile application	Adverting promotion	Complaints
Campaign	1	4.5	0.380	3.75
Mobile application	0.222	1	0.258	1.25
Adverting promotion	2.625	3.875	1	2.75
Complaints	0.266	0.8	0.347	1
	4.11	10.17	1.98	8.75

Table 14:-Normalised Matrix for Awareness

	Campaign	Mobile application	Adverting promotion	Complaints	Average	%
Campaign	0.243	0.442	0.191	0.428	0.3269	32.69%
Mobile application	0.053	0.098	0.129	0.142	0.1056	10.56%
Adverting promotion	0.638	0.380	0.503	0.314	0.4599	45.99%
Complaints	0.064	0.0786	0.174	0.114	0.1076	10.76%

Check for the consistency:-

Calculate largest Eigen value $\delta = S_{c1} X_1 + S_{c2} X_2 + S_{c3} X_3 + S_{c4} X_4 + S_{c5} X_5 + S_{c6} X_6$

Calculate consistency index (CI),

$$CI = \frac{\delta - n}{n - 1}$$

Verify consistency ratio (CR) < 10%

$$CR = \frac{CI}{RI}$$

Order of the matrix															
Matrix order no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI value	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

Figure 1:-Random Index RI (The Consistency Indices of Randomly Generated Reciprocal Matrices)

Referring the equations above, largest Eigen value δ , consistency index and consistency ratio can be calculated. Each criteria, sub criteria and weights are calculated and checked for consistency. Value of consistency ratio should be less than 0.1 at all levels then and only then the judgements are granted correct.

Weight of sub criteria in each set is multiplied by weight of main criteria of its own criteria to determine its weight in whole system.

Calculations of the main criteria to verify the judgements by consistency ratio:-

$$\delta = (2.863 \times 0.29) + (7.05 \times 0.175) + (10.06 \times 0.11) + (13.7 \times 0.068) + (5.02 \times 0.24) + (8.93 \times 0.098)$$

$$\text{Total } \delta = 6.3034$$

$$CI = \frac{0.3034 - 6}{6 - 1} = \frac{0.3034}{5} = 0.060$$

$$CR = \frac{0.060}{1.24} = 0.0489 < 0.1$$

Calculation of every sub criteria was calculated as per the process explained above for the main criteria. The CR value of each of the sub criteria came out to be less than 0.1 which proves the judgements correct.

Comparative analysis of SWM of Jabalpur, Indore and Nagpur cities of India:-

Jabalpur city is located in Jabalpur district of Madhya Pradesh state, on the right Bank of Narmada River. Jabalpur city lies at having coordinates 79° 55' 37" to 79° 57' 54" longitudes and 23° 09' 10" to 23° 11' 06" latitudes. Jabalpur is among the major cities of Madhya Pradesh. The population sum ups up to 1,055,525, and decadal growth rate of 14.51% (according to the 2011 census). The growth of urban population in large Indian cities is leading to pressure of municipal bodies for effective services, SWM being one of the foremost challenges confronting the municipal bodies. Local households, markets, commercial establishments, hotels, restaurants, and hospitals serve as the primary source for production of solid waste. The total quantity of waste generated per day is in the order of 516 tons at the rate of 432 gpcd. In the absence of significant tourism-related activity, there is no significant seasonal variation in the quantity of waste generated.

Nagpur is the 13th largest Indian city in terms of population. It has been proposed as one of the Smart Cities in Maharashtra. Nagpur lies at having coordinates 21.15N 79.09E. The city covers an area under NMC limit of 227.36 Sq.km and population of the city as per the 2011 census is 23,98,165. The city is divided into 38 wards. The Nagpur Mahanagar Corporation gave contract to private companies that will work on the project 'electricity from the waste'. Currently, Bhandewadi area dumping ground is used for the collection of the waste. The project was signed by the NMC back in 2017 which will last for next 15 years including 2 years of construction. NMC donated around 248 Crores for the project. From this project around 11.5 MW electricity will be produced which will be sold at 7 Rs/unit.

Indore is the most populous and the largest city in the Indian state of Madhya Pradesh. It comes under Tier 2 cities in India. Indore lies at having Coordinates 22°43'0"N 75°50'50"E covering area 530 sq. km. It has been ranked first in Swachh Bharat Abhiyan two years in a row (2017 and 2018) and is the cleanest city in India. The city generates nearly 50,000 kilos of municipal waste every day, 13,000 kilos of which is plastic waste. Plastic is non-biodegradable and much of it is difficult to recycle. The city used to dispose its daily plastic waste, all 13,000 kilos of it, by burning it. Just five months ago, the city was almost choking in smog caused due to the burning of such

large amounts of plastic. This is when the Indore Municipal Corporation (IMC) decided to change its strategy and overturn the despicable state of Indore's plastic waste. In January this year they set up a Plastic Collection Centre (PCC) to reuse and recycle the city's plastic waste.

This paper presents the results of a subsequent comparative analysis of the 3 cities, using the fresh and existing data collected to compare and contrast solid waste management systems. This is important to compare performance of cities and to allow cities to learn from each other. Comparative analysis of solid waste management system of Jabalpur, Indore and Nagpur is carried and results are given in below tables.

Collection & storage:-

Main criteria collection & storage covers separation of SW, dumping of SW, frequency of collection at house hold and further level, type of collection i.e. By hand cart, truck or other vehicle, segregation at different levels, amount of waste, type of waste collected from city. The score of criteria collection & storage given in table 15.

It is observed from the score of collection and storage that Indore leads in the first place because it scored 258.55 that is 87% of the weightage. Indore has a better system for collection and segregation of waste and 100% frequency of waste collection. Every day door to door collection twice a day increase awareness in public. Jabalpur has door to door collection but it reached only 60-70%. Jabalpur and Nagpur needs to improvise in terms of collection and segregation of waste.

Table15:- Score of Main Criteria Collection & Storage

Code	Collection & storage	Weight of sub criteria	Score of Jabalpur	Score of Indore	Score of Nagpur
01	Separation	93.76	75.00	81.61	66.97
02	Dumping	12.66	7.59	10.52	5.54
03	Frequency	71.06	42.63	70.36	29.77
04	Method of collection	22.5	14.35	19.85	10.28
05	Amount	20.69	9.72	18.46	8.43
06	Convenience to segregate	51.508	31.78	44.91	23.05
07	Number of containers	26.48	17.57	22.84	14.62
		298.59	198.64	258.55	158.66

Transportation:-

Main criteria transportation covers type of vehicle used for system, time of collection and frequency of transport of solid waste from city. Score of criteria transportation given in table 16. Indore has a better transportation system of waste management. It achieves about 96 percentile of the actual weightage. Indore have 800 vehicles with live tracking by GPS system. They collect garbage twice a day from every area of city. The city also segregated compartments for wet and dry waste, for bio medical waste different cart run all over the city.

Jabalpur has 60 around vehicles and 400 hand cart for collection of waste from different parts of the city. Door to door collection done once a day that it achieves 63% of actual weightage and Nagpur 43%.

Table16:- Score of Main Criteria Transportation

Code	transportation	Weight of sub criteria	Score of Jabalpur	Score of Indore	Score of Nagpur
08	Time of collection	95.88	57.52	87.70	40.17
09	Vehicles used for collection	23.84	19.07	23.84	12.87
10	Frequency of transportation	55.57	33.34	55.57	22.22
		175.29	109.93	167.11	75.26

Disposal:-

In the process of solid waste management, there are different ways of disposal i.e. landfilling, incineration, recycling and biological processing can be implemented depending upon the material. In incineration processing Jabalpur have a 100% score as the incineration plant is in fully working state. Along with incineration, biological processing is also implemented but due to lack of segregation of waste, larger portion of waste which is biologically treated is sent for the incineration plant.

In Indore they have Asia's biggest bio-methanisation plant which treats around 20 tons of organic waste daily, so in biological processing it scores 100%. From being labelled as the biggest plastic waste generator in Madhya Pradesh in 2013, to putting 50% of city's plastic waste to reuse in 2017, Indore is a shining example to other big cities in India battling with waste management woes. Nagpur show poor performance in this criteria it does not have any proper solid waste management plant and not any recycling done at government level. Score of criteria Disposal given in table 17.

Table 17:-Score of Main Criteria Disposal

Code	Disposal	Weight of sub criteria	Score of Jabalpur	Score of Indore	Score of Nagpur
11	Landfilling	12.29	12.29	12.29	7.37
12	Incineration	8.164	8.164	6.53	3.26
13	Recycling	51.422	25.66	45.16	30.79
14	Biological processing	40.517	24.31	40.517	16.20
		112.2392	70.42	104.49	57.62

Energy recovery:-

Waste to energy (WTE) is a term that is used to describe various technologies that convert non-recyclable waste into usable forms of energy including heat, fuels and electricity. WTE can occur through a number of processes such as incineration, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery. Here, the term WTE is commonly used in specific reference to incineration which burns completely combusted waste at ultra-high temperatures allowing for energy recovery. In this, Indore and Jabalpur both have nearly equivalent percentage.

Jabalpur had waste to energy plant at Kathonda, which converts waste of all over city into useful energy (electricity, ash, fuel gases) but efficiency of plant affected if waste is not segregated properly because wet waste has more energy to burn which reduces the efficiency of plant so that wet waste is not properly sent to composting sites.

Indore has its bio-methanation plant but waste to energy plant is not present currently.

Nagpur has its own energy recovery project 'electricity from the waste'. The project was signed by the NMC back in 2017 which will last for next 15 years including 2 years of construction. It is still not completed. Score of criteria Energy recovery given in table 18.

Table 18:-Score of Main Criteria Energy Recovery

Code	Energy recovery	Weight of sub criteria	Score of Jabalpur	Score of Indore	Score of Nagpur
15	Waste to energy	11.524	9.68	8.29	4.60
16	Efficiency	12.073	9.65	6.03	2.41
17	Segregation of waste	45	31.5	41.4	18
		68.59	50.83	55.75	25.01

Financial issue:-

This includes safety measures for workers; whole monthly expenditure for waste collection, transportation, disposal, energy recovery and also workers salary; fine for not following direction and tax for management from public; no of workers and vehicles; profit from energy recovery plant, recycling plant etc.

In financial evaluation Indore scored 90% as it recycles 50% of plastic. Indore generates compost out of biological waste. This city municipal corporation has also set particular charges in terms of fine for splitting on the public

property, not using dustbins etc. Such strict terms also play an important role in cleaning city and creating awareness. Spot fine collection has been roughly noted to around 80lacs in last 18months in Indore. Indore have 800 vehicles with live tracking by GPS system. 2200 twin bins installed in 92 commercial areas. Total number of staff is 6500 at present. Estimated amount spent on the drive was 60crore.

In Jabalpur total number of staff is 3200 at present. Estimated spent amount for waste management plant is 1470 rupee per ton. Waste generation per day around is 520 +/- 10% TPD which is likely to reach at around 600 TPD by 2020. At present plant is working with the capacity of 580 TPD which shows that it only meets present demand and cannot process the dumped waste. This year plant runs on 90% PLF and efficiency at net calorific value 1650 Kcal/Kg. Score of criteria financial issue is given in table 19.

Table 19:-Score of Main Criteria Financial Issue

Code	Financial	Weight of sub criteria	Score of Jabalpur	Score of Indore	Score of Nagpur
18	Safety measure	66.83	40.09	53.54	33.41
19	monthly expenditure	39.652	35.68	35.68	23.79
20	Fine	23.87	9.54	23.87	4.77
21	Tax	16.73	16.73	16.73	16.73
22	Man power	23.52	18.81	23.52	14.11
23	Profit	14.76	10.33	11.80	7.38
24	Waste cultivation	43.55	33.09	41.80	21.77
25	Workers salary	17.94	14.35	16.14	12.55
TOTAL		246.85	178.62	223.08	134.51

Awareness:-

Awareness is very important because public support and is must for proper regulation of solid waste management in cities. This includes campaigns, adverting promotion, and use of mobile applications to achieve the goal of clean cities. How local government react on complaints also encourages public.

Indore has the best performance among other cities. In Indore 6 NGOs including BASIX with 400 volunteers have been roped in to explain sorting, segregation and to create public awareness. A huge awareness campaign was launched across media likeradio FM, TV advertisements, jingles, talk shows and newspapers. Slogans have been painted on one & half lakh square metre of wall space across city. 1, 27,012 swachhta app "Help line 311" downloaded in Indore and from 37,486 complaints 35,548 complaints had been resolved within 24 hours (94.83%).

In Jabalpur slogans have been painted and in some area goal of clean city had been achieved though it is not fulfilled by every area of city. Some parts of city are still unaware of the scheme. Mobile application was launched in Jabalpur nagar nigam but due to lack of mobile application users very few complaints had been received.

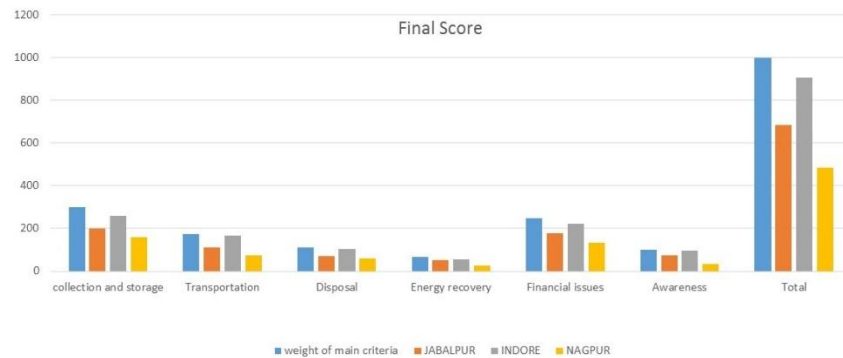
Nagpur had poor performance in this criterion. Nagpur lacksadvertising, mobile application and even few wall slogans wereobservedonly in the civil areas. Score of criteria Awareness given in table 20.

Table 20:-Score of Main Criteria Awareness

Code	Awareness	Weight of sub criteria	Score of Jabalpur	Score of Indore	Score of Nagpur
26	Campaign	32.13	25.70	32.13	12.85
27	Mobile application	10.380	7.26	9.34	2.07
28	Adverting promotion	45.208	36.16	45.208	18.06
29	Complaints	10.57	6.34	9.93	2.11
		98.288	75.46	96.60	35.09

Table 21:-Final Score Showing the Performance of Jabalpur, Indore and Nagpur

Main criteria	Weight of main criteria	Final Score of Jabalpur	Final Score of Indore	Final Score of Nagpur
Collection & storage	298.59	198.64 (66.52%)	258.55(86.59%)	158.66(53.31%)
Transportation	175.29	109.93(62.71%)	167.11(95.33%)	75.26(42.93%)
Disposal	112.392	70.42(62.65%)	104.49(92.96%)	57.62(51.26%)
Energy recovery	68.59	50.83(74.10%)	55.75(81.28%)	25.01(36.46%)
Financial issue	246.85	178.62(72.35%)	223.08(90.37%)	134.51(54.49%)
Awareness	98.288	75.46(76.77%)	96.60(98.28%)	35.09(35.70%)
Total	1000.0	683.9 (68.39%)	905.58 (90.55%)	486.15 (48.61%)

**Figure 2:-**Performance of Jabalpur, Indore and Nagpur

Conclusion:-

Municipal solid waste management is an important factor concerning wellness of the natural environment. In the current study, by pairwise comparison of every element in the hierarchy model, judgemental values were calculated that were further used for the calculation of weightage of the criteria and sub criteria of SWM indicators. The whole process of calculation was termed as analytical hierarchy process (AHP). Referring the table, it can be stated that Indore is efficient in all the categories in SWM. Indore has the best waste transportation system with the usage of multiple number of vehicles (95.33%), highest percentage of social awareness created by implementing social media, mobile application, visual and audible social media as well as advertisements. Jabalpur has performed moderately in all the categories while Nagpur has to the lowest percentage in all the categories.

Though every city corporation have some proposed plans viz. waste to energy recovery plant proposal in Nagpur as well as Indore city etc. and they are taking positive steps for the contribution in the cleanliness of the nation, these cities should follow steps taken by well managed cities for quicker growth in the field of solid waste management.

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