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Selection of the best healthcare waste disposal techniques during and post COVID-19 pandemic era



Vijaya Kumar Manupati ^a, M. Ramkumar ^{b,*}, Vinit Baba ^{a,1}, Aayush Agarwal ^c

^a Department of Mechanical Engineering, National Institute of Technology Warangal, Telangana, India

^b Operations and Quantitative Methods Group, Indian Institute of Management Raipur, Atal Nagar, Kurru (Abhanpur), Raipur, 493 661, India

^c Department of Mechanical Engineering, VIT University, Vellore, India

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ABSTRACT

In recent years, municipal authorities especially in the developing nations are battling to select the best health care waste (HCW) disposal technique for the effective treatment of the medical wastes during and post COVID-19 era. As evaluation of various disposal alternatives of HCW and selection of the best technique requires considering various tangible and intangible criteria, this can be framed as multi-criteria decision-making (MCDM) problem. In this paper, we propose an assessment framework for the selection of the best HCW disposal technique based on socio-technical and triple bottom line perspectives. We have identified 10 criteria on which the best HCW disposal techniques to be selected based on extant literature review. Next, we use Fuzzy VIKOR method to evaluate 9 HCW disposal alternatives. The effectiveness of the proposed framework has been demonstrated with a real-life case study in Indian context. To check the robustness of the proposed methodology, we have compared the results obtained with Fuzzy TOPSIS (Technique of Order Preference Similarity to the Ideal Solution). The results help the municipal authorities to establish a methodical approach to choose the best HCW disposal techniques. Our findings indicate that incineration is the best waste disposal technique among the available alternatives. Even if the dataset indicates 'incineration' is the best method, we must not forget about the environmental concerns arising from this method. In COVID time, incineration may be the best method as indicated by the data analysis, but "COVID" should not be an excuse for causing "Environmental Pollution".

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1. Introduction

Managing the healthcare waste (HCW) is one among the most serious encounters faced by any medical fraternity throughout the world especially during the COVID-19 pandemic crisis (World Health Organization, 2020; Yu et al., 2020). This may be due to the presence of wide range of hazardous materials such as used needles and syringes, personal protective equipment (PPE), soiled dressings, heavy metals, body parts, pathogens, diagnostic samples, blood, toxic chemicals, pharmaceuticals, medical devices, and radioactive materials in these HCWs. (Thakur and Ramesh, 2017; Yu et al., 2020). The outbreak of COVID-19 pandemic may cause

substantial commination to mankind and other creatures like birds, animals, and reptiles and lead to a worldwide crisis because of the highly contagious nature of the disease. To effectively control the escalation of COVID-19 pandemic, the effective HCW management is of crucially important. However, no research to date addresses about the selection of the best HCW disposal technique to effectively manage and control such pandemic outbreaks. The main motivation for us to focus in this direction is if HCWs are improperly treated and disposed, this may further speed up the spread of COVID-19 and create a substantial risk for in the lives of both medical fraternity (healthcare employees, waste handling labors), patients and the society at large. Improper disposal of healthcare wastes further leads to environmental pollution (Baghapour et al., 2018; Ju et al., 2020). Hence it is necessary that all HCWs are separated properly at the point of generation, accurately treated, and disposed carefully (Badi et al., 2019).

In the developing countries like India, bad HCW treatment procedures and improper waste dumping techniques are often

* Corresponding author.

E-mail addresses: manupati.vijay@nitw.ac.in (V.K. Manupati), mramkumar@iimraipur.ac.in (M. Ramkumar), vinitbaba97@gmail.com (V. Baba), aayush.agarwal1097@gmail.com (A. Agarwal).

¹ Late

employed (Thakur and Ramesh, 2017). This poor HCW treatment practices and inappropriate waste disposal methods or techniques causes substantial health threats and ecological contamination due to the contagious nature of the HCW (Minoglou et al., 2017). With a population of approximately 1.3 billion and recent tremendous growth in the medical facilities, the HCW management issue needs to be addressed in a serious manner (Thakur and Ramesh, 2017). As per Indian Society of Hospital Waste Management (ISHWM) reports, it is anticipated that at least 1–2 kg of HCW is generated per bed per day in a hospital and at least 600 g per bed per day is generated in a general practitioner's clinic. It is also estimated that at least 5–10% of this comprises of hazardous/infectious waste. Considering the large number of patients in the country, the daily generation of HCW forms a huge number, which needs to be managed in a proper manner (Thakur and Ramesh, 2017). This induces the need of proper HCW management systems to treat and dispose the hazardous and infectious wastes in an effective manner. Less than 50% of the healthcare facilities in India follow proper waste management practices and even segregate their waste into infectious and non-infectious waste (Thakur and Ramesh, 2017). The sole responsibility of HCW handling is on hospitals to guarantee that there will not be any harmful health and environmental consequences because of their HCW treatment and disposal activities. A WHO report reveals that injections with infected needles affected at least 21 million hepatitis B infections, two million hepatitis C infections, and at least 260,000 HIV infections (World Health Organization, 2020). Therefore, proper treatment and disposal of HCW are of utmost important. This motivates us to develop a tool for the assessment of HCW disposal techniques during and after COVID-19 era.

The problem of HCW management in India is a serious concern and needs to be addressed promptly. This paper effectively analyzes the current HCW management system in India by considering a case study. Patil and Shekdar (2001) describes various systems of HCW management in India and proposes a waste management plan for the existing health care establishments in India. However, it does not compare the effectiveness of different HCW disposal techniques in Indian context as our paper does. The MCDM approach helps to identify the ideal alternative in cases where multiple criteria exist. This paper solves the problem of HCW management by using a Fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian), a Multi-criteria decision-making (MCDM) methodology and presents a rational ranking of different HCW management techniques based on the criteria considered.

We have identified 10 criteria that effect on the selection of best 9 HCW disposal techniques and group the identified 10 factors into 4 major dimensions (social, economic, environmental, and technical) based on triple bottom line and socio-technical perspectives. Today, in the era of Industry 4.0, forward-thinking healthcare companies as well as hospitals across the globe are assessing themselves not only based on their financial bottom line, but also based on their social (community related) and environmental endeavors. Furthermore, there are enough evidence for successful healthcare organizations with the focus on people and planet excels in profits as well. This motivates us to apply the triple bottom line theoretical perspective in our research to further the sustainability related objective. The fundamental idea of socio-technical systems (STS) theory is that every company or business organization is “built up of employees (the social system) utilizing various tools, techniques and expertise (the technical system) so as to deliver valuable goods and services for customers” (Pasmore, 1988, p.1). As in the case of effective HCW management also, employees utilizing tools, techniques and skills are a prerequisite in hospitals and other health related organizations, we have also used STS theory along

with triple bottom line in our research.

The dimensions and factor selection for identifying the 10 criteria that effect on the selection of the best HCW disposal techniques consists of three phases. Primarily, the factors that are relevant in “healthcare waste disposal” are identified from the extant literature through “keyword” search such as “health care waste management”, “health care waste disposal”, and “health care waste treatment” from well-known scientific data bases. Some factors that are not relevant for “health care waste disposal” are eliminated in the second phase after having informal discussions with academic and industry experts. In the final phase, we have categorized the 10 identified selection factors that effect on the selection of the best health care waste disposal techniques out of 9 identified. After the identification of 10 criteria that effect on the selection of the best HCW disposal techniques from the available 9 alternatives, we scrutinized the criteria against economic, environment, social and technical criteria.

This paper enriches the field of healthcare waste management and sustainability by making the following contributions: First, we identify the factors for the assessment of HCW disposal techniques during and via expert opinions grounded in triple bottom line and socio-technical perspectives. Second, we build the model to easily combine the opinions from different experts to reach consensus. Third, we apply the proposed approach to a real-life case in Indian context. Finally, we compare the rankings obtained from Fuzzy VIKOR, Fuzzy TOPSIS (Technique of Order Preference Similarity to the Ideal Solution) and the hybridized ranking to show the robustness of the proposed methodology. Lastly, this study acknowledges the necessity of diversified pool of experts with technical and domain expertise to make right decision as well as to achieve consensus.

The rest of this paper proceeds as follows. In the next section, we present a brief background of healthcare waste management with specific focus on triple bottom line and socio-technical systems perspectives. Then, we provide details related to our proposed Fuzzy-VIKOR to solve the HCW problem identified, followed by its application to a case study in India. We close with a discussion of our results, implications for research and practice, followed by conclusion with the limitations of the study.

2. Background

Since 1900s, this world has been experiencing the increasing number of both natural and human-related calamities (Hawryluck et al., 2005). Among these natural and man-made catastrophes, the outbreak of epidemic disease creates substantial commination to mankind (Yu et al., 2020). If these epidemics are inefficiently managed, it will further lead to a pandemic situation and end up in global crisis (Queiroz et al., 2020). An epidemic is defined as “the outbreak of disease cases in excess of normal expectancy” (World Health Organization, 2020), which is generally spread by human-to-human and animal-to-human communication or through radioactive and hazardous chemical sources like healthcare wastes (Yu et al., 2020). The epidemic outbreak of diseases such as chikungunya, the severe acute respiratory syndrome (SARS), the Marburg hemorrhagic fever, the H1N1 influenza, the Ebola virus, the Nipah virus, smallpox, cholera, Crimean-Congo hemorrhagic fever, Hendra virus infection, Lassa fever, Meningitis, plague, and the Middle East respiratory syndrome coronavirus (MERS-Cov) and the Novel coronavirus (2019-nCoV or COVID-9), have not only impacted the lives of the man-kind through large number of deaths and sharp upsurge in infections in shorter time, but also has a negative impact on the global economy as a whole (Yu et al., 2020). Furthermore, the anxiety of epidemic outbreak has led to a worldwide panic situation. The abrupt growth on the infected

patients within a short span of time due to the contagious nature of these epidemics leads to the increase in demand of doctors, nurses, medical supplies, healthcare facilities, etc., in order to deliver a timely and adequate health service, control the spread of the disease and reduce the economic impact of the country. This abrupt growth of the infected patients further leads to the stock pile up of various healthcare wastes such as used needles and syringes, personal protective equipment (PPE), soiled dressings, heavy metals, body parts, pathogens, diagnostic samples, blood, toxic chemicals, pharmaceuticals, medical devices, and radioactive materials. In this regard, the effective HCW management is of crucially important to contain the spread of these diseases as there will be increase in pile up of HCWs because of the abrupt growth of patients during the outbreak of epidemics.

Since December 2019, Numerous cases of atypical pneumonia of unknown source got detected in Wuhan, China, which was later corroborated that the widespread or outbreak is because to human-to-human transmission. This was initially reported to the WHO office on 31 December 2019. Since January 2020, the COVID-19 cases have risen drastically, and a worldwide emergency has been announced by the WHO on January 31st (Amankwah-Amoah, 2020). Though, the COVID-19 pandemic spread quickly in the China's Wuhan zone, it was at first generally ignored by the Governments in other parts of the globe even though intelligence agency of USA released alerts of a possibly catastrophic incident (Queiroz et al., 2020). To suppress the spread of the COVID-19 virus, Wuhan was set into lockdown (a mixture of provincial and personal level quarantine measures), and number of cases in China got stabilized at around 80,000 by the middle of February 2020 (ECDC 2020; World Health Organization, 2020). By that time, the international air transportation had already brought the COVID-19 virus to all the seven continents and, by the end of June, it had been spread in 215 countries. The actual figure of the COVID-19 cases continues to stay unknown as testing facilities are inadequate in most of the countries. The overall reported cases of COVID-19 by June 26th (20:30 h Indian time) had risen to 9,757,432 and deaths has been increased to 492,731 in at least 215 countries as per Worldometers data, among which more than 25% of the cases are reported in America, 12.5% of the cases are reported in Brazil and around 7% of the cases are reported in Russia (World Health Organization, 2020). Fig. 1 shows the global distribution of COVID-19 cases as on 26th of June 2020. As far as India is concerned, Worldometers reported 497,824 of total cases and 15,406 of deaths. Fig. 2 shows the COVID-19 hotspots in India. From the Fig. 2, one can derive that Mumbai, Chennai, Delhi, Ahmedabad, and Hyderabad are the hotspots in India. Fig. 3 shows the cumulative trends of

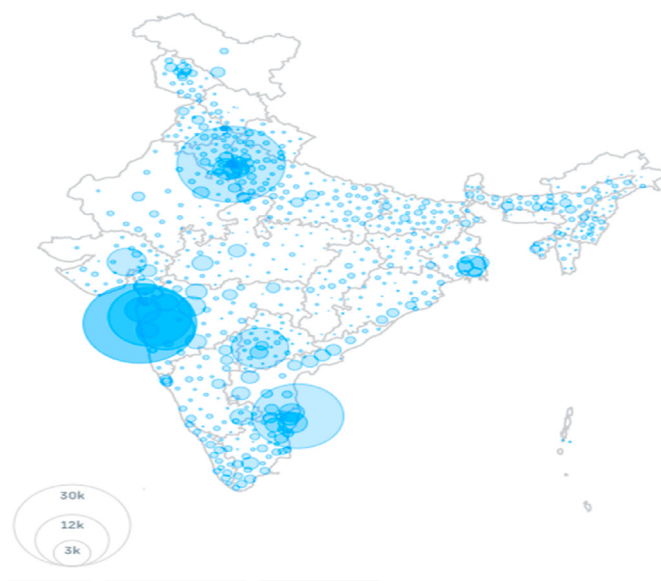


Fig. 2. COVID-19 hotspots in India (COVID19India.org).

COVID-19 cases (confirmed, active, recovered, deceased and tested) in India. As there is no vaccine to treat COVID-19 and because of inadequate medical facilities, different nations including India responded with innumerable ways of nonpharmaceutical interventions such as lockdown (home quarantine, voluntary/ compulsory quarantine), societal distancing (susceptible or whole inhabitants), shutting down of educational institutions and non-essential businesses/offices, stopping or delaying the planned events (i.e. main conventions and trade exhibitions, concerts and celebrations, political discussions and polls, and sport events), and prohibitions on get-togethers of mass gatherings.

As the COVID-19 outbreak spread out worldwide, there is mounting anxiety regarding how to effectively dispose the waste occurring from patients, the healthcare staffs and health laboratories (Klemeš et al., 2020; Wang et al., 2020). The World Health Organization (WHO) recommends that any method applicable for the effective management of infectious HCW will also be able to handle the COVID-19 waste. Segregation techniques should continue to remain the same and wastes related with COVID-19 should no differently treated/disposed like other HCWs. The following are some of the recommendations of WHO to treat/ dispose COVID-19 wastes (World Health Organization, 2020).

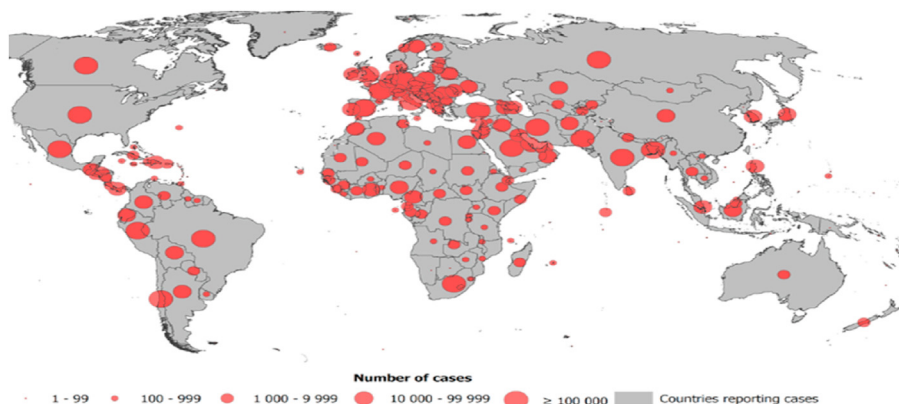


Fig. 1. Global distribution of COVID-19 cases as on 26th June 2020 (Source: ECDC 2020).

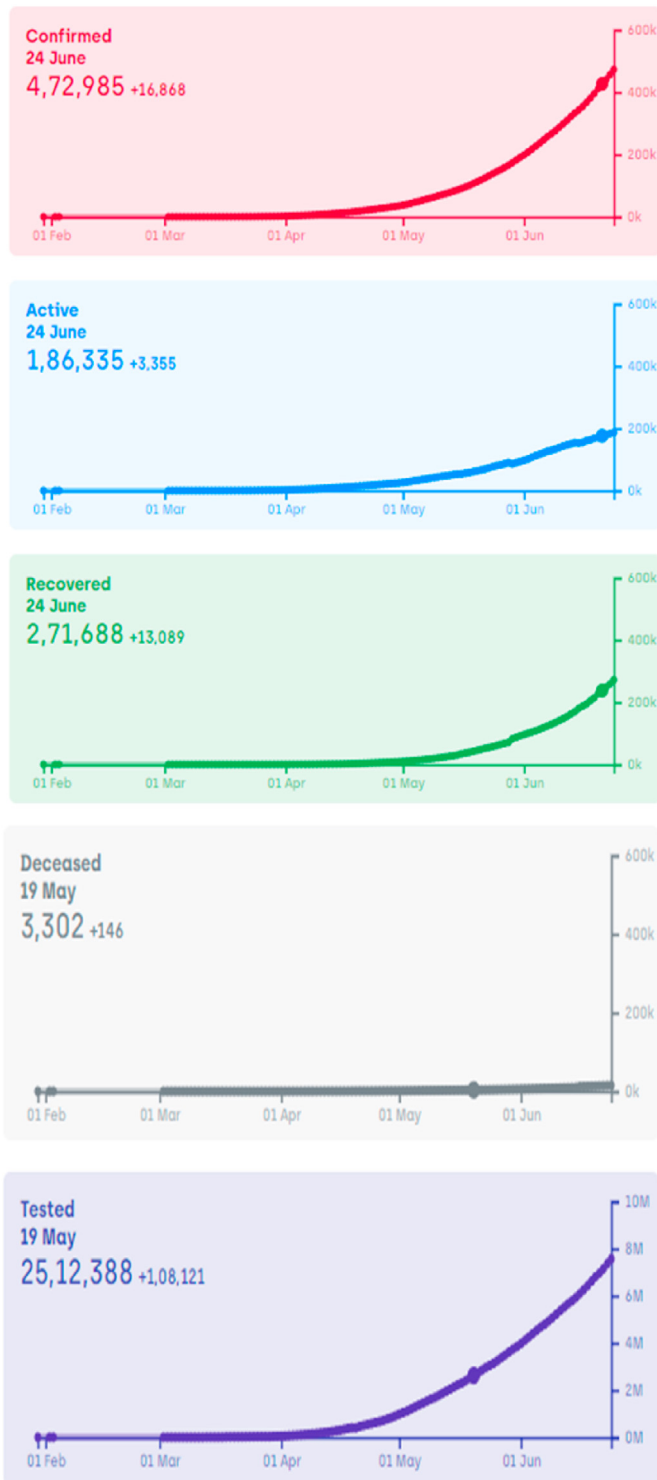


Fig. 3. Cumulative trends of COVID-19 cases in India (Source: Covid19india.org).

- Separate different types of waste at source
- Treat COVID-19 waste like other infectious healthcare waste
- Dump the COVID-19 wastes in irresistible waste bin, with an appropriately color-coded liner
- Collect the accumulated COVID-19 waste at least once in a day, and transport it in sealed leakproof, puncture proof bins, with the biohazard label.

- Storage space of COVID-19 wastes should be maintained sanitized, protected, and safeguarded from the pests and disease vectors.
- Best HCW management practices suggest that COVID-19 waste should be sanitized by non-incineration techniques such as autoclaving or microwaving.
- All the HCW techniques should be validated and thoroughly tested regularly
- After sanitization, COVID-19 waste can be sent for disposal or recycling.
- Any substance that could possibly be recycled and reused should be mutilated.

Lot of attempts has been made in the literature to analyze HCW management practices across different countries. Apart from the country specific studies, there are few cross-country oriented literatures such as Ananth et al. (2010), where the focus was to improve the existing health care waste management practices comprising of 12 Asian countries. However, there were very limited literature, which has its focus specifically on Indian context. For instance, Thakur and Ramesh (2017) used grey-AHP method for the selection of the best HCW disposal strategy.

Selection of the best HCW disposal technique can be considered as a complicated MCDM problem as it involves assessment of the alternative disposal methods. We have grounded our problem based on two well-known theoretical perspectives such as socio-technical perspective and triple bottom line approach to study the assessment of HCW disposal techniques in the context of Tamil Nadu, India. Strange (2002) argues that the goal of sustainable development is one of major driving factors in shaping the waste management policy. Because of which, the approach to waste management should always include the social, economic and environmental dimensions of sustainability. Adeniran et al. (2017) incorporated the sustainable development strategies in solid waste treatment to have a positive impact on the socio-economic and environmental prosperity of their immediate and extended communities. Zen et al. (2016) used a case study on waste minimization in the campus of Universiti Teknologi Malaysia as an effective step towards economic and environmental sustainability. Dursun et al. (2011) argues that the triple bottom line sustainability criteria should be considered in HCW treatment. Brent et al. (2007) used AHP to develop a HCW management system so as to minimize infection risks. The use of MCDM in HCW disposal retains the benefit of extracting the expert opinion in more unbiased and transparent manner (Chung and Poon, 1996). Fuzzy MCDM models have also been used in HCW management to remove the vagueness in human judgment (Lee et al., 2016; Hariz et al., 2017).

3. Research methodology

Different MCDM models such as AHP, ANP, ELECTRE, TOPSIS, PROMETHEE and VIKOR have different effectiveness and applicability depending upon the problem of investigation. A comparative analysis of various MCDM methods has been given in several literature (Opricovic and Tzeng, 2007). As far as AHP and ANP are concerned, pair-wise comparisons of alternatives with respective to criteria and sub-criteria are required (Kim et al., 2019; Manupati et al., 2018; Sharma et al., 2019). ANP is often used whenever there is some sort of interdependencies among the criteria or sub-criteria or both (Ramkumar and Jenamani, 2012, 2015); whereas AHP assumes all the criteria and sub-criteria are independent among one another (Ramkumar, 2016; Ramkumar et al., 2016). The ELECTRE method is generally considered more suitable for problems having not many criteria and several alternatives (Konidari and Mavrakis, 2007). PROMETHEE is an outranking method like

ELECTRE as it also involves multiple iterations and easy to use (Vincke, 1985).

The main advantage of the VIKOR method is that it introduces the multi-criteria ranking index based on the particular measure of “closeness” to the ideal solution (Opricovic and Tzeng, 2007). Because of its advantages, the use of VIKOR method has been enhanced in the recent past including green supplier selection (Awasthi and Kannan, 2016; Abdel-Baset et al., 2019), evaluating service quality in air industry (Gupta, 2018), military airport location selection (Sennaroglu and Celebi, 2018), industrial robots selection (Narayanamoorthy et al., 2019) and much more. Some of the other important applications of VIKOR has been illustrated in Table 1.

Among all the MCDM models considered above, VIKOR is the most suitable method considering the area of application of this paper and hence it has been used for finding apriority ranking of HCW disposal alternatives in accordance with the established criteria. The objective of this research paper is to determine the best HCW disposal alternative in Indian context. In order to achieve the above mentioned objective, a set of 10 criteria grounded on socio-technical and triple bottom line approach was developed from existing literature and recommendations by experts in the field of health care. Also 9 HCW disposal alternatives relevant in Indian context were considered. The preference rating of the criteria and alternatives was taken from decision makers through various questionnaires. In the process of making a group decision, linguistic variables are used by the decision makers to estimate the weights and ratings of the proposed selection criteria which are converted to triangular fuzzy numbers, followed by the application of fuzzy VIKOR to obtain a ranking of various HCW disposal alternatives considered. The Fuzzy VIKOR method comprises of the following steps.

Step 1: Identification of the problem (selection of the healthcare waste techniques in our case) which requires multiple criteria, sub-criteria, and alternatives

Step 2: Identification of the relevant criteria, sub-criteria, and alternatives for the problem. As far as our case is concerned, we have scrutinized the 4 criteria and 10 sub-criteria identified as per the economic, environmental, social, and technical elements derived from triple bottom line and socio-technical perspectives.

Step 3: Recognition of suitable linguistic variables (see Table 2 and Table 3) for our research to get the preference ratings from a pool of experts identified easily. These linguistic variables are translated to triangular fuzzy numbers as shown in Tables 2 and 3.

Step 4: The rating of alternatives with respect to criteria by means of expert opinion.

Step 5: The preference data provided by the experts related to the criteria and alternatives are aggregated by:

- Aggregating the weights of criteria

Table 1
Applications of VIKOR in other MCDM models.

Sl. No.	Author name	Topic	Industry, Country
1	Xu et al. (2017)	Assessing the service performance of electric vehicle sharing programs	Automotive, Beijing
2	Wu et al. (2016)	Supplier selection	Nuclear power, China
3	Li et al. (2016)	Evaluation of eco-industrial thermal power plants.	Energy, China
4	Lin et al. (2016)	Service selection model for digital music service platform	Digital music, China
5	Kaya and Kahraman (2010)	Renewable energy planning	Energy, Turkey
6	Luthra et al. (2017)	Sustainable supplier selection	Automobile, India
7	Wu et al. (2016)	Machine tool selection	Manufacturing, China
8	Hsu et al. (2012)	Best vendor selection	Manufacturing, China
9	Rostamzadeh et al. (2015)	Evaluation of green supply chain management.	Electronics, Malaysia
10	Prakash and Barua (2016)	Evaluation and selection of third-party reverse logistics partner.	Electronics, India

Table 2
Linguistic variables for rating of criteria.

Linguistic variable	Fuzzy numbers
Very Low(VL)	(0,0,0.25)
Low(L)	(0,0.25,0.5)
Moderate(M)	(0.25,0.5,0.75)
High(H)	(0.5,0.75,1)
Very High(VH)	(0.75,1,1)

Table 3
Linguistic variables for alternatives.

Linguistic variable	Fuzzy numbers
Very Low(VL)	(0,0,1)
Low(L)	(0,1,3)
Moderate Low(ML)	(1,3,5)
Moderate(M)	(3,5,7)
Moderate High(MH)	(5,7,9)
High(H)	(7,9,10)
Very High(VH)	(9,10,10)

- Aggregation of the rating of alternatives

Step 6: Defuzzification: The process of defuzzification of fuzzy weight of criteria and fuzzy decision matrix is done for identifying the Best Nonfuzzy Performance value (BNP). We have used center of area (COA) method for calculating the BNP.

Step 7: Calculation of negative ideal solution value (NIS) and positive ideal solution value (PIS)

Step 8: The distance of ith alternative to PIS represented as S_i and the distance of ith alternative to NIS represented as R_i is computed

Step 9: The gaps of ranking Q_i is computed

Step 10: The alternatives are ranked, sorting by the values S_q , R_q , and Q_q in decreasing order. The results are three ranking lists where the best alternative has the lowest value.

Step 11: A compromise solution is proposed, the alternative having the least value of Q_q is selected if it satisfies the following mentioned conditions

1. Acceptable advantage computed by the following equation

$$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{c-1} \tag{1}$$

Where $Q(A^{(1)})$ is the best alternative is ranked by Q value and $Q(A^{(2)})$ is the second position in the ranking list by Q_i

2. There should be a stability in the decision making process meaning that the S_i and R_i rankings should also show $A^{(1)}$ to be the best alternative among all the alternatives.

Step 12: The best compromise solution is selected.

4. Case study description

In this paper, a case study from Tamil Nadu, a southern state in India has been described to illustrate the application of the proposed HCW treatment alternative. Tamil Nadu is one among the fastest developing states in the southern part of India with an average population of 77.8 million. Over the past few decades, there has been a steep increase in the quantity of health care waste collected and processed at different incineration plants present in the state. Hence, the number of incineration plants present in the state is not adequate to incinerate all the medical waste generated from different parts of the state. The prevalent methods like incineration are not sustainable and also have many safety measures associated with its working. Hence these methods are not ideal for medical waste disposal in the twenty-first century. Therefore, nine possible treatment technologies identified from the literature have been stated for the disposal of health-care wastes and the best treatment alternative has been determined using the proposed procedure. The proposed treatment alternatives have been described in Fig. 4.

To determine the most preferred and effective HCW treatment technology, a committee comprising of six decision makers (DM₁, DM₂, DM₃, DM₄, DM₅ and DM₆) was formed. The expert committee consisted of professionals from various fields, which included, a Doctor, an Environmental Engineer, a professor of Industrial Engineering, a field expert from a waste management company and two HCW management experts. Decision maker 1 (DM₁) is currently working as Director of a bio-medical waste treatment cell of a renowned central government owned medical institution in Pondicherry, India. This institute was established to train French citizens in Pondicherry, India in 1823. This medical college has over 300 faculty members, 700 resident physicians, and 3000 nursing staffs. The year 2019-20 alone saw over 24,00,000 outpatient visits, 350,000 inpatient admissions, and 70,000 surgeries performed in this medical institute. As this medical university has an advanced bio-medical waste treatment cell and DM₁ being the in charge of this, we were able to gather valuable data for our research. Also, the past research experiences of DM₁ related to bio-medical waste treatment helped us to gather the valuable input with respect to the technical aspects of different HCW disposal alternatives. Decision DM₂ was a senior environmental engineer in a leading environmental engineering company and provided valuable insight with respect to the environmental factors of the criteria involved. DM₃ was a senior professor in the field of industrial engineering at an esteemed university in India and provided insight in ranking of different alternatives considering primarily the economic aspects of the techniques involved. DM₄ was an expert from a prominent waste management company and was experiences in prevention, characterization, monitoring, treatment, handling, reuse and residual deposition of various types of waste such as agricultural, household and health care wastes. His experience in the field of waste management served as a guidance in ranking the waste disposal techniques based environmental, social and technical aspects. DM₅ and DM₆ were senior researchers in leading companies

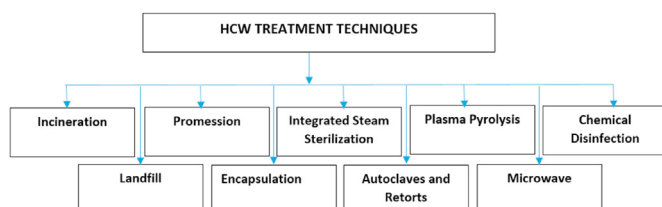


Fig. 4. Proposed HCW Treatment techniques.

in the waste management industry and were involved primarily in medical waste disposal. They had expertise in different health care disposal waste techniques and ranked the alternatives and criteria accordingly. The six decision makers chosen were from different fields of work with extensive knowledge in healthcare waste management. We have chosen these 6 decision makers with diversified expertise in healthcare waste management, so as to avoid any bias in the decision making for the selection of the best HCW technique.

Their judgments and views were acquired and recorded through questionnaires. The alternatives were considered keeping in view the criteria. The decision makers' rated the alternative HCW management technologies and concerning criteria using linguistic variables and importance weights. The factors affecting the HCW treatment techniques are shown in Fig. 5 and a brief description of these factors is given in Table 4. These criteria have been used considering the socio technical and triple bottom line approach into perspective. We evaluate the HCW management problem and determine the best HCW treatment alternative using Fuzzy VIKOR. The robustness of the applicability of fuzzy VIKOR method in the selection of the best HCW technique pertaining to Indian context has been tested by comparing the results obtained with Fuzzy TOPSIS and a hybridized method. The framework of selecting the best HCW management technique is illustrated in the flowchart of Fig. 6.

4.1. Application fuzzy VIKOR in our case

Step 1: The problem and objective of the decision making process are identified. The main objective of this research is to identify the best HCW disposal technique from various alternatives in accordance with the established criteria.

Step 2: Defining and describing a set of significant attributes for the problem. In this case, 6 decision makers, 10 criteria, and 9 alternative HCW disposal techniques have been considered. This has been illustrated in Table 5.

Step 3: Convert the linguistic variables into triangular fuzzy numbers using Tables 2 and 3

Step 4: Decision matrices are constructed with respect to each decision maker (DM₁, DM₂, DM₃, ...DM_n). Table 6 illustrates the weights of criteria provided by decision makers and Table 7 illustrate the rating of alternatives by different decision makers. Due to brevity, we have given only the rating of alternatives by decision maker 1. The fuzzy aggregated matrix is shown in Table 8.

Step 5:

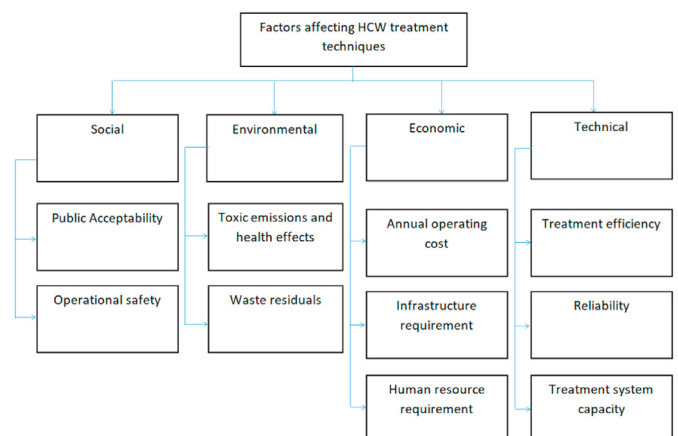


Fig. 5. Hierarchical structure of the problem.

Table 4
Description of criteria.

Serial number	Criterion	Description
C1	Annual Operating cost	This measure estimates the total operating cost involved per year in the operation and maintenance of a particular HCW treatment alternative.
C2	Public Acceptability	This measure takes into account the acceptability of a particular alternative by the public for HCW treatment.
C3	Reliability	This measure estimates the dependability of particular HCW treatment alternative for long term operation.
C4	Treatment Efficiency	This measure analyses the long term suitability and competency of a particular HCW treatment alternative.
C5	Human Resource Requirement	This measure is important for managing the skill, knowledge and competency required for carrying out a particular HCW treatment alternative and achieving the desired output.
C6	Treatment System Capacity	This measure analyses the amount of waste that can be treated by each HCW Treatment alternative in a particular cycle of operation.
C7	Waste Residuals	This measure analyses the amount of waste residual generated after the operation of a particular HCW treatment alternative.
C8	Toxic Emissions and Health Effects	This measure covers the environment degrading toxic emissions associated with each alternative and also the dangerous health effects on the people in the immediate surrounding of the operation.
C9	Operational Safety	This measure analyses the requirement of various safety procedures and risks associated with the operation of a particular HCW treatment alternative.
C10	Infrastructure Requirement	This measure takes into consideration the basic physical and organizational structures and facilities (eg. buildings, power supplies, machinery) needed for the operation of a particular HCW treatment alternative.

Table 5
HCW disposal alternatives for the case study.

Alternative No.	Description
A1	Autoclaves and Retort
A2	Integrated steam sterilization system
A3	Microwave
A4	Chemical disinfection system
A5	Incineration
A6	Plasma pyrolysis
A7	Promession
A8	Encapsulation
A9	Landfill

Table 6
Weights of criteria provided by decision makers.

	DM1	DM2	DM3	DM4	DM5	DM6
C1	H	H	H	M	M	H
C2	H	H	H	VH	VH	M
C3	VH	VH	H	VH	H	VH
C4	VH	VH	H	VH	VH	VH
C5	M	M	H	H	M	H
C6	M	H	H	VH	M	M
C7	H	H	M	VH	VH	VH
C8	VH	VH	L	VH	VH	VH
C9	VH	VH	H	VH	H	VH
C10	M	H	H	H	M	H

Table 7
Rating of alternatives by Decision maker 1 (DM1).

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	H	MH	MH	VH	MH	H	MH	MH	MH	M
A2	H	VH	MH	VH	MH	H	H	ML	M	MH
A3	VH	VH	H	VH	M	H	MH	ML	M	H
A4	MH	MH	L	M	MH	M	M	M	H	ML
A5	H	M	M	M	MH	H	MH	H	MH	M
A6	VH	M	M	H	M	M	M	M	MH	VH
A7	H	VH	M	H	MH	MH	ML	M	H	MH
A8	M	ML	ML	ML	H	H	MH	M	H	L
A9	ML	L	L	VL	VH	H	H	MH	H	VL

- The aggregation of weights of the 10 criteria provided by 6 decision makers is done
- The aggregation of ratings of 9 alternatives provided by the 6 decision makers is done

Step 7: The negative ideal solution (NIS) ($A_{\bar{p}}$) and the positive ideal solution (PIS) (A_{p^*}) are computed.

Step 8: The value of S_i and R_i for all the 9 alternatives is calculated.

Step 9: The values of gaps of ranking (Q_i) for all the 9 alternatives is calculated

Step 10: The 9 alternatives are ranked by sorting the values of S_i , R_i and Q_i in descending order as illustrated in Table 9.

Step 11: A compromise solution is selected in which the alternative having the least value of Q_i is selected if there exists a stability in the decision making process. This is illustrated in Table 10.

The results indicate that A5: Incineration followed by A2: Integrated steam sterilization are among the top ranked alternatives identified using Fuzzy MCDM methodology for health care waste disposal in Indian context. The implications of our research findings has been briefly given in the next section.

5. Results and its implications to research and practice

In accordance with the case study in Indian context, the Fuzzy VIKOR model of MCDM highlights some important findings and implications of the selection of the best healthcare waste management techniques during and post COVID-19 era in Indian context. The results obtained in this paper indicate that Incineration followed by Integrated steam sterilization system are among the top ranked alternatives using Fuzzy VIKOR MCDM technique in Indian context. The results obtained are also consistent with past literature work in the field of HCW and also provide meaningful implications and suggestions for engineering designers to refer. As is pointed out in Lee and Huffman (1996), Incineration has been the most widely used treatment technology for medical waste disposal. It reduces the volume of waste to a great extent along with complete elimination of pathogens and hazardous waste organics. This will help to contain the COVID-19 disease from the HCWs. The techniques of Integrated Steam Sterilization and Microwave are ranked at second and third position respectively. The input from the Decision makers indicate that among the 10 selected criteria for evaluation of alternatives, Treatment Efficiency(C9), Reliability (C3), Treatment System Capacity(C6), Annual Operating Cost(C1) and Operational Safety (C9) were among the major influencing criteria in Indian context. This is reflected in the results obtained as the technique of Incineration is ranked above Integrated Steam Sterilization and Microwave. Reduced land requirement, higher

Table 8
Fuzzy aggregated matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	7.667	6.667	7.778	7.944	5.111	7	5	4.889	4.667	6.556
A2	7.778	7.722	7.833	8.833	5.778	7.778	5	3.333	5.111	7.778
A3	7.167	8.056	8.889	8.944	4.111	8.667	4.111	2.222	6.167	8.722
A4	5.444	6.556	5	5.444	6.222	6.444	4.667	4.222	5.111	4.556
A5	6.667	5	6.889	5.889	6.111	7	5.778	5.444	5.889	5.444
A6	7.944	5.778	6.778	7.667	5	6	4.222	3.444	6	8.778
A7	7	6.389	6.667	6.556	5	5.222	4	4	6.556	7.667
A8	4.111	3.889	4.778	3.889	6.889	5.667	5.333	5	6.444	4.556
A9	2.222	2.111	3	2.778	7.222	5.667	6.333	6.056	4.667	3.111

Table 9
Ranking based on S_i and R_i .

Alternatives	S_i	Ranks	R_i	Ranks
A1	0.409	4	0.116	8
A2	0.321	2	0.088	2
A3	0.311	1	0.095	5
A4	0.566	8	0.088	3
A5	0.377	3	0.058	1
A6	0.423	5	0.090	4
A7	0.453	6	0.100	7
A8	0.539	7	0.096	6
A9	0.709	9	0.188	9

Table 10
Ranking of alternatives using Fuzzy VIKOR.

Alternatives	Alternative description	Q_i	Ranks
A1	Autoclaves and retorts	0.606	7
A2	Integrated Steam sterilization system	0.267	2
A3	Microwave	0.309	3
A4	Chemical disinfection system	0.574	6
A5	Incineration	0.083	1
A6	Plasma pyrolysis	0.410	4
A7	Promession	0.527	5
A8	Encapsulation	0.607	8
A9	Landfill	1.000	9

Table 11
Ranking of alternatives using Fuzzy TOPSIS.

Alternatives	Alternative description	CC_i	Ranks
A1	Autoclaves and retorts	0.608	4
A2	Integrated Steam sterilization system	0.672	2
A3	Microwave	0.641	3
A4	Chemical disinfection system	0.446	7
A5	Incineration	0.713	1
A6	Plasma pyrolysis	0.601	5
A7	Promession	0.581	6
A8	Encapsulation	0.401	8
A9	Landfill	0.356	9

treatment capacity, reduced waste transportation costs along with improved waste to energy processes (Mundial,1999) make incineration one of the ideal and top ranked alternative for HCW disposal in Indian context. This ranking is also consistent with the results of Dursun et al.(2011b), which suggest that disposal techniques of Integrated Steam Sterilization and Microwave which are ranked at second and third place respectively are highly effective because they generate non-hazardous residues and emit fewer pollutants when compared with other techniques.

In addition, to illustrate the robustness and effectiveness of the ranking obtained using Fuzzy VIKOR MCDM model, we use same case study to analyze the rankings obtained by the MCDM model of Fuzzy TOPSIS. Table 11 illustrates the Closeness Coefficient(CC) and rankings obtained by Fuzzy TOPSIS model. A comparison between the rankings derived from Fuzzy VIKOR and Fuzzy TOPSIS has been illustrated in Table 12. The rankings obtained by Fuzzy VIKOR model are A5 (Incineration) > A2 (integrated steam sterilization system) > A3 (Microwave) > A6 (Plasma Pyrolysis) > A7 (Promession) > A4 (Chemical disinfection system) > A1 (Autoclaves and Retort) > A8 (Encapsulation) > A9 (Landfill) and by Fuzzy TOPSIS model are A5 (Incineration) > A2 (integrated steam sterilization system) > A3 (Microwave) > A1 ((Autoclaves and Retort) > A6 (Plasma Pyrolysis) > A7 (Promession) > A4 (Chemical disinfection system) > A8 (Encapsulation) > A9 (Landfill) generating a Spearman ranking coefficient of 0.9. The closeness between the rankings obtained using two different MCDM model further validates our results.

A variation in the alternatives at lower ranks is observed because of the difference in the ranking procedure of the ranking indices in Fuzzy VIKOR and Fuzzy TOPSIS. In Fuzzy VIKOR, the gaps of ranking (Q_i) is used as a ranking index to generate the ranking. A lower value of Q_i indicates a higher ranked alternative whereas in the case of Fuzzy TOPSIS, Closeness Coefficient (CC_i) is used as a ranking index in which a higher value of CC_i indicates a higher ranked alternative. Considering this, the robustness of the ranking obtained using Fuzzy VIKOR model is further indicated by comparing it with a Hybridized ranking model. The hybridized ranking model converts the ranking indices of Fuzzy VIKOR and

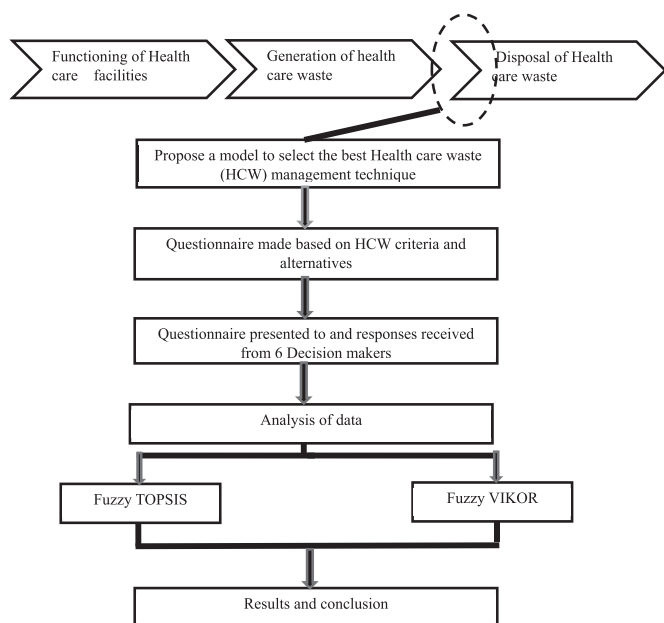


Fig. 6. Proposed framework.

Table 12
Ranking comparison of Fuzzy VIKOR and Fuzzy TOPSIS.

Alternatives	Alternative description	Fuzzy VIKOR rank	Fuzzy TOPSIS rank
A1	Autoclaves and retorts	7	4
A2	Integrated Steam sterilization system	2	2
A3	Microwave	3	3
A4	Chemical disinfection system	6	7
A5	Incineration	1	1
A6	Plasma pyrolysis	4	5
A7	Promession	5	6
A8	Encapsulation	8	8
A9	Landfill	9	9

Fuzzy TOPSIS into their respective utility weights (U(CC) and U(Q)), which are then averaged to obtain a Hybridized ranking index. This Hybridized ranking index is used to generate a single Hybridized ranking as illustrated in Table 13A larger value of Hybridized index indicates a higher ranked alternative. This type of ranking is very much required to achieve a robust solution for the considered multi criteria decision making problem. The hybridized ranking as illustrated in Table 13 is A5 (Incineration) > A2 (integrated steam sterilization system) > A3 (Microwave) > A6 (Plasma Pyrolysis) > A7 (Promession) > A1 (Autoclaves and Retort) > A4 (Chemical disinfection system) > A8 (Encapsulation) > A9 (Landfill). The closeness of the of the Hybridized ranking with the ranking generated using Fuzzy VIKOR model validates and indicates the robustness and effectiveness of our results specific to Indian Context. Even though the dataset indicates ‘incineration’ is the best method, we must not forget about the environmental concerns arising from this method. In COVID time, incineration may be the best method as indicated by the data analysis, but “COVID” should not be an excuse for causing “Environmental Pollution”. Caution should be taken for the environmental degradation/pollution that can result in burning/incinerating tons and tons of biomedical waste in a country like India whose capital is already suffocating under air pollution and so is most of its metropolitan cities. So future researchers should keep this point in mind and should work on more environment friendly bio-medical waste treatment methods.

The case study was validated using sensitivity analysis by varying the relative importance of various criteria. In our case, sensitivity analysis was carried out at two levels (with a 5% change and with a 10% change). The results obtained from our sensitivity analysis imply that a small change in relative importance has no impact on the final decision made.

6. Conclusion

HCW management has been a major concern of most of the developing countries in the World especially during the time of widespread of contagious diseases like COVID-19. Hence, it

becomes a major task to properly dispose of the health care waste generated in various medical facilities using a proper waste disposing technique. In this research work, a case study in the state of Tamil Nadu was considered to find a suitable a HCW disposal alternative in Indian context. For the same, nine alternatives were identified from the literature among which the best alternative was identified based on ten suitable criteria. These criteria were grounded primarily on socio technical and triple bottom line approach.

Municipalities can add or remove healthcare waste disposal techniques based on their requirements. The strength of the methodology is the hybridization of fuzzy TOPSIS and fuzzy VIKOR for arriving the final robust ranking. As far as TOPSIS and VIKOR and concerned, it can easily handle both positive and negative criteria. Also, the fuzzy based decision making can easily handle the vagueness possessed in human decision making. The success of this methodology depends upon the experts chosen for case study. Care should be taken to choose the experts with different functional groups so as to effectively remove bias in decision making. Though our data analysis has pointed out that incineration is the best method to combat biomedical wastes but burning wastes can have untold environmental concerns and future researchers should work on more environmentally feasible methods of disposal.

Overall, this study makes the following four contributions. First, we formally identify the factors for the assessment of healthcare waste disposal techniques via expert opinions grounded in triple bottom line and socio-technical perspectives. Second, we develop the model so that it can conveniently aggregate conflicting opinions from experts with diverse experiences, with the ultimate objective to generate a decision value. Third, as both fuzzy VIKOR and fuzzy TOPSIS belongs to the same category of compromise based ranking method of multi-criteria decision analysis, we have hybridized the two methods to get a robust weight and ranking for our problem. Fourth, we apply the proposed methodology to real life case study in Indian context. We hope the present paper will provide motivation to delve deeper in the topics of healthcare waste disposal techniques.

Table 13
Generation of hybridized ranking.

Alternatives	Qi	CCi	U(Qi)	U(CCi)	Hybridized Index	Fuzzy VIKOR rank	Fuzzy TOPSIS rank	Hybridized Ranking
A1	0.606	0.608	0.429	0.706	0.568	7	4	6
A2	0.267	0.672	0.799	0.885	0.842	2	2	2
A3	0.309	0.641	0.753	0.798	0.776	3	3	3
A4	0.574	0.446	0.464	0.252	0.358	6	7	7
A5	0.083	0.713	1.000	1.002	1.001	1	1	1
A6	0.410	0.601	0.643	0.687	0.665	4	5	4
A7	0.527	0.581	0.516	0.630	0.573	5	6	5
A8	0.607	0.401	0.428	0.128	0.278	8	8	8
A9	1.000	0.356	0	0.002	0.001	9	9	9

CRediT authorship contribution statement

Vijaya Kumar Manupati: Overall Guidance and Idea, correction.
M. Ramkumar: Writing, Theoretical contribution. **Vinit Baba:** and.
Aayush Agarwal: data collection, data analysis, calculation.

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.

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