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Locating temporary waste treatment facilities in the cities to handle the explosive growth of HCWs during pandemics: A novel Grey-AHP-OCRA hybrid approach

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ABSTRACT

The COVID-19 outbreak has not only put the community health at stake but, also the environmental health. Usually, the healthcare wastes (HCWs) are composed of 15-20% of the infectious wastes and the rest of the non-infectious wastes. But, during any communicable health outbreak like COVID-19, the whole HCWs coming from the infected people become contagious. During the COVID-19 outbreak, the infectious waste is not only limited to the hospitals’ premises, but also comes from the households, where COVID-19 infected people are under home quarantine. Hence, keeping in mind the explosive growth in generation rates of infectious HCWs, the present study targets to expand the treatment and disposal capacity by installing temporary healthcare waste treatment facilities (HCWTFs). The study identifies ten criteria from the literature review and in consultation with the field experts, to evaluate the potential candidates for setting up temporary HCWTF during the health outbreaks. The study proposes a hybrid methodology based on grey analytical hierarchy process (G-AHP) and grey operational competitiveness rating analysis (grey-OCRA) for prioritizing the evaluation criteria and selecting the optimal temporary HCWTF location by considering the experts’ inputs, respectively. The stakeholders consider the ‘proximity to the inhabitation’, ‘infrastructure availability’, and ‘transportation distance’ are the most important criteria for selecting the temporary HCWTF location. The proposed methodology is applied to select the temporary HCWTF location in Sundargarh District, Odisha, India. The study identifies the four locations by using geographical information system (GIS) tools and sequences them as per the preferences given by the stakeholders on various identified criteria. The study may be useful for the administration to set up the temporary facilities to quickly dispose of the extra HCWs during the pandemics. However, the future studies can be targeted to coordinate the collection, storage and transportation activities with the temporary HCWTFs.

1. Introduction

Managing the infectious healthcare wastes (HCWs) has been the most challenging task for the hospitals’ administration and waste handlers (WHO, 2014). Furthermore, the health outbreaks have worsened the situation in terms of the environmental threats posed by hazardous HCW generated while delivering healthcare services. Various primary field studies have revealed that usually, the 80-85% of the total HCW is non-infectious, while the rest is infectious wastes (Ilyas et al., 2020; Windfeld and Brooks, 2015; WHO, 2014). But, this share of infectious and non-infectious wastes switches suddenly, whenever, there is any communicable disease outbreak (Thakur, 2021; Suthar et al., 2020).

According to Al-Omran et al. (2021), the wastes produced from COVID-19 outbreak is mainly the infectious waste only. But, the present study has considered both the infectious as well as non-infectious HCWs under its scope.

With the advent of the novel coronavirus, the usage of disposable items, like gloves, masks, PPE kits, etc. has escalated tremendously (Al-Omran et al., 2021). The initial press release from WHO, well predicted the demand of the 76 million gloves, 89 million masks, 1.6 million goggles per month worldwide (WHO, 2020). These disposable items are adding extra infectious wastes in addition to the regular wastes. The initial stats after the COVID-19 outbreak in Wuhan, China revealed that the HCW quantity has increased from 0.6 kg/patient to 2.5

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kg/patient (Yu et al., 2020). A recent study conducted in China, revealed that due to the COVID-19 outbreak, the medical wastes including infectious and non-infectious, have increased by 370% in Hubei Province (Klemes et al., 2020). Another survey in Jordan revealed that the medical wastes quantity escalated 3.5 times (from 3.95 kg/patient to 14.16 kg/patient) higher after the COVID-19 outbreak (Abu-Diab et al., 2020). The HCWs in Netherlands and France have escalated by 40-50% during the recent COVID-19 outbreak (Das et al., 2021). Wei et al. (2020) predicted that due to the population explosion, the amount of HCW will increase by 50% by 2030 compared to 2018, even if there will be no health breakout. The sudden increase in the volume of the HCW during the health outbreaks has exerted extra pressure on the limited existing healthcare waste treatment facilities (HCWTFs) (Kulkarni and Anantharama, 2020). Hence, keeping in mind the current situation of the COVID-19 outbreak and future population index, the world’s most populated countries, like: India and China have to come up with more number of HCWTFs and promote the basic research on the environmental impact and its measures.

As per WHO, proper healthcare waste management (HCWM), is the shared responsibility of the hospitals’ administration as well as the HCWTF (Thakur and Ramesh, 2015). But, unfortunately, the poor collection and transportation, inefficient disposal of infectious wastes, open burnings, contamination of the soil, water, and environment, etc. are some of the major issues which the HCWM system has been facing continuously since its inception (Hantoko et al., 2021; Yazdani et al., 2020). And the situation becomes more dangerous, when the extra burden of health outbreaks is being added up (Klemes et al., 2020). Therefore, to protect the environment and society from the contamination during health outbreaks, finding the temporary optimal HCWTF location for collecting, storing, and disposing of infectious wastes is an utmost priority (Chen et al., 2021; Yazdani et al., 2020). Especially, addressing the issue of locating the temporary HCWTF during the health crisis is still not explored effectively in the literature. Hence, the current study attempts to study the role of various dimensions in locating the HCWTF during health outbreaks.

The novel focus of the study is to manage the extra amount of wastes and by-products, which are being generated during the pandemics (Chen et al., 2021; Hantoko et al., 2021; Mishra et al., 2020). As per WHO guidelines, the HCWTF location should meet the following conditions: i) easy accessibility to the healthcare establishments in the defined catchment area; ii) estimating the amount of wastes generated from the various HCFs; iii) the frequency of transportation of HCWs required; iv) assessment of environmental conditions; v) adequacy of land for future expansion, if required; and vi) public awareness surrounded by the HCWTF about the hazardous wastes (WHO, 2020).

1.1. Research motivation and objectives

The present study is motivated by the various facts learned from the recent COVID-19 outbreak: i) the initial statistics have revealed that the HCW quantity has increased many folds after the current outbreak (Klemes et al., 2020; Wei et al., 2020); ii) the outbreak has exerted extra burden on the existing HCW treatment infrastructure (Kulkarni and Anantharama, 2020); iii) poor waste segregation and collection at the HCFs (Thakur, 2021; Heidari et al., 2019); iv) the house-hold waste coming from the COVID-19 infected patient is now treated as the infectious waste (Hantoko et al., 2021; WHO, 2020); and v) WHO has published special measures in 2020 to maintain hygiene and protect the waste handling workers, while fighting against the COVID-19 outbreak (WHO, 2020).

Therefore, handling the explosive growth in HCW quantity due to the pandemic, has forced the healthcare organizations and local administration for setting up the temporary HCWTFs at the strategic locations (Chen et al., 2021; Yazdani et al., 2020; Suthar et al., 2020). Locating the temporary HCWTF is the multi-criteria decision-making (MCDM) problem, which depends upon the evaluation of the various location alternatives with respect to the listed criteria. The literature is mostly limited to explore the role of sustainability dimensions (social, environmental and economic dimensions) for selecting the location for HCWTF during the routine/normal situations (Rajak et al., 2021; Thakur et al., 2021). But, the health outbreaks like COVID-19 pandemic demand for extra and quick infrastructure to handle the explosive growth in HCWs overnight. Moreover, as per the discussions held with the stakeholders, selecting the criteria for evaluating the temporary HCWTF location alternatives is different from routine facility location, where handling the outbreak situations is the need of the hour rather than sustainability in the longer run. Most of the studies have focused on selecting the HCWTF location under normal conditions, where there is no health outbreak and the amount of routine HCW being treated can be predicted depending upon the population in a particular city (Ilyas et al., 2020). But, during COVID-19 pandemic, the temporary HCWTFs and temporary transportation facilities can help in avoiding the spread of the infection (Das et al., 2021). As the COVID-19 pandemic is unpredictable and repeating every time more strongly in-terms of waves of spread, the temporary transit centres and more number of incinerators could help the administration to handle the HCWs more efficiently (Das et al., 2021; Yu et al., 2020; WHO, 2020). Hence, the literature needs to be enriched with the studies targeting the special concern for handling the extra amount of HCW during the pandemics. Moreover, selecting the temporary HCWTF location is an MCDM problem with full of uncertain and vague environment during pandemics. Hence, keeping in mind the above literature gaps and uncertain pandemic situations, the present study raises the following research questions: i) What are the criteria to be evaluated while selecting the temporary HCWTF location during pandemics? ii) How can be the evaluation criteria assigned the priority weights to assess the various location alternatives? iii) How can the administrators evaluate the sustainability dimensions of the HCWTF locations in the uncertainties of the pandemics? The following objectives are targeted to answer the identified research questions:

To identify the criteria to evaluate the temporary HCWTF location alternatives for efficient HCWM during health outbreaks.

To consider the administrators’ inputs for assigning the priority weights to the identified criteria for making the temporary HCWTF location decision by using the grey analytical hierarchy process (G-AHP).

To evaluate the performance of the various identified temporary HCWTF alternatives using the grey operational competitiveness rating analysis (G-OCR) method.

To implement the proposed methodology to real-life case study for selecting the temporary HCWTF location in Sundargarh District, Odisha, India.

The study will target the above objectives by identifying the various criteria for evaluating the temporary HCWTF location alternatives from the literature review, field surveys and experts’ discussions. Thereafter, the various stakeholders (like: researchers, hospitals’ managers, practitioners and government regulatory authorities) perspectives on prioritizing the evaluation criteria and assessment of location alternatives are considered. The study applies the G-AHP and G-OCR to assign the weights to various identified criteria and locate the most preferred temporary HCWTF location for treating the extra HCWs during pandemics respectively.

2. Literature Review

2.1. HCWTF location selection: Developments during the COVID-19 outbreak

The literature is full of studies targeted on facility locations, site selection and location evaluation using various multi-criteria decision-making (MCDM) techniques and mathematical optimization models. Researchers have also used these approaches to select the optimum location for setting up the waste treatment facility (Yang et al., 2021;
Yazdani et al., 2020). All these studies are conducted to select the permanent HCWTF location under the routine procedure to cope up with the escalating population and increasing demand for healthcare facilities. Thakur et al. (2021) identified 20 factors under six main dimensions for developing sustainable HCW management system: environmental, economic, technological, capabilities, experience and relationships. Yazdani et al. (2020) identified three factors under economic dimension, five factors under environmental dimensions and three factors under social dimension to select the HCWTF location in the big populated cities. Yang et al. (2021) also responded to the emergency situation created by extra HCWs and advocated that stationary and co-facilities should be preferred for handling extra wastes, although some mobile facilities can also supplement to this. Khan and Samadder (2015) considered 11 measures under three main dimensions (social, economic and environment) for evaluating the potential landfill sites. Gergin et al. (2019) used geographical coordinates and HCW generation rates for locating the HCWTF for Istanbul municipality. Hariz et al. (2017) accessed triple bottom line dimensions of sustainability to find the best location for setting up the HCW treatment facility.

Since, in the recent past, the COVID-19 outbreak has generated a tremendous amount of HCWs, the field experts and scholars have contributed some important literature on evaluating and locating the preferred locations for setting up the extra HCW disposal centers for fighting against the pandemics. The increasing generation rates of HCWs, when most of the countries are experiencing second and third waves of COVID-19 outbreak, have overburdened the existing HCWTFs (Yang et al., 2021; Yazdani et al., 2020). The role of setting up new temporary HCWTFs and incineration centers, in nipping the spread of the infectious virus cannot be ignored (Chen et al., 2021; WHO, 2020; Yu et al., 2020; Kargar et al., 2020). Therefore, the new locations should be evaluated keeping in mind the expected demand from the coverage area of the location, which may be tracked by observing the population density of that area, healthcare facilities, industries, etc. (Yu et al., 2020; Gergin et al., 2019).

As per WHO (BMW management & handling rules, 1998) guidelines, the HCW should be transported from the hospitals to the treatment centers within 48-72 h after the generation. But, in case of communicable diseases like the COVID-19 outbreak, the long storage of infectious wastes may contaminate the hospitals’ environment and should be removed every 12 h (Yazdani et al., 2020; Ferronato et al., 2020; Thakur, 2021). Hence, the role of temporary storage areas outside the hospitals’ premises as well in the treatment centers is very crucial to handle the extra amount of HCWs (Ferronato et al., 2020).

The above literature review and discussions with the stakeholders, helped in identifying the ten criteria (shown in Table 1) to evaluate the various potential candidates for setting up the temporary HCWTFs during any health outbreak. The stakeholders also expressed their concern on raising number of COVID-19 infected patients under the effect of second and third waves and stressed on the necessity of opening up the temporary waste treatment facilities to cope up with the increasing HCWs in the populated countries like India.

### 2.2. MCDM structure under uncertainty

The site selection for setting up temporary HCWTF during pandemics, is the most challenging and quick MCDM problem. Hence, a structured and efficient approach has to be opted for making the trade-offs among the various criteria involved in the selection of the potential location candidates. Literature highlights various fuzzy set theory-based MCDM tools to evaluate the waste treatment facility location candidates to address the uncertain situation during the health outbreaks (Thakur et al., 2021; Gergin et al., 2019). Researchers have also adopted MCDM techniques in selecting the optimal HCTWF locations, like: Yazdani et al. (2020) proposed a rough based MCDM model for selecting the safe HCW disposal site for a private hospital in Madrid, Spain; Yu et al. (2020) proposed a multi-objective multi-period mixed-integer program to select the temporary locations for setting up more incinerators to treat extra HCWs during COVID-19 outbreak in Wuhan, China; and Kargar et al. (2020) used multi-choice goal programming MCDM method to design the reverse logistics network and setting up temporary waste treatment facilities for fighting against the novel coronavirus outbreak.

The application of Grey theory in combination with AHP and OCRCA is a novel methodology contribution of the present study in the field of selecting the temporary HCWTF during the pandemics. AHP technique

### Table 1

| Criteria Description | Sources |
|----------------------|---------|
| Compliance of environmental laws | Manupati et al. (2021); Hariz et al. (2017); Khan and Samadder (2015); |
| Waste generation rates under the coverage area | Gergin et al. (2019); |
| Distance from the existing HCWTFs | Stakeholders’ contribution |
| Waste residuals management after treatment | Manupati et al. (2021); |
| Transportation distance from the hospitals | Ferronato et al. (2020); Hariz et al. (2017); |
| Proximity to the inhabitation | Manupati et al. (2021); Rahimi et al. (2020); Khan and Samadder (2015); |
| Land availability for expansion if required | Dan et al. (2021); Yazdani et al. (2020) Ferronato et al. (2020); |
| Basic infrastructural availability | Manupati et al. (2021); Rahimi et al. (2020); |
was originally proposed by T.L. Saaty, who criticised the fuzzy extension of the AHP and stated that researchers are using the hybrid version for publishing articles by highlighting more computer-based mathematical calculations (Saaty, 2006). The main reason behind the criticism was the excessive inclusion of the numbers and making it more complex to deal with uncertain and vague decision-making situations. Hence, to make computations easier than fuzzy numbers and also consider the expert’s subjectivity while giving their preferences, the present study has proposed the Grey theory-based AHP and OCRA hybrid MCDM technique for evaluating the HCWTF location candidates (Sun, 2020). OCRA was initially proposed by Parkan (1994) to evaluate the operational competitiveness of the production units. OCRA method adopts an intuitive approach for capturing the experts’ inputs and can also consider the dependence of the criteria weights on the alternatives. Thereafter, the OCRA methodology has been used as a strong MCDM tool for various types of sequencing problems: material selection problem (Chatterjee and Chakraborty, 2012); evaluation of public banks’ performance (Ozbek, 2015); hotel selection (İpek and Adali, 2016); selecting the electronic device (Ozdağolu and Girkın, 2019) etc. Stavljenic et al. (2017) further proposed a grey theory-based OCRA approach for handling the vagueness and uncertainty in MCDM while selecting the contractors.

Hence, the present study proposes a new hybrid MCDM methodology (AHP and OCRA), based on grey theory to handle the vagueness in the decisions analysis. The main advantages of adopting the hybrid Grey-AHP-OCRA methodology are: Grey theory well captures the fuzziness and uncertainty in the experts’ opinion (Thakur and Anbanandam, 2015); Grey scale is an appropriate tool to collect the opinion of few stakeholders involved in the decisions making (Kumar and Anbanandam, 2020); integrating AHP technique will help in accumulating the experience and knowledge of the field experts by taking their subjective preferences on prioritizing the criteria weights (Sun, 2020; Ulutas, 2019); OCRA methodology can handle the MCDM situations, where the criteria weights are depending on the alternatives and also when all the criteria are not applicable on all the alternatives (Parkan, 1994); and using OCRA, different weight distributions can be given to criteria for different alternatives (Parkan, 2006).

2.3. Research novelty and contributions

Most of the studies in the literature finding the optimum location for setting up HCWTFs, have been conducted considering the normal medical conditions and healthcare demands. But, during health outbreaks, the situation gets worst and the demand for setting up more temporary facilities to treat the healthcare by-products increases overnight (Yu et al., 2020). The literature lacks studies specially targeted to design the extra reverse supply chain facilities in the healthcare industry during the pandemic situations, which is of paramount significance (Yu et al., 2020). The author’s knowledge, no research has been conducted to provide the structured approach to set up more temporary HCWTFs, especially, in countries, like India, US, UK, where there is a situation of the community spread and also the amount of HCWs has increased many folds (Al-Omran et al., 2021; Yu et al., 2020; WHO, 2020; Klemes et al., 2020). The present study bridges the above research gaps and enriches the existing literature by: developing the evaluation criteria for assessing the potential location alternatives for setting up temporary HCWTF for meeting extra demand during pandemics; considering the above criteria, the study aims to propose a hybrid MCDM approach to facilitate the practitioners and managers to take the quick and efficient decisions for setting up temporary HCWTFs during the pandemics; finally, the proposed research solution is implemented through a real-life situation for evaluating the various location alternatives in Sundargarh District, Odisha, India.

3. Research Methodology: G-AHP and G-OCRA

Integrating G-AHP and G-OCRA for selecting the temporary HCWTF location under the uncertain situations of pandemic, is the novel approach of the present study. Grey numbers can handle the vagueness and uncertainty, while collecting the experts’ inputs in the present study. Some of the basic operations on the grey numbers are shown in Appendix I.

3.1. G-AHP approach

AHP has been the most widely used MCDM approach for prioritizing and ranking the criteria (Thakur et al., 2021; Ulutas, 2019; Thakur and Anbanandam, 2015). The present study includes the following steps of G-AHP for prioritizing the criteria to evaluate the potential location alternatives:

Step 1: Define the MCDM problem and its associated parameters in the form of hierarchical tree. This step also defines the various potential alternatives to be evaluated.

Step 2: Preparing the grey pair-wise comparison matrix (GPCM)

Here, the pair-wise comparisons among all the criteria are developed by taking the qualitative inputs from the experts on the grey scale (shown in Table 2). Here, the questionnaire is designed and circulated among the stakeholders or the group of experts for recording their preferences on one criterion over the other. The experts’ preferences are collected in-terms of linguistic variables, which are further converted into grey numbers using grey scale shown in Table 2.

Step 3. Calculate the average GPCM

The average GPCM is calculated by applying Eqn. (1) on all the pairwise comparison matrices collected from ‘N’ number of experts.

\[ G_i = \left( \frac{1}{N} \sum_{j=1}^{N} G_{ij} \right) \]

Step 4. Computing the crisp pair-wise comparison matrix (CPCM)

Here, the GPCM is converted into CPCM by applying the ‘De-greying’ method including three steps procedure (explained in Appendix II) proposed by (Thakur and Ramesh, 2017; Opricovic and Tzeng, 2003).

Step 5. Investigating the robustness of the CPCM matrices

The experts’ preferences have to be logical and consistent. The robustness of the CPCM matrices can be evaluated by computing the consistency index (CI) and consistency ratio (CR) for each pair-wise comparison matrix collected from different experts.

\[ CI = \frac{\lambda_{max} - n}{n - 1} \]

\[ CR = \frac{CI}{RCI \text{ table value}} \]

Where, \( \lambda_{max} \) is the maximum Eigen value computed from the pair-wise comparison matrix. The random consistency index (RCI) value can be read from the standard table (Thakur and Ramesh, 2017). The CR value ensures the logical flow of the qualitative inputs collected from the experts and in order to be consistent, the CR value should be less than

| Table 2: Grey linguistic scale. |
|---------------------------------|
| Criteria ratings linguistic scale (G-AHP scale) | Grey numbers (\( \bowtie \) W) | Alternatives ratings linguistic scale (G-OCRA scale) |
| Very low preferred (VLP) | [0.0, 0.1] | Very low (VL) |
| Low preferred (LP) | [0.1, 0.3] | Low (L) |
| Moderately low preferred (MLP) | [0.3, 0.4] | Medium low (ML) |
| Average (M) | [0.4, 0.5] | Medium (M) |
| Moderately high preferred (MHP) | [0.5, 0.6] | Medium high (MH) |
| High preferred (HP) | [0.6, 0.9] | High (H) |
| Very high preferred (VHP) | [0.9, 1.0] | Very high (VH) |

Source: Adapted from Thakur and Anbanandam (2015),
10%. For any inconsistency, the inputs are collected again from the experts, until CR value is less than 0.10.

**Step 6.** Calculating the priority weights of listed criteria ($w_k$)

Here, the final weights of the criteria to evaluate the temporary HCWTF locations, are calculated by computing the eigen-vector of the whole matrix and final ranking is done based on the priority vector.

### 3.2. Grey-OCRA approach

The criteria weights calculated by using G-AHP are further processed using G-OCRA approach for finding the preference sequence of the temporary HCWTF location alternatives. The present study uses the following steps of G-OCRA to rank the various temporary HCWTFs location alternatives:

**Step 1.** Developing the alternatives grey decision matrix ($\odot D$)

Here, the experts give their preferences over the various HCWTFs location alternatives in terms of linguistic variables, which are converted into grey numbers using the scale shown in Table 2.

$$D = \begin{bmatrix} \odot d_{11} & \odot d_{12} & \ldots & \odot d_{1j} \\ \odot d_{21} & \odot d_{22} & \ldots & \odot d_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ \odot d_{i1} & \odot d_{i2} & \ldots & \odot d_{ij} \end{bmatrix}$$

Where, $\odot d_{ij}$ (represented by $D$), represents the preference of the $i^{th}$ alternative with respect to $j^{th}$ criterion assigned by the $n^{th}$ expert. The average grey decision matrix for all the alternatives, given by 'n; number of experts can be calculated.

**Step 2.** Performance ratings for cost criteria ($\odot P_C$)

Firstly, the grey aggregate performance ratings of the various alternatives are calculated with respect to the non-beneficial criteria by using Eqn. (5-6).

$$P_C^i = \sum_{j \in \Omega_{b,c}} w_j \left[ \frac{\max j \odot d_{ij} - \min j \odot d_{ij}}{\max j \odot d_{ij} - \min j \odot d_{ij}} \right]$$ (5)

$$P_C^i = \sum_{j \in \Omega_{b,c}} w_j \left[ \frac{\max j \odot d_{ij} - \min j \odot d_{ij}}{\max j \odot d_{ij} - \min j \odot d_{ij}} \right]$$ (6)

**Step 3.** Linear performance ratings for benefit criteria ($\odot L_B$)

The grey linear performance ratings for the cost criteria can be calculated using Eqn. (7):

$$L_B^i = \odot P_C^i - \min i \odot P_C^i = \left[ P_C^i - \min i \odot P_C^i \right] \text{ and } \left[ P_C^i - \min i \odot P_C^i \right]$$ (7)

**Step 4.** Performance ratings for benefit criteria ($\odot P_B$)

The grey aggregate performance ratings of the various alternatives are calculated with respect to the beneficial criteria by using Eqn. (8-9):

$$\odot P_B^i = \sum_{j \in \Omega_{b,c}} w_j \left[ \frac{\min j \odot d_{ij} - \max j \odot d_{ij}}{\max j \odot d_{ij} - \min j \odot d_{ij}} \right]$$ (8)

$$\odot P_B^i = \sum_{j \in \Omega_{b,c}} w_j \left[ \frac{\max j \odot d_{ij} - \min j \odot d_{ij}}{\max j \odot d_{ij} - \min j \odot d_{ij}} \right]$$ (9)

**Step 5.** Linear performance ratings for benefit criteria ($\odot L_B^i$)

The grey linear performance ratings for the benefit criteria can be calculated using Eqn. (10):

$$L_B^i = \odot P_B^i - \min i \odot P_B^i = \left[ P_B^i - \min i \odot P_B^i \right] \text{ and } \left[ P_B^i - \min i \odot P_B^i \right]$$ (10)

**Step 6.** Final grey score of each alternative ($\odot A^i$)

The final grey score for each alternative can be calculated by applying Eqn. (11):

$$A_i = \odot L_B^i + \odot L_B^i - \min \left( \odot L_B^i + \odot L_B^i \right)$$ (11)

**Step 7.** Sequencing of alternatives

Here, the final grey score for each alternative ($A_i$) is converted into crisp value using Eqn. (13) and then the alternatives are sequenced from highest to lowest score.

$$A_i = (A_i + \overline{A_i})/2$$ (13)

### 4. Case Study: Application of the Research framework

In this section, the application of the proposed research framework is applied to the case study of selecting a temporary HCWTF to handle the extra amount of HCW generated during the COVID-19 outbreak in the Sundargarh District, Odisha, Eastern State of India.

#### 4.1. Problem description

India is experiencing the second wave of COVID-19 outbreak, where more than 24.7 million people are already infected and approximately 0.27 million people have lost the battle against the pandemic (https://www.covid19india.org/ accessed on 16th May, 2021). When this case study was compiled, the Odisha state has confirmed more than 0.62 million COVID-19 infected patients and more than 2500 people have already lost their lives (https://www.covid19india.org/ accessed on 16th May, 2021). Sundargarh District is the third worst affected District in Odisha, India. Fig. 1 is clearly showing the effect of COVID-19 spread in Sundargarh District with respect to Odisha State. Odisha is one of the under-developed states in India, where the resources and infrastructure availability is a significant challenge for any disaster management system. Hence, to handle the extra amount of HCWs generated from the various COVID-19 hospitals, either the capacity of the existing HCWTFs needs to be enhanced or the temporary treatment centers can be opened as a quick measure. However, the researchers and international disaster management organizations (Yazdani et al., 2020; WHO, 2020; Yu et al., 2020; Kargar et al., 2020) have advocated for setting up the temporary facilities to treat extra HCWs during the pandemics. Therefore, realizing the need of the hour, the present study has targeted to identify the optimal location for temporary HCWTF in Sundargarh District, Odisha, the eastern state of India. Fig. 2 is showing the overall case description highlighting the various sources of HCWs (COVID-19 treatment centers), existing HCWTFs and the potential location candidates for setting up the temporary HCWTFs during pandemics.

#### 4.2. Mathematical analysis of the case study

The proposed research methodology has been applied in two phases to evaluate and select the optimal location for setting up temporary HCWTF to handle the explosive growth of HCWs during the COVID-19 outbreak. The first phase prioritizes the criteria listed to evaluate the various candidates for HCWTF locations using G-AHP and the second
phase evaluates and ranks the various alternatives with respect to each criterion using the G-OCRA approach.

4.2.1. Survey design and data collection

The study considers the various stakeholders’ perspectives, who are actively involved in the policy-making for ensuring the safe disposal of healthcare by-products in Sundargarh District, Odisha, India. The stakeholders include: HCWTF managers (4 nos.); hospitals’ administrators (9 nos.); Rourkela and Sundargarh municipal corporation and regulatory authority (7 nos.); and academicians and researchers (12 nos.). The complete profiles along with the responsibilities of the experts are highlighted in Appendix Table A1. The study objectives and proposed methodology were discussed with the experts involved in the data collection process. The hierarchical structure including the selection parameters and location candidates for setting up the temporary HCWTF was presented to the experts in the form of Fig. 3.

Initially, the identified criteria are validated with the experts’ inputs through the online platform. The questionnaire is designed using the final validated criteria and stakeholders are also informed about the grey scale (shown in Table 2) for converting their ratings inputs to the grey numbers. For collecting the stakeholders’ opinion, four separate brainstorming sessions at the following four different locations are held: HCWTF centre (held on 23rd March, 2021); hospitals (held on 11th April, 2021); Rourkela and Sundargarh municipal corporation (15th April, 2021); and academic institutes (held on 5th May, 2021). Each brainstorming session resulted in one compiled questionnaire including the consensus from all the experts involved in that particular panel. Hence, the data collection process resulted in four grey pair-wise comparison matrices for weighting 10 criteria and four alternatives grey decision matrices. The literature well supports the applicability of the proposed methodology with fewer experts being included (Zhao et al., 2020; Kumar and Anbanandam, 2020; Thakur and Mangla, 2019).

Fig. 1. Status of COVID-19 infected patients in Sundargarh/Odisha, India.

Fig. 2. Geographical location highlighting various sources of HCWs and treatment location alternatives in Sundargarh District, Odisha, India.
4.2.2. Phase-I: Prioritizing the listed criteria of evaluating HCWTF location candidates: G-AHP

The study identifies 10 criteria (shown in Table 1) to evaluate the temporary HCWTF location alternatives in Sundargarh district, Odisha, India. The location alternatives including the selection criteria are highlighted in the decision tree (shown in Fig. 3). Thereafter, the questionnaire (sample questionnaire highlighted in Appendix Table A2) is presented to experts for recording the preferences (in-terms of linguistic variables) of one criterion over the other. The experts in each brainstorming session, are asked to produce one pair-wise comparison matrix among all the listed 10 criteria with the consensus of everyone involved in the discussions. This resulted in four GPCM matrices (shown in Appendix Table A3) from four different types of stakeholders involved in this study: regulatory authority, hospitals administration, waste treatment centers, and academicians. The consistency index and ratios are calculated to ensure the robustness of each pair-wise comparison matrix collected from four different brain-storming sessions by applying Eqns. (2-3) (shown in Appendix Table A4). After, ensuring the CR value less than 10% for each GPCM, the average GPCM matrix is calculated by applying Eqn. (1) (as shown in Appendix VII). The GPCM is converted into CPCM matrix by applying three steps procedure (highlighted in Appendix-II). Finally, the local priority vector (weights) is calculated for each criterion. The final prioritized weights of the listed criteria are shown in Table 3.

4.2.3. Phase-II: Ranking the various HCWTF candidates: G-OCRA

Here, firstly the preferences for various HCWTFs location candidates with respect to the listed criteria are collected from all the four different types of stakeholders and an aggregate linguistic grey decision matrix is developed (shown in Appendix Table A4). The linguistic grey decision matrix is converted into an aggregate grey decision matrix as highlighted in Table 4. Thereafter, the aggregate performances and linear ratings of the alternatives with respect to non-beneficial criteria are computed by applying Eqns. (5-7). Similarly, the aggregate performances and linear ratings of all the alternatives with respect to beneficial criteria are computed by applying Eqns. (8-10). Finally, Eqn. (11) is applied to find the overall rating of each HCWTF location candidate considering all the criteria. The computational results of the G-OCRA methodology are highlighted in Table 4.

5. Discussions

This study proposes a hybrid approach using AHP and OCRA under grey environment, to locate the temporary HCWTF to handle the extra amount of HCW coming out during the health outbreaks. The proposed hybrid methodological solution is applied to the real-life case study of Sundargarh District in Odisha, India, to evaluate the various temporary HCWTF location candidates.

To answer the first research question (What are the criteria present in the external as well as the internal environment, which should be evaluated while selecting the temporary HCWTF location during
### Table 3
Local priority weights of criteria for evaluating HCWTF location alternatives.

| Criteria                                                      | Compliance of environmental laws | Waste generation rates under the coverage area | Distance from the existing HCWTFs | Economic sustainability | Community displacements due to new facility setup | Waste residuals management after treatment | Transportation distance from the hospitals | Proximity to the inhabitation | Land availability for expansion if required | Basic infrastructural availability | Priority weights | CR    |
|---------------------------------------------------------------|----------------------------------|---------------------------------------------|----------------------------------|------------------------|-----------------------------------------------|------------------------------------------|------------------------------------------|-------------------------------|---------------------------------------------|--------------------------------|-----------------|-------|
| Compliance of environmental laws                              | 1.0                              | 0.43                                       | 0.2                              | 0.65                   | 0.75                                          | 0.5                                      | 0.4                                      | 0.13                          | 0.84                                        | 0.77                                          | 0.046           | 0.065 |
| Waste generation rates under the coverage area                | 1.97                             | 0.99                                       | 0.15                             | 0.55                   | 0.75                                          | 0.55                                     | 0.48                                     | 0.22                          | 0.76                                        | 0.42                                          | 0.046           |       |
| Distance from the existing HCWTFs                            | 3.83                             | 5.25                                       | 0.95                             | 0.63                   | 0.5                                           | 0.49                                     | 0.45                                     | 0.33                          | 0.84                                        | 0.42                                          | 0.086           |       |
| Economic sustainability                                       | 1.21                             | 1.41                                       | 1.34                             | 1.0                    | 0.45                                          | 0.13                                     | 0.05                                     | 0.05                          | 0.53                                        | 0.03                                          | 0.033           |       |
| Community displacements due to new facility setup            | 1.06                             | 1.07                                       | 1.7                               | 1.83                   | 1                                             | 0.05                                     | 0.08                                     | 0.1                           | 0.48                                        | 0.03                                          | 0.036           |       |
| Waste residuals management after treatment                    | 1.6                              | 1.41                                       | 1.96                             | 4.31                   | 11.01                                         | 0.99                                     | 0.13                                     | 0.1                           | 0.5                                         | 0.13                                          | 0.074           |       |
| Transportation distance from the hospitals                    | 2.1                              | 1.78                                       | 1.96                             | 10.99                  | 6.43                                         | 5.71                                     | 1                                        | 0.05                          | 0.69                                        | 0.28                                          | 0.108           |       |
| Proximity to the inhabitation                                 | 6.12                             | 3.42                                       | 2.59                             | 21.22                  | 4.9                                          | 7.21                                     | 21.36                                    | 0.87                          | 0.84                                        | 0.66                                          | 0.264           |       |
| Land availability for expansion if required                   | 1.03                             | 1.07                                       | 1.02                             | 1.48                   | 1.73                                          | 1.59                                     | 1.09                                     | 0.97                          | 0.99                                        | 0.25                                          | 0.074           |       |
| Basic infrastructural availability                            | 1.11                             | 1.98                                       | 2.07                             | 21.22                  | 21.32                                         | 5.71                                     | 2.59                                     | 1.38                          | 3.54                                        | 0.88                                          | 0.233           |       |
The investigation to the second research question (how can be the evaluation criteria assigned the priority weights to assess the various location alternatives?), seeks the application of G-AHP methods to assign the weights to the listed criteria by considering the stakeholders’ inputs. The results clearly show that stakeholders have given approximately 50% of the weightage to the top two criteria: ‘proximity to the inhabitation (26.4%)’ and ‘basic infrastructural availability (23.3%)’. The results clearly justify the basic purpose of conducting this study to ensure the safe disposal of the infectious HCWs during the pandemics and also nip the spread of the infection while dealing with the COVID-19 health outbreak. Thakur (2021) also advocated that the water and soil pollution near the habitation can contaminate the whole nearby community. Since, Rourkela city in Sundargarh District, Odisha, India is proposed under the smart city mission by the Government of India, therefore, identifying the location for HCWTF is very crucial to ensure the smart environment for the community. Hence, the waste treatment facilities and the dumping area should be as away as possible from the community area and markets (Manupati et al., 2021; Rahimi et al., 2020). But, at the same time ensuring the quick availability of the basic infrastructure (like: electricity, water supply, roads, quick constructions etc.) for making the waste treatment facility quickly operational, the basic infrastructure should be readily available (Manupati et al., 2021).

Experts have also rated ‘transportation distance from the hospitals (10.8% weightage)’ and ‘distance from the existing HCWTFs (8.6% weightage)’ criteria on the higher side while evaluating the temporary HCWTF location for handling an extra amount of waste during the health outbreaks. The transportation distance is the critical criterion for evaluating a new HCWTF location, as it will reduce the logistics costs and risks of exposing the infectious to the society during the transit (Torkayesh et al., 2021). Moreover, as per WHO guidelines, the HCWs should be disposed of within 24 hrs after the generation from the hospitals (Yang et al., 2021). Hence, nearer the HCWTF from the hospitals, quicker and frequent treatment of the by-products can be ensured. Stakeholders have moderately rated the ‘waste residuals management after treatment (7.4% weightage)’ and ‘land availability for expansion if required (7.4% weightage)’ criteria while selecting the HCWTF location. According to European Union members, the quantity of HCWs generated during the COVID-19 outbreak is escalated and is more infectious in nature, hence, the capacity to treat the wastes should also be enhanced (Das et al., 2021). As per the stakeholders and past studies, the wastes treatment technologies coupled with energy recovery, can further reduce the carbon footprint (Purnomo et al., 2021; Klemes et al., 2020). Purnomo et al. (2021) further stressed that most of the COVID-19 wastes is the plastic polymers (including gloves, masks, PPE kits, face shields, sanitizer bottles etc.), which can be potential source of fuels through the thermochemical processes. Another study by Valizadeh et al (2021) revealed that 34% of the total collection and transportation costs can be recovered by converting the COVID-19 wastes into energy.

The ‘compliance of environmental laws (4.6% weightage)’; ‘waste generation rates under the coverage area (4.6% weightage)’; and ‘community displacements due to new facility setup (3.6% weightage)’ criteria are prioritized on the lower side for evaluating the HCWTF location candidates. Since, the present study targeted to take the immediate and temporary measures to handle the explosive growth of infectious HCWs, hence, as per experts’ opinion, the environmental concerns and community displacements issues are prioritised on the lower side. Setting up the temporary HCWTF to handle the extra HCWs during health outbreaks, should also be backed up by the community relocation plans for the affected areas (Thakur, 2021; Hariz et al., 2017). As per stakeholders’ suggestions, the policymakers should figure out the waste generations’ rates from the area under the coverage of new HCWTF location and clearly list out environmental obligations for larger implications. Stakeholders have given the least priority to the ‘economic sustainability (3.3% weightage)’ criterion while setting up temporary HCWTF location, where experts specially mentioned that during the COVID-19 outbreak, reducing the spread of infection is the main concern, which sometimes may require higher investments.

The study addresses the third research question (How can the administrators evaluate the sustainability dimensions of the HCWTF locations in the uncertainties of the pandemics?) by opting the G-OCRA approach to the case study of Sundargarh District, Odisha, India, for selecting the temporary HCWTF to treat the extra HCWs during the health outbreaks. The study identifies four temporary HCWTFs location alternatives (as shown in Fig. 2). The G-OCRA methodology prioritized the four locations as per the following sequence: HCWTF1 (first rank with a grey score of [-0.796,1.532]); HCWTF3 (second rank with a grey score of [-0.849,1.508]); HCWTF2 (third rank with a grey score of [-0.881,1.43]); and HCWTF4 (fourth rank with a grey score of [-0.923,0.923]). The temporary HCWTF can meet the short-term requirements of the city to handle the extra infectious wastes by ensuring safe disposal (Das et al., 2021; Yu et al., 2020). The results of the study are discussed with the stakeholders in the Sundargarh District, Odisha, and they found the study very relevant for implementing the sustainable HCWM system in the current pandemic situation. Moreover, some stakeholders also suggested the mobile HCW treatment facilities in the big cities to meet the instant demand from the hospitals. The Rourkela, Odisha, India case study results and discussions have underlined various policy and theoretical implications (highlighted in Sec. 6), which can be discussed in general for handling the similar situations worldwide, as this pandemic has hit all over the world with varied intensity.

6. Managerial and Theoretical Implications

This section presents the general managerial and theoretical implications of the proposed research framework from the application and results computed from the case study of Sundargarh District, Odisha, India.

6.1. Implications for practices of HCWM in Sundargarh District, Odisha, India

The national and local (Rourkela and Sundargarh Municipal Corporations) administration should immediately issue the emergency guidelines for setting up the temporary HCWTF to handle the explosive growth of HCWs quantity. The populated cities can adopt the proposed model as it is to select the temporary HCWTF location to handle the extra burden of HCWs during any pandemics. The local administration should consider the listed criteria and find suitable location to dispose of the extra HCWs coming from the thickly populated areas. However, as per the local requirements, the administration may add or delete some of the listed criteria.

The study obtained the crucial role of the factors like proximity to inhabitation to the new location and availability of basic infrastructure for setting up the temporary HCWTF. Therefore, the Municipal Corporations should ensure in their respective cities the probable locations with the availability of roads, water supply, electricity, extra land for...
expansions without disturbing the community, etc., for emergency treatment of the extra HCWs during the pandemics. The HCWTF administration should also consider the distance of the new potential sites from the existing ones and also from the hospitals, while selecting the optimal location for setting up temporary HCWTF.

The policymakers should also ensure the proper management of residual after the incineration of the HCWs, as this can lead to spared of infection to the whole nearby community.

**6.2. Theoretical implications**

The study also presents the key theoretical implications to the various researchers working in the related field or using the MCDM techniques.

The study is the first of its kind to apply the AHP and OCRA under grey environment for selecting the temporary HCWTF location to handle the extra HCWs during the pandemics. Furthermore, the study adds to the theory by presenting the grey extension of the integrated AHP and OCRA techniques.

The study lists the ten criteria to evaluate specifically the temporary HCWTF locations, other than the regular studies for identifying the routine permanent HCWTF locations. The policymakers can feed the criteria as per their local requirements to the proposed model to select the HCWTF location.

The present adds to the theory by highlighting and targeting the HCWs handling problem during the health outbreaks. The role of selecting HCWTF location to handle the explosive growth of HCWs during pandemics is the key contribution of the study.

**7. Conclusions**

Along with India, the whole world is worst hit by COVID-19 outbreak and still, several new mutants of the virus are on the way in terms of second and third waves. The HCWs generation rates are escalating with the increasing number of COVID-19 infected patients. Health outbreaks are always leading to explosive growth in the quantity of infectious wastes. Hence, HCWTF’s capacity expansion and temporary locations for disposal are the need of the hour. Therefore, the present study targets to identify the temporary HCWTF locations based on the evaluation of certain criteria in the Sundargarh District, Odisha, India.

The paper adds the scientific value by addressing the problem of handling extra infectious HCWs generated during the pandemics and setting up temporary HCWTFs to manage the extra burden. The present study identifies ten criteria to evaluate the temporary HCWTF location candidates from the filed surveys, experts’ discussions and literature review. Proposing the hybrid model based on G-AHP and G-OCRA to identify the optimal temporary HCWTF location during the health outbreaks, is the novel contribution of the present study. The study proposes the idea of selecting the locations through GIS tool in any particular city under consideration and applying the scrutiny criteria to select the optimal location for setting up the temporary HCWTFs to handle extra amount of HCWs during pandemics. The major findings of the study and their applications are as below:

The study prioritises the 10 criteria for scrutinising the temporary HCWTF locations using G-AHP approach while considering stakeholders’ inputs and computes ‘transportation distance from the hospitals’ and ‘distance from the existing HCWTFs’ as the most important criteria.

The study proposes G-OCRA approach for sequencing the various temporary HCWTFs location alternatives with respect to listed criteria.

The proposed model is further illustrated with the help of real-life case study based on selection of temporary HCWTF locations to handle the explosive growth in the HCWs during the health outbreaks in Sundargarh District, Odisha, India.

The study identifies four HCWTF location candidates using GIS tools and depending upon the calculated criteria’s weights, prioritized the location alternatives.

The results of the study were discussed with the Rourkela and Sundargarh cities municipal officials and the policymakers were highly satisfied with the proposed methodology solution and optimal alternative pick. They mentioned the safety parameters at the selected location and highlighted that the selected location being away from the residential area and availability of the basic infrastructure will make it more strategic decision for instant use. The stakeholders find the decision-making model useful for setting up temporary HCWTF locations in other cities also.

Like every study, the present study is also limited by many ways and hence, opens the directions for future research. This study may further motivate the researchers working in the related field to focus their studies to the current need of the hour and more research directions like: capacity-building during pandemics, collection, storage and transportation of HCWs during health outbreaks, etc. can be explored. However, the study defines the evaluation criteria based on the experts’ inputs and field surveys done in Rourkela, Odisha, India, but, the same set of criteria may not be generalised for every city. Hence, administration should focus on identifying the evaluation criteria based on the local requirements and needs to be validated regional specific. The present study focuses only on quick release of the extra HCWs burden on the current HCWTFs due to the pandemic going on; hence, the study might have missed some important factors like: reverse supply chain measures, recycling, sustainability etc.

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**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Performance ratings of location alternatives for profit/beneficial criteria

| Performance ratings of location alternatives for profit/beneficial criteria | G-OCRA Results |
|-----------------------------|-----------------|
| Waste residuals management after treatment | Land availability for expansion if required | Basic infrastructural availability | $P_i$ | $L^b_i$ | $P_i + L^b_i$ | $A_i$ | $A_i$ | Ranking |
| [0.75,0.95] | [0.75,0.95] | [0.25,0.38] | [0.12,0.59] | [0.06,0.63] | [0.07,0.47] | [0.33,0.51] | [0.27,1.14] | [0.86,1.53] | 0.37 First |
| [0.13,0.28] | [0.05,0.20] | [0.83,0.98] | [-0.01,0.40] | [0.07,0.44] | [0.12,0.57] | [0.28,0.6] | [0.351,1.04] | [0.88,1.4] | 0.28 Third |
| [0.20,0.35] | [0.25,0.38] | [0.83,0.98] | [-0.04,0.42] | [0.10,0.46] | [0.18,0.62] | [0.22,0.65] | [0.32,1.12] | [0.85,1.51] | 0.33 Second |
| [0.55,0.75] | [0.55,0.75] | [0.15,0.33] | [0.09,0.06] | [0.03,0.10] | [-0.03,0.39] | [-0.43,0.43] | [-0.39,0.53] | [-0.92,0.92] | 0.00 Fourth |

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Appendix

Appendix-I: Some basic operations on the grey numbers:

Let $G_1 \in [G_{11}, G_{12}]$ and $G_2 \in [G_{21}, G_{22}]$ be the two grey numbers, then $G_1 + G_2 = \min \{G_{11} + G_{21}, G_{12} + G_{22}\} / \max \{G_{11}, G_{12}, G_{21}, G_{22}\}$

$G_1 - G_2 = \max \{G_{11} - G_{21}, G_{12} - G_{22}\} / \min \{G_{11}, G_{12}, G_{21}, G_{22}\}$

$G_1 \times G_2 = \max \{G_{11} / G_{21}, G_{12} / G_{22}, G_{11} G_{22}, G_{12} G_{21}\}$

$G_1 / G_2 = \max \{G_{11} / G_{22}, G_{12} / G_{21}\}$

Appendix-II: De-greying method

Normalizing the GPCM matrix:

Let, $G_{ib}^b$ be the grey number assigned by the nth expert on the importance of ith criterion over jth criterion.

Table A1

Experts’ details.

| Organization | Designation and Experience (years) | Operational responsibilities | Number of respondents contacted | Number of respondents | Response rate (%) |
|--------------|-----------------------------------|-----------------------------|-------------------------------|----------------------|------------------|
| HCWTF        | Operations managers (10-17)       | Monitoring the routine segregation, collection, storage, disposal and maintaining records of HCWs coming from various hospitals and COVID-19 treatment centers. Responsible for the overall functioning of the HCWTF. | 03 | 03 | 100 |
| HCWTF        | Chairman (32)                     | Owner and coordinator of three HCWTFs in the Sundargarh district of Odisha. | 01 | 01 | 100 |
| Healthcare facilities | Hospitals’ managers (15-23) | Responsible for overall functioning of the HCFs including the HCWM: collection, storage, outsourcing etc. | 06 | 04 | 66.67 |
| Healthcare facilities | COVID-19 hospitals’ superintendents (10-15) | Responsible for the overall functioning of the HCFs including the HCWM: collection, storage, outsourcing etc. | 07 | 05 | 71.4 |
| Rourkela and Sundargarh municipal corporation | Officers (07-18) | Regulating the municipal and healthcare wastes in the district by providing the guidelines to the HCFs and conducting the regular audits to ensure hygiene. | 10 | 07 | 70 |
| Academics    | Professors and Associate Professors (12-25) | Whose research works and interests include: healthcare services, municipal solid wastes management, healthcare waste management, facility locations, etc. | 20 | 12 | 60 |

Table A2

Sample Questionnaire for comparing the first criterion with rest of the nine criteria (Please rate the importance ranging from ‘VLP’ to ‘VHP’, as scale shown in Table 2).

| Statements                                                                 | Ratings |
|---------------------------------------------------------------------------|---------|
| ‘Compliance of environmental laws’ is preferred over ‘Waste generation rates under the coverage area’ | 0.55    |
| ‘Compliance of environmental laws’ is preferred over ‘Distance from the existing HCWTFs’ | 0.03    |
| ‘Compliance of environmental laws’ is preferred over ‘Economic sustainability’ | 0.75    |
| ‘Compliance of environmental laws’ is preferred over ‘Community displacements due to new facility setup’ | 0.25    |
| ‘Compliance of environmental laws’ is preferred over ‘Waste residuals management after treatment’ | 0.01    |
| ‘Compliance of environmental laws’ is preferred over ‘Transportation distance from the hospitals’ | 0.33    |
| ‘Compliance of environmental laws’ is preferred over ‘Proximity to the inhabitation’ | 0.09    |
| ‘Compliance of environmental laws’ is preferred over ‘Land availability for expansion if required’ | 0.03    |
| ‘Compliance of environmental laws’ is preferred over ‘Basic infrastructural availability’ | 0.15    |

Note: Similarly the scale has been extended for rest of the pair-wise comparisons.
| Criteria                                                                 | Compliance of environmental laws | Waste generation rates under the coverage area | Distance from the existing HCWTFs | Economic sustainability | Community displacements due to new facility setup | Waste residuals management after treatment | Transportation distance from the hospitals | Proximity to the inhabitation | Land availability for expansion if required | Basic infrastructural availability |
|-------------------------------------------------------------------------|----------------------------------|-----------------------------------------------|-----------------------------------|-------------------------|-----------------------------------------------|---------------------------------------------|-----------------------------------------------|-------------------------------|-----------------------------------------------|-----------------------------------|
| Compliance of environmental laws                                        | 1                                | M,MHP,M,M                                    | MLP,LP,LP,MLP                     | VHP,HP,HP,HP            | M,MHP,M,MHP                                  | MLP,M,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Waste generation rates under the coverage area                           | 1                                | M,MHP,M,M                                    | MLP,LP,LP,MLP                     | VHP,HP,HP,HP            | M,MHP,M,MHP                                  | MLP,M,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Distance from the existing HCWTFs                                       | 1                                | HP,MHP,M,H,M                                 | MLP,LP,LP,MLP                     | VHP,HP,HP,HP            | M,MHP,M,MHP                                  | MLP,M,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Economic sustainability                                                 | 1                                | VLP,MLP,MLP                                  | M,MHP,M,H,M                       | MLP,LP,LP,MLP                     | VHP,HP,HP,HP                                  | M,MHP,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Community displacements due to new facility setup                       | 1                                | VLP,MLP,MLP                                  | M,MHP,M,H,M                       | MLP,LP,LP,MLP                     | VHP,HP,HP,HP                                  | M,MHP,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Waste residuals management after treatment                               | 1                                | VLP,MLP,MLP                                  | M,MHP,M,H,M                       | MLP,LP,LP,MLP                     | VHP,HP,HP,HP                                  | M,MHP,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Transportation distance from the hospitals                              | 1                                | VLP,MLP,MLP                                  | M,MHP,M,H,M                       | MLP,LP,LP,MLP                     | VHP,HP,HP,HP                                  | M,MHP,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Proximity to the inhabitation                                           | 1                                | VLP,MLP,MLP                                  | M,MHP,M,H,M                       | MLP,LP,LP,MLP                     | VHP,HP,HP,HP                                  | M,MHP,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Land availability for expansion if required                              | 1                                | VLP,MLP,MLP                                  | M,MHP,M,H,M                       | MLP,LP,LP,MLP                     | VHP,HP,HP,HP                                  | M,MHP,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |
| Basic infrastructural availability                                       | 1                                | VLP,MLP,MLP                                  | M,MHP,M,H,M                       | MLP,LP,LP,MLP                     | VHP,HP,HP,HP                                  | M,MHP,M,MHP                                | MLP,MLP,MLP,MLP                  | VHP,HP,HP,HP                  | M,MHP,M,MHP                        | HP,HP,HP,HP                       |

Note: CR values of all four brain-storming sessions < 0.10 (10%) (CR1 = 0.071; CR2 = 0.562; CR3 = 0.068; CR4 = 0.075).
### Table A4
Linguistic grey decision matrix.

| Criteria Alternatives | Performance ratings of location alternatives for cost/non-beneficial criteria | Performance ratings of location alternatives for profit/beneficial criteria |
|------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------|
|                        | Distance from the existing HCWTFs VH,MH,H,VH | Community displacements due to new facility setup VL,VL,L,VL | Transportation distance from the hospitals VH,VH,VH,VH | Proximity to the inhabitation VL,VL,L,VL | Compliance of environmental laws VH,H,H,H | Waste generation rates under the coverage area ML,ML,ML | Economic sustainability ML,ML,ML | Waste residuals management after treatment H,VH,H,VH | Land availability for expansion if required H,VH,H,VH | Basic infrastructural availability ML,ML,ML |
| HCWTF candidate 1      | L,ML,L,VL                                      | H,MH,MH,H                                                             | L,ML,MH,VL                                                  | H,H,MH,ML                                             | ML,ML,L,L                                               | H,VH,H,H                                               | L,ML,L,ML                                              | L,ML,L,ML                                              | L,ML,L,ML                                              |
| HCWTF candidate 2      | L,ML,MH,ML                                      | H,VH,H,H                                                             | ML,ML,ML,ML                                                  | H,MH,MH,H                                             | L,ML,ML,ML                                              | H,VH,H,H                                              | L,ML,L,ML                                              | L,ML,L,ML                                              | L,ML,L,ML                                              |
| HCWTF candidate 3      | H,H,VH,H                                        | L,ML,ML                                                             | H,H,VH,MH                                                   | L,ML,ML,ML                                             | H,VH,H,VH                                               | VH,VH,H,VH                                             | L,ML,L,ML                                              | ML,ML,L,ML                                              | VH,VH,H,VH                                              |
| HCWTF candidate 4      | L,H,VL,ML                                       | H,H,VH,MH                                                           | L,ML,L,VL                                                   | H,H,VH,H                                               | L,ML,L,L                                               | L,ML,L,ML                                              | H,H,MH,ML                                              | H,H,MH,ML                                              | L,ML,L,ML                                              |
Lower normalized grey limit of $G_i^j$:

$$
\overline{G_i} = \left( \overline{G_i^j} - \min \overline{G_i^j} \right) / \Delta_{min}^n
$$

Upper normalized grey limit of $G_i^j$:

$$
\overline{G_i} = \left( \overline{G_i^j} - \min \overline{G_i^j} \right) / \Delta_{min}^n
$$

Where, $\Delta_{max}^n = \max \overline{G_i^j} - \min \overline{G_i^j}$

ii) Compute the total normalized crisp value:

$$
Z_n = \left( G_i^j (1 - \overline{G_i}) + (\overline{G_i} \times \overline{G_i}) \right) / \left( 1 - \overline{G_i} + \overline{G_i} \right)
$$

iii) Compute the final crisp value:

$$
Z_n = \left( \min \overline{G_i^j} + (Z_n \times \Delta_{max}^n) \right) / \text{number of experts}
$$

$$
\min \overline{G_i^j} : \text{maximum value of lower limit for } j^{th} \text{ column, assigned by } n^{th} \text{ expert}
$$

$$
\max \overline{G_i^j} : \text{maximum value of upper limit for } j^{th} \text{ column, assigned by } n^{th} \text{ expert}
$$

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