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Application of Solid Waste Performance Index for Infrastructural Development

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Abstract—*In this study, a novel Solid waste performance index (SWPI) is proposed to understand the infrastructural development of the cities according to fifteen different indicators, i.e. estimated population, floating population, area of municipal corporation (sq. km), no. of households, total waste produced (tons per day), biodegradable waste (tons per day), non-biodegradable waste (tons per day), other waste (tons per day), no. of zones, no. of wards, no. of sanitation workers, no. of vehicle fleet size, households under door to door collection (%), households covered in which segregation of waste (%) and waste processed (%). To overcome the previous problems (eclipsing and ambiguity) involved in indexing process, this study used Principal Component Analysis (PCA) and hybrid aggregation technique for development of SWPI. Accordingly, Bhopal in Madhya Pradesh ranked one (SWPI = 0.26), whereas Kakinada in Andhra Pradesh got last rank (SWPI = 0) among all the 28 cities. This study will be useful for researchers and academia to analyze the infrastructural development of different places globally.*

Keywords: *Solid waste infrastructure, Performance indicators, Index, Principal Component Analysis, Aggregation, Arithmetic, Geometric, Rank.*

INTRODUCTION

The management of municipal solid waste has emerged as a critical issue in the face of rapid urbanization [6, 10, 17], causing significant concern among Municipal Corporations, Government Departments, Urban Development Authorities, regulatory bodies, and the general public in many developing countries. The majority of the published literature has focused on high income countries, and very few on developing countries [16, 18]. In recent years, there has been a great deal of focus on developing indicators for specific aspects of the modernization of a solid waste management (SWM) system.

In India, ten solid waste management indicators were carried out in more than 400 urban local bodies (ULB's) across Gujarat and Maharashtra five year project to create and demonstrate a framework for measuring performance in urban water and sanitation [1]. In mid-20th century the average municipal solid waste generation rate in India was 100 gm/capita/day to 450 gm/capita/day. According to TERI (The Energy Resources Institute) India's waste generation is likely to happen exceed 260 million tons per year in the year 2047 [8].

The World Bank reports that the world is currently generating 2.01 billion tons of municipal solid waste (MSW), out of which more than 33% is managed in an unsafe environmental manner [7]. The report also forecasts that the MSW generated by the world will increase to reach 2.59 billion tons by 2030 and 3.4 billion tons by 2050. Also the report stated that MSW production 3.5 million tons per day by the year 2019 to 6.1 million tons per day by the year 2025 [16].

MATERIAL AND METHODS

The development of solid waste performance index (SWPI) consists of four major steps, as follows:

2.1 Selection of performance indicators (PIs)

According to the survey conducted by NITI Aayog (2021) [9] presented 15 PIs are as follow: estimated population (C1), floating population (C2), area of Municipal Corporation (sq. km) (C3), no. of households (C4), total waste produced (tons per day) (C5), biodegradable waste (tons per day) (C6), non-biodegradable waste (tons per day) (C7), other waste (tons per day) (C8), no. of zones (C9), no. of wards (C10), no. of sanitation workers (C11), no. of vehicle fleet size (C12), households under door to door collection (%) (C13), households covered in which segregation of waste (%) (C14), waste processed (%) (C15).

2.2 Clustered the performance indicators and data reduction using Principal Component Analysis (PCA)

The statistical software (SPSS) used for clustering the indicators and reducing the components into principal components (Eigen value >1) [2].

2.3 Development of sub-indices

The value of sub-indices determined using the principal components value.

2.4 Using hybrid aggregation technique to obtain final index value

After the development of sub-indices the hybrid aggregation method used to reduce the eclipsing and ambiguity problem [3, 4, 12, 14, 15]. The final SWPI obtained using Eq. (1) as follows:

$$\mathrm{SWPI} = (Q_i Q_j Q_k)^{1/p} \qquad \text{Eq. (1)}$$

where,

SWPI = solid waste performance index
p = number of principal components
Q_i, Q_j, Q_k = sub-indices
i, j, k = components.

ANALYSIS

The analysis were carried out using Principal Component Analysis (PCA), the indicators are grouped into rotated component matrix to correlate between indicators and principal components. The principal components have eigen values more than 1. The curve (scree plot) is plotted between eigen value and component number [2, 5, 11, 13].

Table 1 presents the rotated component matrix. There are three principal components which account for highest value (neglected negative sign). Principal Component (PC) 1 has maximum value (0.981) of C5 (total waste produced (tons per day)). The PC1 accounts for C1, C2, C3, C4, C5, C6, C7, C8, C10, C11, C12 and C14. Similarly, C9 (no. of zones) is the PC2 also accounted C9 and C13. Lastly, PC3 accounted C15 (waste processed (%)) has accounted its maximum value of 0.915.

Table 1: Rotated component matrix for 28 cities

Performance indicators	Principal Components			Component function
	1	2	3	
C1	**0.975**	0.029	-0.163	**0.975**
C2	**0.907**	0.114	-0.092	**0.907**
C3	**0.917**	0.167	-0.037	**0.917**
C4	**0.945**	0.083	-0.144	**0.945**
C5	**0.981**	-0.003	-0.173	**0.981**
C6	**0.966**	0.044	-0.172	**0.966**
C7	**0.951**	-0.047	-0.162	**0.951**
C8	**0.944**	-0.091	-0.186	**0.944**
C9	0.064	**0.922**	0.080	**0.922**
C10	**0.584**	0.576	-0.010	**0.584**
C11	**0.920**	-0.040	-0.080	**0.920**
C12	**0.842**	0.110	-0.106	**0.842**
C13	0.207	**-0.701**	0.425	**0.701**
C14	**-0.644**	0.177	0.578	**0.644**
C15	-0.219	-0.155	**0.915**	**0.915**

Figure 1 presents the scree plot (Eigen value vs Component number) observed first three eigen values are more than 1. The first three components consist of 66.628%, 12.151% and 7.621% variance respectively which is cumulative 86.4% of total variance. Further, hybrid aggregation technique (combination of arithmetic and geometric methods) applied to calculate the sub-indices as follow using Eq. (2).

$$\mathrm{SWPI} = (Q_i Q_j Q_k)^{1/3} \qquad \text{Eq. (2)}$$

where,

$$Q_i = \frac{C1 + C2 + C3 + C4 + C5 + C6 + C7 + C8 + C10 + C11 + C12 + C14}{12}$$

$$Q_j = \frac{C9 + C13}{2}$$

$$Q_k = C15$$

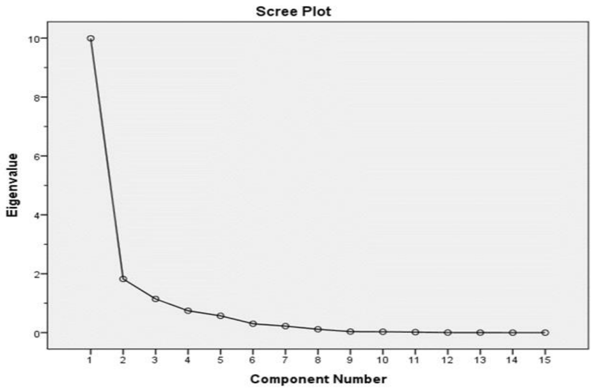

Figure 1: Scree plot for 28 cities (using PCA)

The SWPI is simplified as,

$$\mathrm{SWPI} = \left[\left\{\frac{1}{12}\sum_{i=1}^{12} Q_i\right\} * \left\{\frac{1}{2}\sum_{j=1}^{2} Q_j\right\} * \{Q_k\}\right] \qquad \text{Eq. (3)}$$

RESULTS AND DISCUSSION

Table 2 was categorized into three classes based on SWPI. Table 3 presented the rank of 28 cities with their SWPI value and also class of indices. Results reveal that Bhopal in Madhya Pradesh ranks first and Kakinada in Andhra Pradesh got last rank among all the 28 cities. Its SWPI value (using Eq. (3)) was 0.263 which is highest among all the 28 utilities in India. This highest value of sub-indices Qi, Qj and Qk for Bhopal are 0.302202, 0.869565 and 1 respectively. Further Pune (0.231370), Surat (0.227232) and Indore (0.217729) secured second, third and fourth rank respectively. Although, Kakinada got last rank among all the cities has zero value because Qk got zero value. Thiruvananthapuram got second last rank has SWPI value 0.005464.

Table 2: Classification of SWPI range for 28 cities

SWPI range	Classification
Greater than 0.2	Good
Between 0.1 to 0.2	Average
Less than 0.1	Poor

Table 3: Rank of 28 cities with their class

S. No.	Name of city	SWPI	Rank	Classification
1	Bhopal	0.263	1	Good
2	Pune	0.231	2	Good
3	Surat	0.227	3	Good
4	Indore	0.218	4	Good
5	Jamshedpur	0.160	5	Average
6	North Delhi	0.116	6	Average
7	Ambikapur	0.087	7	Poor
8	Vijayawada	0.073	8	Poor
9	Bobbili	0.053	9	Poor
10	Keonjhar	0.050	10	Poor
11	Dhenkanal	0.050		Poor
12	Paradeep	0.049	11	Poor
13	Leh	0.047	12	Poor
14	Panchgani	0.047		Poor
15	Vengurla	0.044	13	Poor
16	Karad	0.043	14	Poor
17	Chandrapur	0.043		Poor
18	Bicholim	0.040	15	Poor
19	Taliparamba	0.036	16	Poor
20	Mysuru	0.035	17	Poor
21	Panaji	0.034	18	Poor
22	Alappuzha	0.032	19	Poor
23	Bengaluru	0.022	20	Poor
24	Kumbakonam	0.009	21	Poor
25	Gangtok	0.008	22	Poor
26	Gurugram	0.008		Poor
27	Thiruvananthapuram	0.005	23	Poor
28	Kakinada	0.000	24	Poor

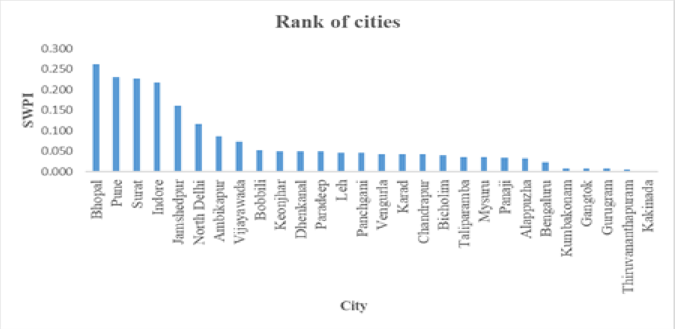

Figure 2: Bar diagram showing rank of cities in order

CONCLUSIONS

This study used hybrid aggregation technique to minimize the problem of eclipsing and ambiguity in the development of sub-indices and the development of final index (SWPI) value is the combination of Principal Component Analysis (PCA) and hybrid aggregation technique. Among the top four good ranked cities with a SWPI score more than 0.20, the state Madhya Pradesh have two i.e Bhopal (1st) and Indore (4th). According to researcher with score less than 0.10 (poor class), Keonjhar and Dhenkanal, Leh and Panchgani, Karad and Chandrapur, Gangtok and Gurugram have ten, twelfth, fourteen, twenty-two respectively (Figure 2).

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