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Evaluation of the Contaminated Area Using an Integrated Multi-Attribute Decision-Making Method

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ABSTRACT

Air pollution affects public health and the environment, creating great concern in developed and developing countries. In India, there are numerous reasons for air pollution, and festivals like Diwali also contribute to air contamination. Determining the polluted region using several air contaminants is significant and should be analyzed carefully. This study aims to analyze the air quality in Tamil Nadu, India, during the Diwali festival from 2019 to 2021, based on multiple air pollutants. The study models the impact of air pollution as a Multi-Attribute Decision-Making (MADM) problem. It introduces a hybrid approach, namely the Analytical Hierarchy Process-Entropy-VlseKriterijumska Optimizacija I Kompromisno Resenje (AHP-Entropy-VIKOR) model, to analyze and rank the areas based on the quality of air. A combined approach of AHP and entropy is employed to determine the weights of multiple air pollutants. The VIKOR approach ranks the areas and identifies the areas with the worst air quality during the festival. The proposed model is validated by performing the Spearman's rank correlation with two existing MADM methods: Combinative Distance Based Assessment (CODAS) and Weighted Aggregates Sum Product Assessment (WASPAS). Sensitivity analysis is carried out to assess the effects of the priority weights and the dependency of the pollutants in ranking the regions. The highest air pollution level during the festival was seen in Cellisini Colony (2019), Rayapuram (2020), T. Nagar and Triplicane (2021) in their respective year. The results demonstrate the consistency and efficiency of the proposed approach.

INTRODUCTION

Detrimental atmospheric substances contaminate the air and affect human health and the environment. It arises from various sources, including industrial emissions, transportation, and agricultural activities (Suresh et al. 2021). According to the State of Global Air Report (SGA 2020), air pollution causes around 7 million deaths annually, making it the fourth largest risk factor for death worldwide. Air pollution is a significant public health concern in India because many cities are ranked among the most polluted globally (Verma et al. 2020). Even festivals such as Bhogi and Diwali significantly contribute to air pollution in India. This study focuses on the Diwali festival, known as the "festival of lights." Diwali is celebrated in many parts of the world and is a major festival in India. It is usually celebrated in October or November and marks the victory of good over evil and light over darkness. During the festival, people light fireworks and burn lamps and candles to honor the festival. These rituals enhance the level of sulfur dioxide, nitrogen oxides, particulate matter, and other air pollutants. The consequences of these air pollutants are severe. It causes respiratory and cardiovascular diseases, chronic obstructive pulmonary disease, and many more (Mandal et al. 2022). Creating efficient methods for evaluating air quality based on multiple pollutants to tackle the air pollution issue is crucial. Many studies have employed mathematical methods that convert multiple air pollutant concentrations into a single value, offering a clear representation of the air quality (CPCB 2022, Kumaravel & Vallinayagam 2012, Dionova et al. 2020, Zeydan & Pekkaya 2021).

The sources of these pollutants are diverse and interconnected. Therefore, the present study employed a hybrid MADM model that simultaneously offers ranking and analysis to assist decision-makers in addressing real-time issues involving independent attributes. The main aim of the current research is to formulate a hybrid model that suggests a strategy for enhancing air quality. MADM is a branch of Operations Research that assists in evaluating decision alternatives against a performance attribute by a single decision-maker or a group of decision-makers. Various decision-making methodologies such as AHP, ELECTRE, PROMETHEE, TOPSIS, and VIKOR exist to facilitate efficient decision-making (Tzeng & Huang 2011). Many methods include attribute weights during the aggregation process. Various weighting techniques have been developed to assign weights to the attribute. These methodologies fall into two categories: subjective and objective weighting methods. The subjective methods determine weights according to the preferences of decision-makers. The most popular subjective weighting methods are the AHP and the best-worst method. The objective methods determine attribute weights using mathematical models and neglecting the decision maker's subjective judgment information. The most popular objective weighting methods are entropy and standard deviation (Zardari et al. 2015). The utilization of these methodologies is broad and far-reaching (Abdul et al. 2022, Chundi et al. 2022, Dev et al. 2022, Hasanzadeh et al. 2023, Morkunas & Volkov 2023, Shahnazari et al. 2021, Siew et al. 2021, Stanković et al. 2021).

In air quality assessment, Chen et al. (2019) employed VIKOR and DANP to analyze the potential improvement strategies for air quality in Kaohsiung, Taiwan. Ozkaya & Erdin (2020) utilized TOPSIS and VIKOR methods to evaluate sustainable forest and air quality management and the current situation in European countries. Lin et al. (2021) proposed an air quality assessment method that considers several pollutants using Entropy and TOPSIS. Xu & Chernikov (2021) applied a combined Entropy-TOPSIS-PROMETHEE method to assess air quality in several cities in China. Torkayesh et al. (2022) employed the Best-Worst Method and the Measurement of Alternatives and Ranking According to the Compromise Solution method to conduct a comparative analysis of air pollutants in 22 European countries. The objective was to provide a reference for regional and national strategies aimed at enhancing environmental sustainability.

The literature showed that several studies presented air quality assessment as a significant MADM problem due to its dependency on multiple quality indicators. Several studies adopted different approaches for the assessment of air quality. No study has presented the combined AHP-Entropy weighting approach for assessing weights based on air pollutants. Thus, this study incorporates the combined AHP-Entropy weighting approach with VIKOR, named the AHP-Entropy-VIKOR method, to determine the air quality and rank the areas. The rest of the paper is structured as follows: study area and data collection represent the considered alternatives, attributes, and statistical data. The methodology section focuses on the algorithms of the methods. The research findings are summed up and validated using Spearman's rank correlation, and sensitivity analysis is determined in the results and discussion section. Finally, the article is concluded in conclusion.

Study Area and Data Collection

This study aims to assess the air quality and to identify the most contaminated region during the Diwali festival in the 26 zones of Tamil Nadu, India, as depicted in Table 1, and the ambient air pollutants Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), and Particulate matter (PM_{10} microns $\leq 10\,\mu g\backslash m^3$ and $PM_{2.5}$ microns $\leq 2.5\,\mu g\backslash m^3$) have been selected as the attribute to evaluate the air quality using the proposed model.

The concentration of these pollutants during the Diwali festival from 2019 to 2021 was procured from the Tamil

Table 1: The considered areas of Tamil Nadu during the Diwali festival.

State	District	Regions	Abbreviation
Tamil Nadu	Chennai	Besant Nagar	BSN
		T.Nagar	TNR
		Nungambakkam	NGM
		Triplicane	TRP
		Sowcarpet	SCT
	Coimbatore	Gowndampalayam	GDM
		Collectorate Office	COO
	Cuddalore	Imperial Road	IMR
		Pudupalayam	PDP
	Madurai	Thirunagar	THN
		Birla Vishram	BVM
	Salem	Sri Saradha Balamandhir School	SBC
		Siva Tower	SVT
	Tirunelveli	Pettai	PET
		Vannarpettai	VPT
	Trichy	Ramalinga Nagar	RMN
		Gandhi Market	GNM
	Vellore	Gandhi Nagar	GNN
		Sidco Industrial Estate	SIE
	Dindigul	Rajagopal Iyangar	RGI
	Hosur	ESI Hospital	ESI
		Inel Transit House	ITH
	Thoothukudi	Raju Nagar	RNR
		Cellisini Colony	CCY
	Tiruppur	Kumaran Complex	KMC
		Rayapuram	RPM

Fig. 1: Data distribution of each pollutant.

Nadu Pollution Control Board (TNPCB 2022) in Chennai. The data distribution for the four contaminants is presented in Fig. 1.

Descriptive statistics of the pollutants studied in the community of Tamil Nadu have been carried out. Table 2 shows a statistical summary of these data, including measures of central tendency and variability in the form.

The maximum concentration values of SO_2 and NO_2 in 2019, 2020, and 2021 were within the permissible limits, with values ranging from 36 μg.m^{-3} to 49 μg.m^{-3} However, all three years exceeded the average daily limit of 100 μg.m^{-3} for PM_{10}, with maximum values ranging from 226 μg.m^{-3} to 283 μg.m^{-3} Similarly, all three years exceeded the average limit of 60 μg.m^{-3} for $PM_{2.5}$, with maximum values ranging from 66 μg.m^{-3} to 231 μg.m^{-3} It is worth noting that

Table 2: Summary statistics of the air pollutant concentrations.

Year	2019				2020				2021			
Pollutants	SO_2	NO_2	PM_{10}	$PM_{2.5}$	SO_2	NO_2	PM_{10}	$PM_{2.5}$	SO_2	NO_2	PM_{10}	$PM_{2.5}$
Count	26	26	26	26	26	26	26	26	26	26	26	26
Average $[\mu g.m^{-3}]$	17.23	23.77	108.23	54.23	16.31	26.27	96.58	39.04	16.62	23.58	153.54	82.81
Standard dev. $[\mu g.m^{-3}]$	7.31	9.86	51.75	39.59	6.85	9.14	37.23	16.32	9.35	8.88	77.58	74.45
Coeff. of variation %	42%	41%	48%	73%	42%	35%	39%	42%	56%	38%	51%	90%
Minimum $[\mu g.m^{-3}]$	8	5	45	11	9	10	49	12	4	8	56	15
Maximum$[\mu g.m^{-3}]$	41	48	266	165	36	49	226	66	37	40	283	231
Range $[\mu g.m^{-3}]$	33	43	221	154	27	39	177	54	33	32	227	216
Stnd. Skewness	1.41	0.55	1.54	1.81	1.23	0.56	1.66	-0.15	1.05	-0.16	0.37	1.06
Stnd. Kurtosis	3.17	0.42	2.57	2.98	1.14	0.82	4.73	-1.34	0.09	-0.57	-1.26	-0.56

large standard deviations were found for PM_{10} in all years, indicating significant variations in the concentration levels within the studied regions. Additionally, the coefficient of variation for $PM_{2.5}$ was higher in 2019 and 2021, suggesting more variability in the concentration levels of this pollutant during those years. Furthermore, the skewness values indicate the distribution characteristics of the contaminants. $PM_{2.5}$ exhibited higher skewness values in 2019 and 2021, indicating a skewed distribution. PM_{10} showed higher skewness in 2020. These observations highlight the elevated levels of particulate matter, specifically PM_{10} and $PM_{2.5}$, during the Diwali festival period. The results emphasize the need for effective measures to reduce and control particulate matter pollution, as it poses a significant health risk to the population.

MATERIALS AND METHODS

This study aims to fill the gap in the limited application of MADM methods in air quality assessment. We propose a hybrid approach that combines the AHP and Entropy weighting techniques to prioritize the attributes (parameters) in the decision-making process. The VIKOR method evaluates and ranks the alternatives (areas) and identifies the most polluted region. The flowchart in Fig. 2 presents the methodology of the proposed AHP-Entropy-VIKOR model.

Initial Decision Matrix

A MADM decision matrix $A = [a_{ij}]_{p\times k}$ consists of p alternatives and k attributes as presented in equation (1).

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1k} \\ a_{12} & a_{22} & \cdots & a_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ a_{p1} & a_{p2} & \cdots & a_{pk} \end{bmatrix} \quad \ldots(1)$$

Here, $a_{ij}\,(1 \le i \le p,\ 1 \le j \le k)$ i indicates the performance ratings of i^{th} alternative to the j^{th} attribute for the initial data shown in Fig. 1.

Weighting Methods

The weights assigned to the attributes can be determined through alternative data or expert opinions. This study adopts standard weighting methods, including the AHP and Entropy methods.

AHP

Saaty (1990) developed the AHP in 1977 to assign relative importance to options based on their comparison on a ratio scale. Fig. 3 depicts the decision hierarchy utilized in the AHP method to determine the most polluted region.

The relative significance of each attribute is ranked based on the ratio scales presented in Table 3.

The paired comparison matrix $P = [p_{ij}]_{p\times k}$ Utilized in this analysis to determine the weight of each attribute is displayed in equation 2.

$$P = \begin{bmatrix} 1 & 3 & 0.33 & 0.20 \\ 0.33 & 1 & 0.20 & 0.14 \\ 3 & 5 & 1 & 0.33 \\ 5 & 7 & 3 & 1 \end{bmatrix} \quad \ldots(2)$$

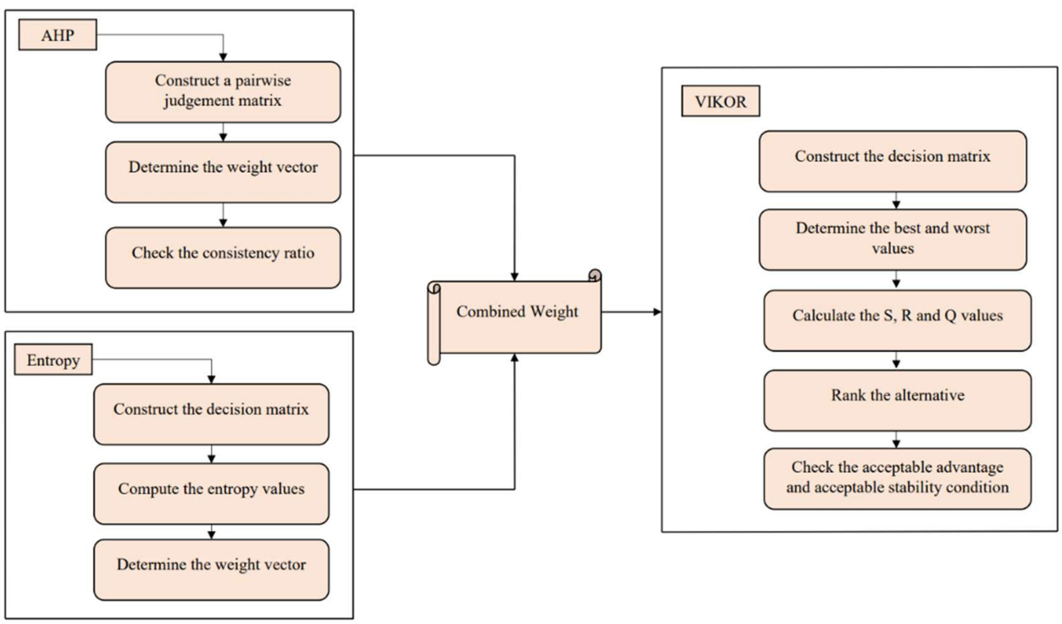


Fig. 2: AHP-Entropy-VIKOR Model.

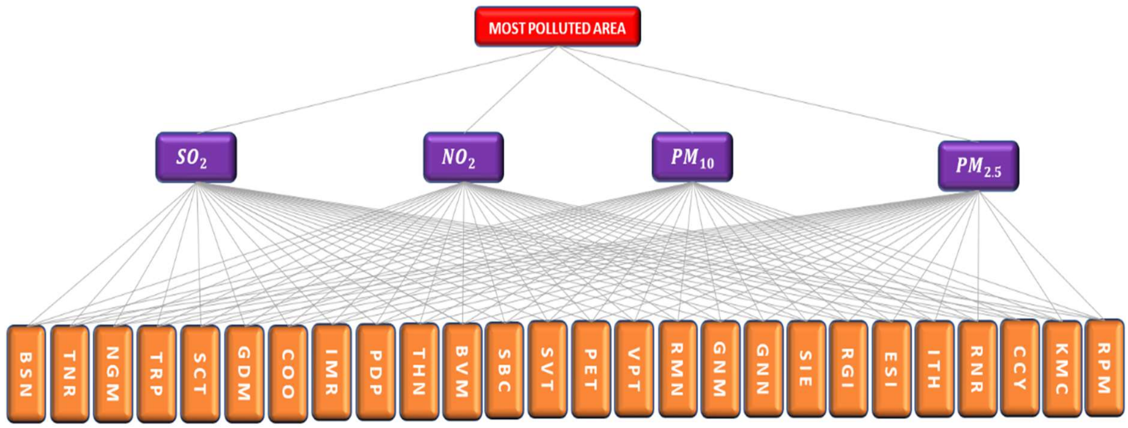


Fig. 3: Decision hierarchy of alternatives and attributes.

Table 3: Ratio Scale.

Numerical Rating	1	3	5	7	9	2,4,6,8
Importance	Equal importance	Moderate importance	Strong Importance	Very strong importance	Extreme Importance	Intermediate Values

We require the vector $\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_k]$, which represents the weight of each attribute in matrix P. To obtain the vector α from P, divide each column of P by its sum to receive a new column in P, referred to as P_{norm}. The weight α_i is estimated by taking the mean values in the i^{th} row of P_{norm}.

The Consistency Index (C.I.) and Consistency Ratio (C.R.) are calculated using equations (3) and (4), respectively. The Random Index (R.I.) value for a 4 × 4 matrix is 0.9.

$$C.I. = \frac{\lambda_{max} - n}{n-1} \quad \ldots(3)$$

Here, $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{p} \frac{P\alpha_i^T}{\alpha_i}$

$$C.R. = \frac{C.I}{R.I} \quad \ldots(4)$$

The C.R. value must be lower than 0.1 for the results to be considered.

Entropy

The entropy method, a weighting approach introduced by Shannon (1948), has been selected to assign relative significance to the various attributes. The algorithm for the entropy method is as follows:

Step 1: Using the following formula, normalize the decision matrix by substituting each a_{ij} by n_{ij}.

$$n_{ij} = \frac{a_{ij}}{\sum_{i=1}^{p} a_{ij}} \quad (1 \le i \le p, 1 \le j \le k) \quad \ldots(5)$$

Step 2: Calculate the entropy value e_j of j^{th} attribute by

$$e_j = -h\sum_{i=1}^{p} n_{ij} \ln n_{ij} \quad \left(h = \frac{1}{\ln p},\ 1 \le i \le p, 1 \le j \le k\right) \quad \ldots(6)$$

Step 3: Determine the degree of diversification of the j^{th} attribute

$$v_j = 1 - e_j \quad (1 \le j \le k) \quad \ldots(7)$$

Step 4: Calculate the weight of the attributes using

$$\beta_j = \frac{v_j}{\sum_{j=1}^{k} v_j} \quad (1 \le j \le k) \quad \ldots(8)$$

Combined Weights

This study employs a hybrid approach to maximize the advantages of both the AHP and Entropy methods by combining the relative importance of each attribute. The final weight of each attribute w_j is calculated as follows:

$$w_j = \frac{\alpha_j \beta_j}{\sum_{j=1}^{k} \alpha_j \beta_j} \quad \ldots(9)$$

Where α_j represents the weight assigned to the j^{th} attribute determined through the AHP approach and β_j represents the weight assigned to the j^{th} attribute determined through the Entropy method.

VIKOR

Opricovic and Tzeng (2004) developed the VIKOR method to rank and select a range of alternatives in a conflicting attribute. It provides a multi-attribute ranking index based on the closeness measure to the ideal solution. The algorithm for the VIKOR method is as follows:

Step 1: The best f_i^* and worst f_i^- values for each attribute can be determined using equation (10) for the benefit attribute and equation (11) for the non-benefit attribute.

$$f_j^* = max_i f_{ij},\ f_j^- = min_i f_{ij} \quad \ldots(10)$$

$$f_j^* = min_i f_{ij},\ f_j^- = max_i f_{ij} \quad \ldots(11)$$

Step 2: The S_i and R_i values can be calculated using equations (12) and (13), respectively.

$$S_i = \sum_{j=1}^{k} w_j \frac{\left(f_j^* - f_{ij}\right)}{\left(f_j^* - f_j^-\right)} \quad \ldots(12)$$

$$R_i = max_j \left[w_j \frac{\left(f_j^* - f_{ij}\right)}{\left(f_j^* - f_j^-\right)} \right] \quad \ldots(13)$$

Step 3: The Q_i values can be calculated using equation (14).

$$Q_i = \frac{v(S_i - S^*)}{(S^- - S^*)} + (1 - v)\frac{(R_i - R^*)}{(R^- - R^*)} \quad \ldots(14)$$

where $S^* = min_i S_i,\ \ S^- = max_i S_i,\ \ R^* = min_i R_i,\ \ R^- = max_i R_i$. The parameter v serves as a weight for the strategy of maximum group utility, while $1 - v$ is the weight of individual regret. Typically, $v = 0.5$ is taken in this calculation.

Step 4: The alternatives are ranked based on the lowest value of Q. The alternative with the lowest value of Q is considered the best-ranked alternative.

Step 5: If the following two conditions are satisfied, a compromise solution can be proposed with an alternative A^1, which is ranked the highest based on the measure Q

C1: Acceptable advantage:

$$Q(A^2) - Q(A^1) \geq DQ$$

where A^2 is the second-ranked alternative according to Q and $DQ = \frac{1}{(p-1)}$ (p is the number of alternatives).

C2: Acceptable stability in decision-making:

The alternative A^1 must also be the best ranked according to S or/and R.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of the following:

- The alternatives A^1 and A^2 if only condition 1 is true or
- The set of alternatives $A^1, A^2, \ldots, A^p$ if condition 1 is false; A^p is determined by $Q(A^p) - Q(A^1) < DQ$.

RESULTS AND DISCUSSION

An endeavor has been undertaken to identify the most contaminated region by employing the proposed AHP-Entropy-VIKOR model based on the air pollutant concentration in diverse parts of Tamil Nadu. The AHP calculates the attribute's subjective weights through a pairwise comparison matrix in equation (2). The determined weights are $\alpha_j = [0.122\ 0.057\ 0.263\ 0.558]$. After constructing the pairwise comparison matrix, it is imperative to assess its consistency. The obtained Eigenvalue λ_{max},is 4.119, and the consistency ratio is 0.04, less than the permissible value of 0.1, indicating good consistency in the judgments made. The Entropy technique uses the initial data to calculate the objective weights of the attribute. The resulting weight, β_j, as determined by equation (8), is represented in Table 4.

Table 4: Entropy weights of the attributes.

Year	β_1	β_2	β_3	β_4
2019	0.167	0.177	0.206	0.450
2020	0.266	0.201	0.221	0.312
2021	0.206	0.108	0.181	0.506

Table 5: Final weights of the attributes.

Year	w_1	w_2	w_3	w_4
2019	0.061	0.030	0.161	0.748
2020	0.118	0.041	0.210	0.630
2021	0.070	0.017	0.132	0.782

A hybrid weighting approach is adopted to derive more moderate weights, incorporating the AHP and Entropy methods. The final weights w_j of the attributes calculated by equation (9) are presented in Table 5.

Using the VIKOR approach, the best and worst values of all attributes from the initial data are identified, and then the VIKOR parameters. S_i, R_i,and Q_i are determined by applying equations (12), (13), and (14) These values are represented and ranked in Table 6. Following the methodology, two conditions are verified to determine the most suitable alternative in the VIKOR method.

By verifying the conditions, it can be inferred that the alternatives satisfied the requirements for acceptable advantage and stability in 2019 and 2020. As a result, CYY and RPM have ranked as the most contaminated regions in their respective years. However, in 2021, while the acceptable stability condition is fulfilled, the acceptable advantage condition is not. Consequently, TNR and TRP are identified as the most polluted areas among alternatives. COO was the least polluted area in the years 2019 and 2020. For the year 2021, PET was the least polluted area. However, since the TNPCB result (TNPCB 2022) was based on the breakpoint concentration of these pollutants and obtained through the maximum aggregation operator, the ranking of these twenty-six areas was slightly different. The result is represented in Fig. 4.

According to the TNPCB results, Cellisini Colony, Rayapuram, and T. Nagar were the worst polluted areas in 2019, 2020, and 2021, respectively, and Thirunagar, ESI Hospital, and Ramalinga Nagar were considered the least contaminated area in 2019, 2020, and 2021. For the most

Table 6: Ranks of the VIKOR parameters.

Areas	2019				2020				2021			
	S_i	R_i	Q_i	Rank	S_i	R_i	Q_i	Rank	S_i	R_i	Q_i	Rank
BSN	0.725	0.520	0.693	9	0.679	0.339	0.577	15	0.319	0.203	0.247	6
TNR	0.718	0.529	0.696	10	0.716	0.397	0.652	17	0.059	0.051	0.001	1
NGM	0.762	0.558	0.743	12	0.694	0.374	0.618	16	0.138	0.076	0.062	4
TRP	0.762	0.568	0.750	13	0.361	0.137	0.199	5	0.098	0.048	0.021	2
SCT	0.666	0.500	0.644	6	0.447	0.175	0.287	10	0.124	0.069	0.050	3
GDM	0.873	0.690	0.904	21	0.939	0.607	0.979	25	0.652	0.554	0.668	9
COO	0.958	0.748	0.997	26	0.928	0.630	0.993	26	0.625	0.517	0.628	8
IMR	0.764	0.573	0.755	14	0.393	0.163	0.243	8	0.799	0.688	0.839	13
PDP	0.777	0.583	0.769	15	0.307	0.165	0.191	4	0.821	0.698	0.858	17
THN	0.916	0.685	0.926	23	0.720	0.444	0.697	18	0.802	0.691	0.843	15
BVM	0.876	0.680	0.899	20	0.792	0.514	0.804	21	0.747	0.677	0.803	11
SBC	0.666	0.515	0.654	8	0.423	0.198	0.293	11	0.879	0.691	0.885	20
SVT	0.773	0.607	0.784	16	0.407	0.234	0.314	12	0.866	0.684	0.873	19
PET	0.964	0.728	0.986	25	0.904	0.572	0.926	23	0.977	0.782	1.000	26
VPT	0.901	0.690	0.920	22	0.912	0.572	0.931	24	0.969	0.774	0.991	25
RMN	0.647	0.481	0.618	5	0.583	0.292	0.476	13	0.962	0.760	0.977	24
GNM	0.674	0.500	0.648	7	0.406	0.143	0.232	7	0.912	0.731	0.930	22
GNN	0.198	0.165	0.123	3	0.626	0.362	0.565	14	0.824	0.680	0.848	16
SIE	0.707	0.578	0.724	11	0.742	0.455	0.721	19	0.776	0.626	0.784	10
RGI	0.563	0.452	0.547	4	0.317	0.133	0.168	3	0.774	0.662	0.808	12
ESI	0.911	0.690	0.926	24	0.851	0.514	0.841	22	0.925	0.749	0.950	23
ITH	0.787	0.607	0.793	17	0.357	0.152	0.210	6	0.809	0.684	0.842	14
RNR	0.178	0.060	0.035	2	0.753	0.490	0.759	20	0.411	0.271	0.344	7
CCY	0.121	0.059	0.000	1	0.416	0.163	0.257	9	0.284	0.181	0.213	5
KMC	0.868	0.641	0.866	19	0.233	0.114	0.099	2	0.854	0.771	0.926	21
RPM	0.804	0.660	0.842	18	0.137	0.070	0.000	1	0.836	0.691	0.862	18

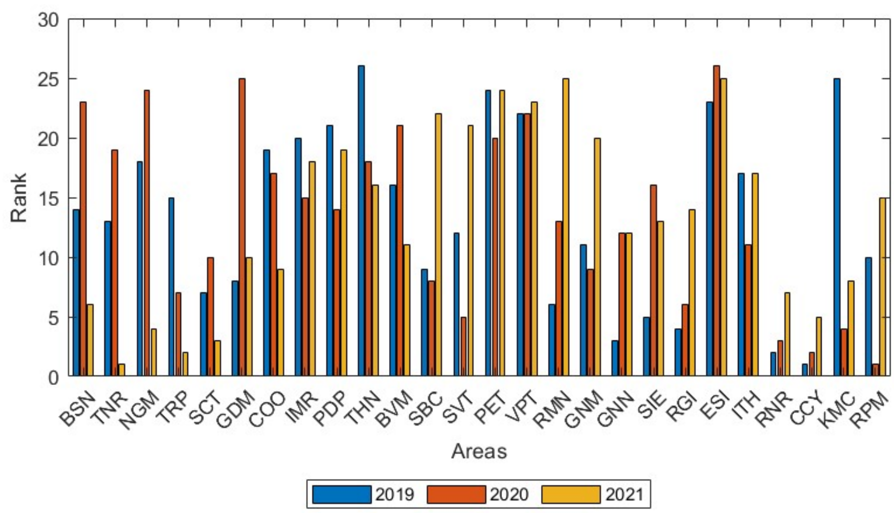


Fig. 4: TNPCB Ranking.

polluted area, the result obtained from AHP-Entropy-VIKOR is similar to the TNPCB result.

Comparison with MADM Methods

The present study validates the methodology by conducting a comparison between the proposed VIKOR approach and two established MADM approaches: Combinative Distance Assessment (CODAS) (Keshavarz et al. 2016) and Weighted Aggregated Sum Product Assessment (WASPAS) (Zavadskas et al. 2012). Both techniques are applied to the same dataset to rank the areas and determine the most polluted area in Tamil Nadu. The ranking outcomes of these methods are illustrated in Table 7.

From Table 7, the CODAS and WASPAS results indicate that Cellisini Colony, Rayapuram, and T. Nagar were ranked as one of the twenty-six areas of Tamil Nadu. Pettai and Collectorate Office was ranked as the least polluted area for 2019 by CODAS and WASPAS, respectively. Gowndampalayam (2020) and Pettai (2021) were ranked as the least polluted areas from CODAS and WASPAS methods in their respective year.

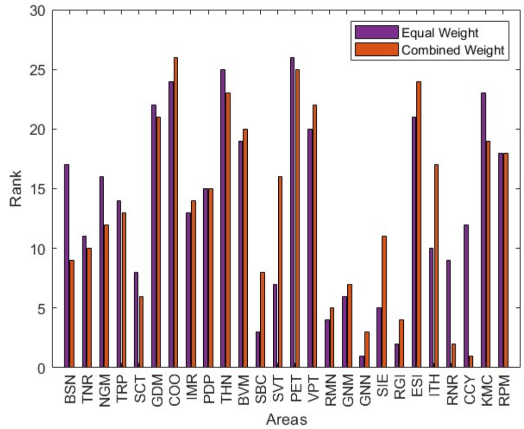
Moreover, a statistical test called Spearman's rank correlation test is employed to examine the interrelationship between the rankings derived from the proposed VIKOR model and the rankings obtained from CODAS and WASPAS methods. Spearman's coefficient assesses the significance of correlation among two or more rankings. The ranking of two datasets (A_1 and A_2) is calculated using the following equation:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \quad \ldots(15)$$

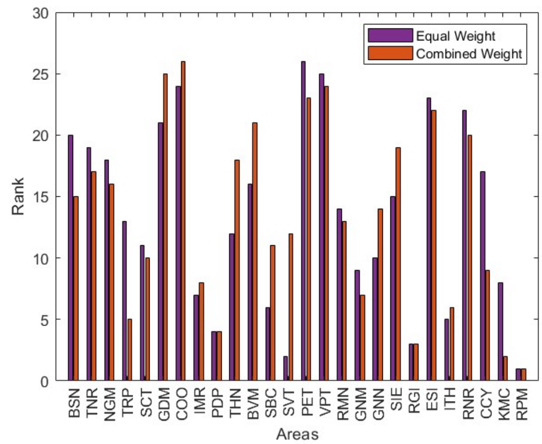
Here, n represents the number of alternatives and d^2 denotes the squared difference between the two rankings. The resulting ρ value indicates the relationship between the

Table 7: Ranking of CODAS and WASPAS.

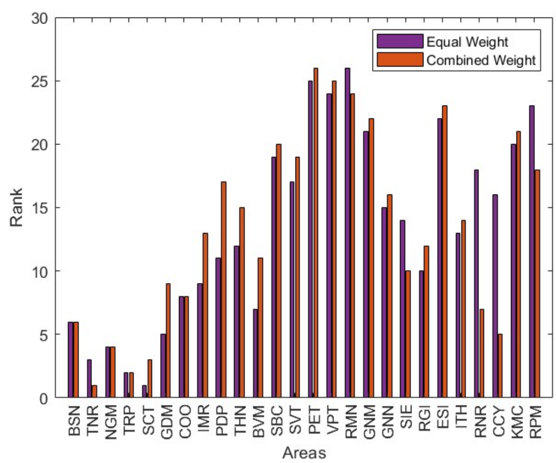
Year	2019		2020		2021	
Methods	CODAS	WASPAS	CODAS	WASPAS	CODAS	WASPAS
BSN	9	11	15	15	6	6
TNR	10	9	17	17	1	1
NGM	12	12	16	16	4	4
TRP	13	13	5	6	2	2
SCT	6	6	10	12	3	3
GDM	20	21	26	26	9	9
COO	25	26	25	25	8	8
IMR	14	14	8	7	13	13
PDP	15	15	4	4	17	17
THN	23	24	18	18	15	14
BVM	21	20	21	21	11	11
SBC	8	7	11	10	21	20
SVT	16	16	12	8	19	19
PET	26	25	23	23	26	26
VPT	22	22	24	24	25	25
RMN	5	5	13	13	24	24
GNM	7	8	7	9	22	22
GNN	3	3	14	14	16	16
SIE	11	10	19	19	10	10
RGI	4	4	3	3	12	12
ESI	24	23	22	22	23	23
ITH	17	17	6	5	14	15
RNR	2	2	20	20	7	7
CCY	1	1	9	11	5	5
KMC	19	19	2	2	20	21
RPM	18	18	1	1	18	18



(a) Ranking for the year 2019 using equal and combined weight

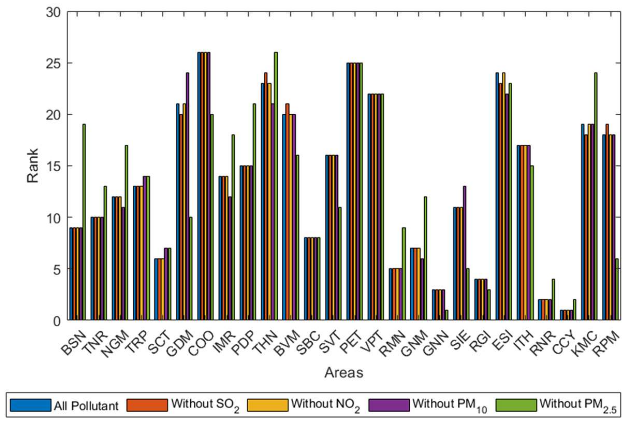


(b) Ranking for the year 2020 using equal and combined weight

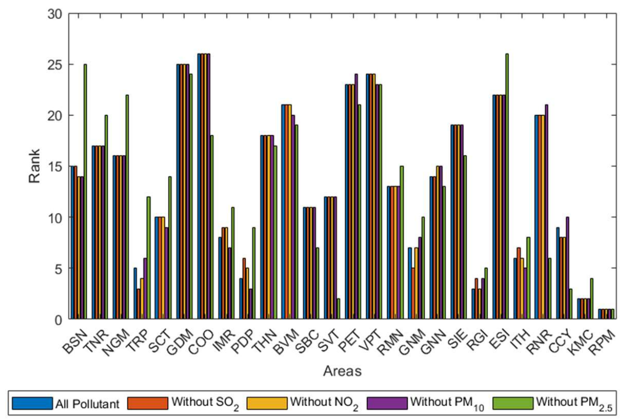


(c) Ranking for the year 2021 using equal and combined weight

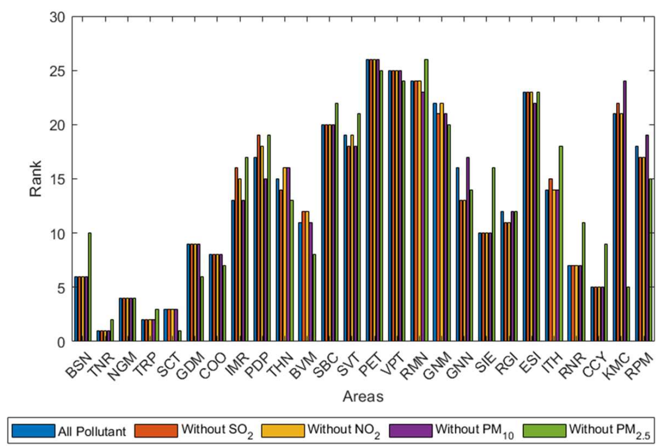
Fig. 5: Sensitivity analysis for scenario 1.



(a) Variations in the rank for the year 2019



(b) Variations in the rank for the year 2020.



(c) Variations in the rank for the year 2020.

Fig. 6: Sensitivity analysis for scenario 2.

two sets. The value closer to +1 signifies a strong positive relationship, whereas the value nearer to − 1 indicates a strong negative relationship.

From the ranks obtained from AHP-Entropy-VIKOR, CODAS, and WASPAS, the correlation is determined using the equation (15). The Spearman's rank correlation among the AHP-Entropy-VIKOR approach with CODAS and WASPAS methods in 2019 is 0.999 and 0.997; in 2020, it is 0.999 and 0.988; in 2021, it is 0.999 and 0.999 respectively. It is also observed that the correlation between the AHP-Entropy-VIKOR is a little higher with CODAS when compared with WASPAS. However, Spearman's rank correlation indicates a strong positive correlation between the methods.

Sensitivity Analysis

A sensitivity analysis is carried out to examine the effect of priority weights on the ranking of regions and to identify the impact of a specific air pollutant on air quality. The sensitivity analysis in the present study considers two scenarios:

- The priority weights have changed.
- Reduction of pollutants

Scenario 1

This scenario presents the changes in the weights of the attributes and the comparison between the 2 cases:

Case 1: By applying a combined AHP-Entropy approach.

Case 2: Equal weights are considered for all attributes.

Fig. 5 depicts the ranking of the areas that vary while applying the AHP-Entropy approach and the equal weight approach. It can be seen that the ranking of the areas changes in many places when using equal weights across the years. In 2019, all the area ranks were changed, whereas in 2020, PDP, RGI, and RPM are the only areas where the rank is unchanged. In 2021, BSN, NGM, and COO attained the same rank, and the ranks of other areas were changed when applying the equal weight approach.

When evaluating any decision-making problem, the weights of the attributes are vital. Air has different concentrations of multiple pollutants. So, scenario 1 indicates that computing the pollutant's weights is essential while finding the most polluted region.

Scenario 2

In this case, sensitivity analysis removes air pollutants one at a time to observe how they affect the ranking of contaminated places. This sensitivity analysis gives information on the pollutant that significantly impacts air quality and the contaminant that affects the region's rank. For the study, SO_2 is eliminated first, NO_2 second, then PM_{10} finally $PM_{2.5}$ is eliminated, and Fig. 6 illustrates the area's ranking after removing the pollutant.

This scenario represents the impact of a particular pollutant and changes in ranking while eliminating each pollutant. When eliminating the air pollutant SO_2, NO_2, and PM_{10} the ranks of the areas are not affected, but while eliminating the pollutant $PM_{2.5}$ it causes a significant change in rank across the years. This sensitivity case concludes the effect of the pollutant $PM_{2.5}$ causes more impact while ranking the most polluted areas. The air quality of these areas can be improved by reducing the sources that emit the air pollutant $PM_{2.5}$.

CONCLUSION

This study identified the most polluted area in Tamil Nadu during the Diwali festival in 2019-2021 by implementing the AHP-Entropy-VIKOR model. Four different pollutants were considered, and their weights were determined using AHP and Entropy methods to attain the advantage from both the subjective and objective weight approach. The study encompassed 26 different areas in Tamil Nadu as alternatives and ranked them through the proposed model based on the priority weights attained from the combined AHP and entropy methods. The results indicated that Cellisini Colony (CYY) in Thoothukudi and Rayapuram (RPM) in Tiruppur were the most polluted areas in 2019 and 2020, respectively. However, due to the failed condition in the year 2021, T. Nagar and Triplicane in Chennai were the most contaminated areas in that year. The proposed model has many advantages, like less complexity and computation of air pollutant weights using subjective and objective weight concepts.

Furthermore, the validation of the proposed decision support system is checked through Spearman's rank correlation with the other two existing MADM approaches, CODAS and WASPAS. The result proved the consistency and strong correlation in the ranking of the proposed approach. Sensitivity analysis is also carried out to identify the importance of specific air pollutants on overall air quality and to determine whether the pollutant's weight affects the ranks of the city. The first analysis provided the ranks of the area to illustrate that the priority weights of the pollutants are vital in ranking the areas, and the second analysis indicated that the pollutant has more impact on the area's rank. These results might help government agencies in making the right decisions. In the future, the present work can be enhanced by incorporating more pollutants and factors like temperature, humidity, and wind to analyze the air quality.

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