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SCIENTIFIC RESEARCH PAPER

An Approach for Ranking of Hospitals Based on Waste Management Practices by Analytical Hierarchy Process (AHP) Methodology

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Abstract In this study, the analytical hierarchy process (AHP) technique has been used to assess waste management practices of different hospitals in the city of Prayagraj (India). Based on AHP analysis, hospital 3 was ranked as the most promising sustainability hospital with a weight value of 0.2788 with strict abidance to Bio-medical waste management (amendment), 2018 rules and regulations. Regular monitoring is needed to improve the waste management in hospitals substantially, and hospital 6 is ranked lowest among the surveyed hospitals.

Keywords Analytical hierarchy process (AHP) · Hospital waste management · Ranking of hospitals

1 Introduction

A hospital provides treatment facilities to the patient with specialised medical, nursing staff, and equipment and provides healthcare services to people. The exponential growth in urban cities leading to raised pollution levels in the environment is the root cause of illness [1, 2]. The pandemic diseases like COVID-19, tuberculosis, or other communicable diseases also accelerated the rate of sickness among people, leading to increased demand for hospitals for well-being. The hospital includes clinics, OPD, dispensaries, and specialised care centres such as surgery, maternity hospitals, trauma centres, psychiatric, intensive care unit, etc., for serving patients. Vast quantities of hospital waste are generated from different departments of the hospital, which are categorised into non-hazardous, hazardous, and infectious wastes [3]. A World Health Organization report states that around 10% of waste generated from hospitals is infectious, while 5% is a hazardous waste but not infectious, whereas in India, 15–35% of hospital wastes are classified as infectious, 10–25% are hazardous wastes, and 40–60% are non-hazardous wastes [4–6]. Mismanagement of biomedical waste leads to disastrous situations like the COVID-19 pandemic, which not only had health and physical implications, but it affected the economic and socio-cultural aspects of society too. The benefits of safe collection and disposal associated with hygiene provide improvements in service quality in hospitals.

Multiple-criteria decision-making (MCDM) techniques are available; depending upon the nature and type of decision-making problem, each MCDM tool has its own merits and limitations in applications [7]. The analytical hierarchy process (AHP) techniques are one of the MCDM tools applied in environmental sciences, management, economics, and product design and in business to choose the best from available options [8]. AHP is used to relate subjective criteria and allows both quantitative and qualitative analysis through field data and expert's judgments. The parameters related to environmental, social, and human health, etc., in AHP are the decision-making parameters [9, 10]. The AHP has been widely used for decision-making in several fields, e.g. economic problems, policy evaluation, and urban planning [11]. These tools are also widely used as a basis for prioritizing investments in safety measures in the chemical industry [12, 13]. The AHP tool is used by many researchers in different areas like urban water supply systems, the selection of material suppliers [14, 15], environmental impact assessment [16],

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environmental vulnerability assessment [17], energy resources [18], and environmental impacts of manufacturing [19]. The questionnaire is based on different criteria to survey hospitals to assess their solid waste management practices. The results of analysis compliance with Indian acts of biomedical waste management (amendment), 2018 of the Government of India, were used as the standards help in the ranking of hospitals.

2 Background and Context

Prayagraj is regarded as a holy city of Uttar Pradesh in India and is situated on the confluence of rivers Ganga and Yamuna. It is located at 25.25° north latitude and 81.58° east longitude. Prayagraj city had a population of 10,87,167 in 2011, and the current population is 12,94,505 in 2018 and has about 30 hospitals. Only five hospitals are government hospitals, and the rest are private hospitals. The questions in the questionnaire depend on physical, chemical, biological, ecological, sociological, economic, and operational aspects of waste management practices in hospitals used for the surveying in the city. The questionnaire is attached in "Appendix". In this study, eight hospitals were considered, out of which two are government hospitals, and six are private hospitals. Approximately 265 respondents, including patients, staff members, and waste collection workers of hospitals, were approached (about 30 respondents per hospital) for the survey; nearly 173 responded in all eight hospitals. All the responses have been analysed by the current waste management practices and hygienic conditions of hospitals. As per the confidentiality policy of the survey, which protects the identities of hospitals under this study, fictitious names used for hospitals, i.e. Hosp. 1, Hosp. 2, etc., and list of hospitals and their details are listed in Table 1.

3 Methodology

Saaty [20] and Hambali et al. [21] developed a mathematical tool and used as the MCDM tool for many complex decision-making problems. The hierarchy levels depend upon the nature or type of problem, complexity, and degree of difficulty required to solve. Figure 1 represents the three-level hierarchy process of AHP [8, 21]. The top level of the hierarchy represents the main aim, i.e. ranking of hospitals; the second level represents the criteria considered for the study. Finally, the last level of the hierarchy is the technology options considered for decision-making. The matrix order depends upon the number of elements at the lower level linked to each other.

In AHP, pair-wise comparison matrix, eigenvectors or the relative weights, global weights, and the maximum eigenvalue ($\lambda_{\max}$) for each matrix were evaluated. The $\lambda_{\max}$ value is the essential validating parameter used as a reference value, i.e. consistency ratio (CR), calculated as per the following steps:

(a) The consistency index (CI) is estimated by adding the columns in the judgement matrix and multiplying the resulting vector by the vector of priorities (i.e. the approximated eigenvector) obtained earlier. It yields an approximation of the maximum eigenvalue, denoted by $\lambda_{\max}$.
(b) The consistency index (CI) is computed for each matrix of order 'n' by the formulae,

$$\mathrm{CI} = \frac{(\lambda \max - n)}{n - 1}$$

(c) The consistency ratio is then calculated as follows,

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RCI}}$$

Random consistency index (CI) obtained from many simulations runs and varied depending upon the order of matrix as mentioned by Hambali et al. [21]. If the value of

Table 1 List of hospitals and their details

Hospitals	Category	Maternity	OPD	Surgery	Paediatrics	Neonates	ICU	Kidney dialysis	Orthopaedic	Emergency	Lab	Research and development
Hosp. 1	Government	√	√	√	√	√	√	√	√	√	√	-
Hosp. 2	Government	√	√	√	√	√	√	√	√	√	√	-
Hosp. 3	Private	√	√	√	√	√	√	√	√	√	√	-
Hosp. 4	Private	√	√	√	√	√	√	√	√	√	√	√
Hosp. 5	Private	√	√	√	√	√	√	√	√	√	√	-
Hosp. 6	Private	√	√	√	√	√	√	√	√	√	√	-
Hosp. 7	Private	√	√	√	√	√	√	√	√	√	-	-
Hosp. 8	Private	√	√	√	√	√	√	√	√	√	√	-

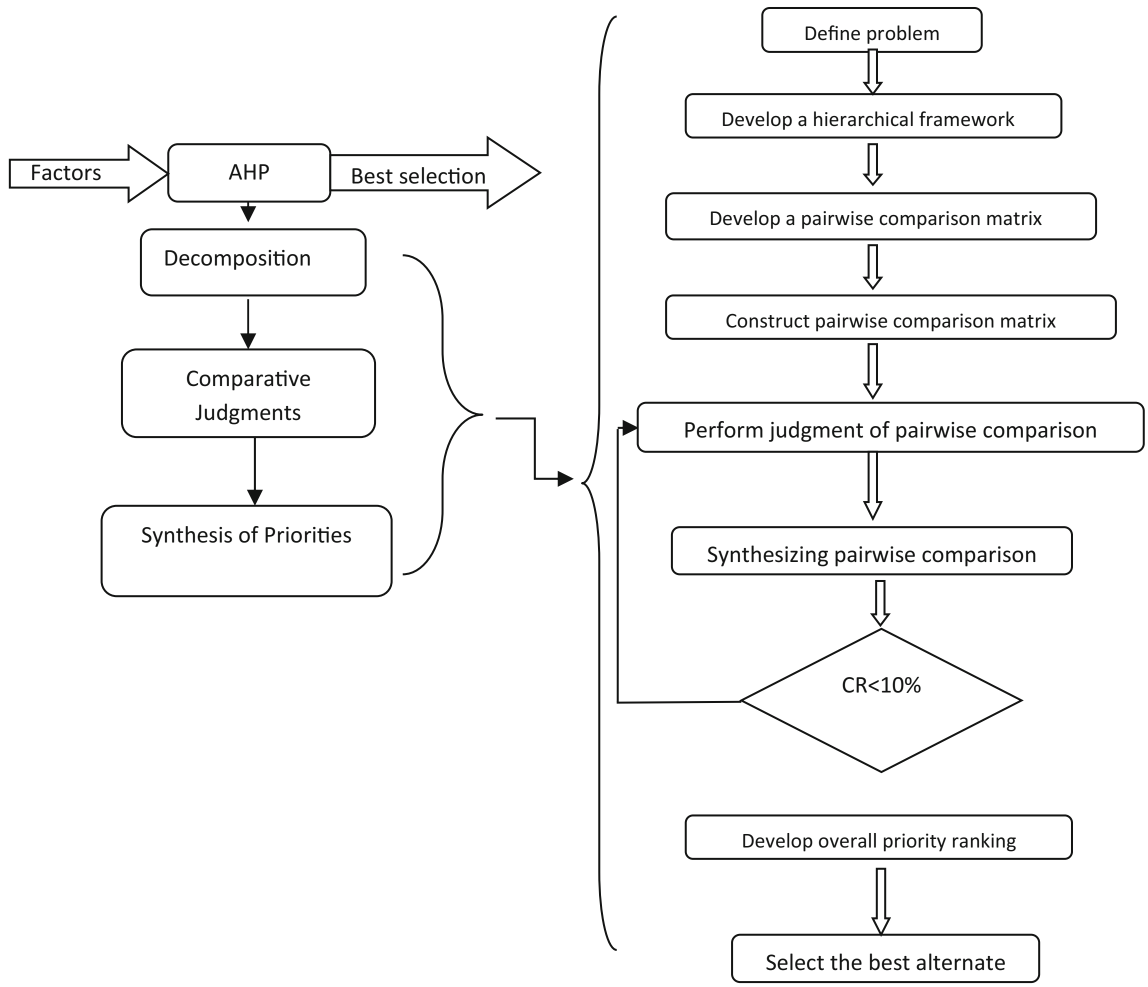

Fig. 1 AHP principles and its steps (Hambali et al. [21])

CR is equal to or less than that value, it implies that the evaluation within the matrix is acceptable or indicates a good level of consistency.

4 Results and Discussion

The decision-makers have to indicate preference or priority for each hospital, and pair-wise comparison matrices are developed. Table 2 represents the pair-wise comparison matrices for each criterion, i.e. physical/chemical criteria (PC), biological/ecological criteria (BE), social/cultural criteria (SC), and economical/operational criteria (EO) of each hospital. Table 3 lists pair-wise comparison matrix for all four criteria in terms of the importance of each in contributing to the overall goal regarding the importance of each in assisting.

The elements of each row are multiplied by each other and then the nth root (where *'n'* is the number of elements in the row). Next, the numbers are normalised by dividing them by their sum. The consistency ratio (CR) value of all the hospitals is less than 0.10 for 8 × 8 matrix in all four criteria, which means that the matrix is acceptable or indicates a good level of consistency in the comparative judgments.

The criteria priorities and the priorities of each hospital relative to each criterion are combined in order to develop an overall priority ranking of all the hospitals. The analysis results are termed as the decision matrix and ranking of hospitals, as given in Table 4. From the overall rank of the design options against calculations done using the AHP analysis, the hospital 3 is the best hospital having a very high overall priority vector among the criteria among all hospitals. Similarly, hospital 6 is the least hospital having rank 8 among all hospitals.

Table 2 Pair-wise comparison matrix of all the hospitals

	Hosp. 1	Hosp. 2	Hosp. 3	Hosp. 4	Hosp. 5	Hosp. 6	Hosp. 7	Hosp. 8	
A. Physical/chemical criteria (PC)									
Hosp. 1	1.00	2.00	0.50	5.00	3.00	4.00	3.00	3.00	Maxi. Eigen value = 8.73
Hosp. 2	0.50	1.00	0.33	4.00	2.00	3.00	2.00	2.00	C.I. = 0.11
Hosp. 3	2.00	3.00	1.00	6.00	3.00	4.00	3.00	3.00	CR = 0.078
Hosp. 4	0.20	0.25	0.17	1.00	0.14	0.33	0.20	0.13	
Hosp. 5	0.33	0.50	0.33	7.00	1.00	3.00	2.00	0.33	
Hosp. 6	0.25	0.33	0.25	3.00	0.33	1.00	0.33	0.50	
Hosp. 7	0.33	0.50	0.33	5.00	0.50	3.00	1.00	0.25	
Hosp. 8	0.33	0.50	0.33	8.00	3.00	2.00	4.00	1.00	
B. Biological/ecological criteria (BE)									
Hosp. 1	1.00	0.33	0.50	2.00	3.00	5.00	3.00	2.00	Maxi.
Hosp. 2	3.00	1.00	0.33	3.00	4.00	6.00	4.00	2.00	Eigen value = 8.87
Hosp. 3	2.00	3.00	1.00	3.00	5.00	7.00	4.00	3.00	C.I. = 0.12
Hosp. 4	0.50	0.33	0.33	1.00	3.00	4.00	2.00	0.20	CR = 0.085
Hosp. 5	0.33	0.25	0.20	0.33	1.00	3.00	0.33	0.25	
Hosp. 6	0.20	0.17	0.14	0.25	0.33	1.00	0.17	0.20	
Hosp. 7	0.33	0.25	0.25	0.50	3.00	6.00	1.00	0.17	
Hosp. 8	0.50	0.50	0.33	5.00	4.00	5.00	6.00	1.00	
C. Social/cultural criteria (SC)									
Hosp. 1	1.00	0.50	0.33	2.00	3.00	4.00	5.00	2.00	Maxi. Eigen value = 8.32
Hosp. 2	2.00	1.00	2.00	3.00	5.00	6.00	6.00	3.00	C.I. = 0.046
Hosp. 3	3.00	0.50	1.00	2.00	4.00	5.00	5.00	2.00	CR = 0.032
Hosp. 4	0.50	0.33	0.50	1.00	3.00	4.00	5.00	2.00	
Hosp. 5	0.33	0.20	0.25	0.33	1.00	2.00	2.00	0.33	
Hosp. 6	0.25	0.17	0.20	0.25	0.50	1.00	2.00	0.33	
Hosp. 7	0.20	0.17	0.20	0.20	0.50	0.50	1.00	0.25	
Hosp. 8	0.50	0.33	0.50	0.50	3.00	3.00	4.00	1.00	
D. Economical/operational criteria (EO)									
Hosp. 1	1.00	2.00	0.33	3.00	4.00	5.00	6.00	4.00	Maxi. Eigen value = 8.41
Hosp. 2	0.50	1.00	0.50	2.00	3.00	4.00	5.00	3.00	C.I. = 0.058
Hosp. 3	3.00	2.00	1.00	3.00	4.00	6.00	6.00	4.00	CR = 0.41
Hosp. 4	0.33	0.50	0.33	1.00	3.00	3.00	4.00	2.00	
Hosp. 5	0.25	0.33	0.25	0.33	1.00	2.00	3.00	0.33	
Hosp. 6	0.20	0.25	0.17	0.33	0.50	1.00	2.00	0.50	
Hosp. 7	0.17	0.20	0.17	0.25	0.33	0.50	1.00	0.33	
Hosp. 8	0.25	0.33	0.25	0.50	3.00	2.00	3.00	1.00	

Table 3 Pair-wise comparison matrix of the criteria PC, BE, SC, EO using AHP

Pair-wise comparison matrix					Standardised criteria matrix				
Standardised criteria	PC	BE	SC	EO	PC	BE	SC	EO	Weights
PC	1	0.5	3	2	0.26	0.24	0.3	0.31	0.28
BE	2	1	4	3	0.52	0.48	0.4	0.46	0.47
SC	0.33	0.25	1	0.5	0.09	0.12	0.1	0.08	0.1
EO	0.5	0.34	2	1	0.13	0.16	0.2	0.15	0.16

Table 4 Decision matrix for ranking of hospitals

Priority vector	PC (0.28)	BE (0.47)	SC (0.10)	EO (0.16)	Weights	Ranking
Hosp. 1	0.21	0.14	0.15	0.22	0.1748	3
Hosp. 2	0.14	0.21	0.28	0.16	0.1915	2
Hosp. 3	0.27	0.28	0.22	0.31	0.2788	1
Hosp. 4	0.02	0.08	0.13	0.11	0.0738	5
Hosp. 5	0.09	0.04	0.05	0.06	0.0586	6
Hosp. 6	0.05	0.02	0.04	0.04	0.0338	8
Hosp. 7	0.07	0.06	0.03	0.03	0.0556	7
Hosp. 8	0.14	0.17	0.1	0.08	0.1419	4

5 Conclusion

In this study, eight hospitals are surveyed in Prayagraj city for ranking them based on their efficient hospital waste management systems. Hospital 6 ranks lowest, while hospital 3 is on top. Hospital 3 is ranked highest due to its exceptionally efficient solid waste management practices. It is one of the biggest hospitals in Prayagraj and not only plays a vital role for its patients but by taking proper measures. It has installed its water treatment plant and has excellent aesthetics, and very safe storage and handling facilities. The waste is taken to the disposal site twice a day in closed dumpers, and special attention is given to the cleanliness and hygienic conditions preventing the risk of any disease. Hospital 6 is ranked lowest among the surveyed hospitals due to the lack of basic facilities like proper storage and proper waste disposal facility tie-ups. The generated waste is treated carelessly by untrained employees who are not immunized by the hospital authorities. The hospital maintains just qualifying hygienic conditions.

Appendix

Questionnaire on Waste Management Practices in Hospitals

A. Physical/Chemical criteria

1. Number of beds………………
2. Number of in/out patients………
3. Waste generated per bed per day……
4. Waste recycling rate per day…………..
5. Waste disposal frequency………………
6. Waste incinerated per day
7. Mixing with Infectious waste Yes/No
8. Quality of waste bags/sacks employed Bad/Good/Very Good
9. Radioactive/carcinogenic waste generated Yes/No
10. Number of cleaning personnel employed

B. Biological/Ecological criteria

1. Open/closed storage……………
2. Means of waste collection (Special/General)
3. Fly control Yes/No
4. Odour control Yes/No
5. Exposure to insects/animals Yes/No
6. Risk of mixing with nearby water source or leaching Low/High
7. Risk of leakage while collection/handling Low/High
8. Risk from sharps, chemicals, drug Low/High

C. Social/Cultural criteria

1. Aesthetic problem Yes/No
2. Exposure to public health Yes/No
3. Cleaning of storage area Yes/No
4. Safe transportation Yes/No
5. Emission of gas from incinerator Yes/No
6. Compliance with state and central authority regulations Yes/No
7. Immunisation of cleaning personnel against hepatitis B Yes/No
8. Training for waste handling Yes/No
9. Biological hazard symbol…………
10. Colour coded bag Yes/No

D. Economical/ Operational criteria

1. Cost of safety materials/measures…

2. Cost of sacks/bags……………..
3. Cost of employing personnel for cleaning…………………………………
4. Cost of treatment provided (if any)/sterilising waste………………
5. Cost of waste collection/disposal…
6. Cost of transportation involved………
7. Cost of infrastructure for storage………
8. Cost for radioactive waste handling-encapsulation etc…………..

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