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The interplay of circular economy with industry 4.0 enabled smart city drivers of healthcare waste disposal

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ABSTRACT

Generation of healthcare waste from different patient care activities in hospitals, pathology labs and research centres has been a matter of great concern for environmental and social bodies across the world. This concern comes from its infectious and hazardous nature which brings life taking disease such as human immunodeficiency virus and Hepatitis-B. Moreover, with the outbreak of corona virus disease 2019 (COVID-19) pandemic across the world, healthcare waste has become even more infectious like never before and showing its potential for claiming lives if not disposed properly. Additionally, the COVID-19 has put up another challenge in terms of exponentially increasing demand for personal protective equipments for healthcare workers such as doctors, nurses, ward boys, and sanitation workers. In this paper, seven criteria related to smart healthcare waste disposal system infused by circular economy aspects to recover value from disposables are identified and analysed using a decision making trial and evaluation laboratory (DEMATEL) method. The criteria have been prioritized by its importance and net cause and effect relationship through a causal diagram. Two criteria, (i) digitally connected healthcare centres, waste disposal firms and pollution control board, and (ii) providing a pollution control board's feedback app to public and other stakeholders, feature as strong reasons for a smart healthcare waste disposal system. Conclusively, this study provides a causal relationship model among the intertwined drivers of industry 4.0 and circular economy for developing a smart healthcare waste disposal system enriched with the benefits of circular economy.

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1. Introduction

The increasing quantities of hazardous and infectious healthcare waste generated from improved patient care has posed a serious challenge to the entire world. The prevailing challenge of disposing the healthcare waste in an environmentally, socially and economically sustainable manner has now become even more complicated with highly infectious waste coming from Covid-19 patients and healthcare workers. The lack of compatible infrastructure and presence of barriers in achieving an effective healthcare waste disposal system, especially in low- and middle-income countries, has been noticed as a major challenge in tackling of the waste (Campion et al., 2015; Caniato et al., 2015; Zhang et al., 2019). Due to these issues, WHO (2020) has attempted to tackle the issue of scarcity of personal protective equipments with optimized usage and recycling activities wherever possible.

The Covid-19 pandemic has put up an extremely high pressure on movements of surgical equipments due to supply chain disruptions and backward movement of disposal and recycling activities to manage the infectious medical wastes (Ivanov, 2020). Hence, for such circumstances, the Circular Economy (CE) model has emerged as an alternative to the previously existing decades old model of "take, make and dispose" (Ness, 2008). Since, CE model provides a sustainable solution to the problem of disposal and minimizes the requirement of virgin material for manufacturing purposes; the concept has been widely appreciated across the world (Ghisellini et al., 2016; Naustdalslid, 2014; Ness, 2008). To accommodate the challenge of greener economy implementation and environmentally effective usage of resources, *"Cleaner Production technologies"* has been observed as an important aspect of CE models for ecological sustenance (Birat, 2015;

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Campion et al., 2015; Hens et al., 2018). Interestingly, few studies limits the scope of CE to waste management which often fails to recognize its impact in terms of low environmental, material or energy costs to society (Geng et al., 2014; Ghisellini et al., 2016).

Similar to CE, the application of various platforms of smart technologies such as Internet of things (IoTs), Artificial intelligence (AI) and Big Data are essential for tracking of generated waste (Esmaeilian et al., 2018). An inclusive approach towards the application of these smart technologies leads to the coining of the term "*Industry 4.0*". Global positioning system and mobile applications are two important Industry 4.0 platforms which can assist in developing a healthcare waste disposal system in the smart cities. Pereira et al. (2017) defines the fourth industrial revolution (i.e. Industry 4.0) as a complex technological system with exploratory innovations to develop smart factories. Industry 4.0 brings forth a new industrial paradigm with an amalgamation of digital and physical worlds through cyber-physical systems. This has significantly impacted the current work environment by proposing the new business models. The applications of these technological advancements in terms of the cyber-physical systems have been implemented to create smart cities across the world. Indeed, Radziwon et al. (2014) noted that the term "smart" has become a central theme within the Industry 4.0 framework. However, defining it precisely remains a challenge.

The concept of smart cities has originated from various definitions, including digital city, information city, telicity, electronic city, wired city, knowledge city, and intelligent city (Cocchia, 2014; Mohanty et al., 2016). The debate on outlining the definition of a smart city is still in its nascent stage and changing its shape consistently (Lovehagen and Bondesson, 2013). Some studies have described the smart city as a fuzzy concept while others picture it as a broad term encompassing a vast variety of tasks related to management of information, optimal service provisions for citizen welfare, and improvement of government processes (Nam and Pardo, 2011; Balakrishna, 2012). Hence, it covers numerous domains, processes, and actors, each with their own goals (Kramers et al., 2013).

For a smart city, the making of an advanced waste disposal system has been observed to be of an utmost important for the citizens as well as for ecological well-beings (Anagnostopoulos et al., 2015a; Mohanty et al., 2016). Medvedev et al. (2015) have argued that an efficient waste collection system should be fundamental goal in smart cities. Similarly, Sharma et al. (2015) elaborated on the availability of a smart waste management system in a smart city, and emphasized at developing smart solutions for a smart waste management system in India.

Based on above discussion, below we present the motivation for our study along with research questions and research objectives.

1.1. Motivation of the study

India among the fastest growing economies of the world with 1.3 billion people is continuously looking for smart solutions to numerous urban issues and various smart city projects have already been launched (SBM, 2014). The implementation focus of a smart city resides in the development of a seamless railroad network, waste collection and disposal planning, and advance healthcare facilities (Pan et al., 2017; Pan et al., 2018). Among these issues, the development of a smart waste management system remains a key aspect of a successful smart city model. Moreover, with generation of hazardous waste from Covid-19 pandemic, the issue of healthcare waste management is gaining more and more tractions. In fact, the Indian Government is already encouraging the industry and academia to co-develop smart waste management solutions under the name "Smart City Mission" (Smart Cities, 2015). Hence, we seek to identify and study the factors (criteria) to tackle the disposal of one of the most typical types of waste, i.e. healthcare waste, for smart cities in India.

1.2. Research questions

- Why smart healthcare waste disposal planning is critical to provide a long-term solution to problems such as COVID-19 pandemic?
- What are the key drivers of smart healthcare waste disposal planning in smart cities of India?
- How interplay of industry 4.0 and circular economy plays an important role in smart healthcare waste disposal planning?

1.3. Research objectives

- Identifying the drivers of smart healthcare waste disposal planning for smart cities in India.
- Exploring and understanding the role and causal relationships of drivers in developing smart healthcare waste disposal system for smart cities.
- Achieving circular economy goals such as maximizing the circularity of resources, energy saving and value retention from different components of disposable healthcare waste through the learned drivers.

Hence, the objective of this study is to analyse the inter-twined drivers of industry 4.0 and circular economy for assisting the development of smart healthcare waste disposal system. Precisely, the aim is to converge the healthcare waste output through circular economy perspective to attain the maximum retention of material while containing its negative impact on environment and society.

The rest of this paper is organized into following sections: Section 2 details the review on circular economy, smart cities and identification of the criteria of healthcare waste disposal. Section 3 provides the description of Research Methodology. The results and the discussions are given in Section 4. Implications to practitioners and Future research directions are provided in Section 5. The conclusions drawn from this study are appended in Section 6. Limitations and future research directions are given in section 7.

2. Literature review

2.1. Circular economy and waste disposal

The sectoral initiatives of circular economy in the countries and sub-continents such as United States of America, Japan, Vietnam, Korea, Croatia and Europe have been noticed in relation with waste management (Luttenberger, 2020; Sakai et al., 2011); additionally, the new innovative initiatives for circular economy are encouraged through empowering people towards collaborative efforts (Jakhar et al., 2019; Levoso et al., 2020). The literary evidence of 3 R's principles of waste management i.e. *Reduce, Reuse, and Recycle* have been considered as the guiding source of circular economy models in various studies carried out across the world (Ghisellini et al., 2016; Kristensen and Mosgaard, 2020; Sakai et al., 2011; Su et al., 2013). In Reduction principle, the minimization of inputs radicalised through improvement of eco-efficiency and consumption patterns results in the usage of less raw material, primary energy and waste generation (Su et al., 2013). Reuse principle is lucrative to producers, consumers and environmentalists as it requires very limited resources such as labour and energy in comparison to manufacturing of the new product with virgin material which disseminates very obnoxious gases and particles to the environment (Castellani et al., 2015). The principle of Recycling gives an opportunity to extract the reusable material from generated waste in the end of a product's lifecycle diminishing its environmental impact (Birat, 2015; de Sousa Jabbour et al., 2019). The principle of Recycling is often considered parallel to the circular economy model as it has potential to bring waste to zero level (Song et al., 2015; Stahel, 2013); however, it discourages the principle of reduction and reuse especially in terms of resource efficiency and environmental sustainability (Ghisellini et al., 2016).

2.2. Industry 4.0 and smart cities waste management

Industry 4.0 allows firms to exchange information, execute actions, and independently control themselves (Weyer et al., 2015). Cyber Physical Systems (CPS), Internet of Things (IOT), and Internet of Services (IOS) are the key technology enablers of Industry 4.0. Using IoT paves the way for the advanced healthcare waste disposal planning of smart cities. According to Atzori et al. (2010), IoT semantically means "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols". Objects like Radio Frequency Identification (RFID) tags, actuators, sensors, Near Field Communication (NFC), smart phones, are some examples (Atzori et al., 2010; Whitmore et al., 2015). The application of these IoT objects has been widely discussed in various domains for example security (tracking), healthcare, education, homes and offices, personal and social care, smart museum, and gyms. Of late, IoT has been considered as an important factor in helping to enable a smart environment and better urban planning (Perera et al., 2013; Whitmore et al., 2015). Atzori et al. (2010) redefined urban planning as a city information model which can continuously monitor urban facilities such as railways, transport corridors, energy distribution and management, and sewer lines/ waste disposal.

Binder et al. (2008) explored the potential of using RFID tags during the stages of waste generation, separation, and treatment. They conducted a multi-criteria assessment of available options in consultation with the experts of waste management. Their analysis revealed that the social and ecological aspects were more appreciated by experts in contrast to the economic aspects. Further, Abdoli (2009) stated that using RFID tags on the recyclable components of municipal solid waste helps to increase the recovery value. Chowdhury and Chowdhury (2008) described a multi-layer architecture for automatic waste identification using RFID and sensors. They argued that the use of RFID and load sensor technology helps to reduce the cost of waste management and facilitates the identification and weight measurement of waste through automation and streamlining of the process.

2.3. Circular economy, industry 4.0 and smart healthcare waste management

Traditionally, landfilling and incineration are the prevalent ways of getting rid of generated wastes (Ghisellini et al., 2016). However, the environmental impact and loss to valuable extractable resources cannot be neglected for these prevalent methods of disposal. Hence, to diminish the impact of these waste disposal methods, the concept of circular economy (CE) model is getting traction in recent times. The CE uses newly emerged typologies of "scavengers" and "decomposers" to recover the valuable material from the disposable waste using innovative technologies and redistribute the recovered material in the system (Geng and Cote, 2002). Various studies have been carried out in various cities across the world on value creation from different types of waste along with zeroing down the generation of waste through circular economy models (Song et al., 2015; Zhang et al., 2019). Such programmes of zero waste generation have been analysed in South Africa and European cities (Matete and Trois, 2008; Zerowaste Europe, 2014).

For efficiently dealing the issues of substandard landfilling to achieve circular economy targets of Croatia, Luttenberger (2020) described the significance of incorporating the intelligent transportation systems and surveillance systems (e-ONTO). Additionally, the application of the "Internet of Things" i.e. RFID, sensors, actuators, mobile apps, has been studied in the waste management of smart city by Abdoli (2009) and Caragliu et al. (2011). Medvedev et al. (2015) argued that the efficient waste collection is fundamental to smart cities which happens through transportation systems. Anagnostopoulos et al. (2015b) described that the waste disposal planning is an important part of a smart city and has a significant impact on society. They also pointed to the importance of the sensors and actuators in tackling the issues of waste management. Moreover, they also conducted a case study of a smart city by putting waste collection bins with attached sensors in different parts of the city. They retrieved the real-time position data for immediate waste collection by highlighting the importance of schools, elderly homes, and hospitals as high priority areas. Mohanty et al. (2016) stated that the components of a smart city include smart healthcare services and waste management, smart technology, smart transportation, smart energy, and smart infrastructure. They argued categorically that smart cities are faster, safer, greener, and friendlier.

Sharma et al. (2015) emphasized that a smart waste management system is essential for a smart city. They proposed a smart bin model incorporating a network of sensors generating generous data that can be visualized and analysed in real-time to understand the urban waste situation. Xu et al. (2015) described in their study that there is an urgent need to carry out an extensive work using smart technologies for the disposal of heavily generated waste due to rapid urbanization especially in developing countries. Zhang et al. (2019) studied the barriers of smart waste disposal in the context of China and they suggested conducting future research in other important areas.

2.4. Research gap

As discussed above, lots of studies have highlighted the importance of circular economy, smart cities and efficient waste management. Moreover, the papers in extant literature also highlighted the importance of emerging technologies such as Industry 4.0. However, none of the studies considered circular economy, industry 4.0 and smart healthcare waste management. Specifically, with respect to the identification of key drivers of smart healthcare waste disposal system. Hence, to tackle the issue of healthcare waste management in smart cities with the help of IoT, we have identified the factors (criteria) from the literature as well as a field survey and carried out our research to pave the way for a smart waste disposal system. The seven criteria (C1 to C7) are elaborated below.

2.4.1. C1. RFID labelling of waste

The RFID labelling of waste has been considered as an important method to track waste. This helps in generating the information about waste in terms of its quantity, location, travel time, storage, and final disposal. It also assists in preventing any unlawful activities which can be conducted by waste disposal firms and hospitals to gain at the cost of public and social health. Nolz et al. (2011) have shown the importance of RFID labelling of healthcare waste in developing a waste collection network.

2.4.2. C2. GPS and GIS tracking of waste collection vehicles

The Global Positioning System (GPS) and Geographic Information System (GIS) help to track the location of vehicles of the waste disposal firms. The GPS and GIS enabling of a vehicle with cameras helps to monitor the movement of a waste collection vehicle and its different transfer locations (Arebey et al., 2010; Wilson and Vincent, 2008). Since the healthcare waste disposal business is not exactly a profit making business, therefore to save cost, many firms tend to violate the guidelines on waste disposal. As a result, such firms dispose of their waste at the municipal solid waste sites, rivers, and other illegal dumping grounds. Hence, to prevent such wrongful activities, using a GPS tracking system in the collection vehicles of the healthcare waste disposal firms is viewed as an important solution.

2.4.3. C3. Common user interface for uploading waste generation data

The collection and feeding of the data related to waste generation is another critical information point useful for the planning of waste disposal of a smart city (Hannan et al., 2011). A common user interface should have a compulsory feature of entering information about the waste for hospitals as well as the waste disposal firms. The input of waste quantities by both parties i.e. generators as well as disposers would curb the mishandling of the waste disposal quantities. Making this data available in the public domain would encourage the environmental researchers to sense and develop solutions for future problems.

2.4.4. C4. Digitization of chimneys at waste disposal sites

The chimneys of the healthcare waste disposal plants need attention as disposing waste this way leads to the generation of toxic and harmful gas emissions (Dlamini and Joubert, 1996). The lack of understanding of the effect of these emissions by the waste disposal firms and as environmental bodies do not pay much attention to this important aspect, they usually decide on a particular height to release the emissions into the atmosphere, polluting the environment even more. Hence, to prevent this negligence and irregularity, the mounting of digital devices is required on a chimney, providing information on the presence of toxins in the emissions, their requirement for treatment, appropriation of its height, and its usage information.

2.4.5. C5. Direct monitoring of hospital's temporary storage sites

Aziz et al. (2016) observed that globalisation needs smart cities and these cities need smart systems such as Intelligent Transportation Systems (ITS), and GPS & GIS enabled areas for monitoring waste disposal and numerous healthcare functions. Further, some hospitals throw their waste with municipal solid waste or they dispose of it at their temporary storage sites in an unhygienic manner. Also, the waste collecting vehicles do not visit the hospital premises frequently. Hence, based on the information and complaints provided from different stakeholders, the direct digitized monitoring of a hospital's temporary waste storage sites is very important. These temporary waste storage sites should be traceable for each activity in its premises including the storage and visiting of the waste collection vehicles.

2.4.6. C6. Digitally connected healthcare centres, waste disposal firms, and pollution control board

The healthcare centres include the primary, secondary, and tertiary types of hospitals and generate healthcare waste from patient care for disposal. The waste generated by these entities is meant to be collected and disposed of by an authorized waste disposal firm. Finally, the assessment of a waste disposal program is conducted by the pollution control board in India so as to protect the interest of the people. The digital connectivity of these three stakeholders helps to provide a smart waste disposal system for smart cities. Using digital connectivity, evidence based quick monitoring is thus easier and more reliable.

2.4.7. C7. Pollution control board's feedback app to public and other stakeholders

The data help in improving the lacunas of a system by analysing critical information. This data is captured in various forms with the help of RFID, sensors, GPS and GIS (Asri et al., 2015; Landman et al., 2015). In spite of this, a gap remains in the system if external stakeholders are not given enough opportunity to give their responses. For such cases, this gap can be filled by providing a feedback App to the public through a pollution control board which is a point of contact for both the public as well as the government. As mentioned, waste disposal has a significant impact on society and environment. Thus, the public often has complaints and suggestions regarding the waste disposal activities. At the same time, the government wants to understand the efficiency in implementing guidelines for waste disposal. The pollution control board used to be an authority for monitoring, controlling, and successfully ensuring the best interest of the public and government. Hence, it needs to implement a digital mechanism to record the feedback, complaints, and suggestions to better reflect on the issues of public. At the same time, it needs to provide an evidence-based implementation of waste disposal guidelines to be better informed.

3. Research methodology

In this study, the responses for the seven criteria were recorded with the help of expert groups. Next, the Decision Making Trail and Evaluation Laboratory (DEMATEL) method was applied to understand the tendency and relationship of identified criteria. Fontela and Gabus (1976) developed a mathematical procedure naming as DEMATEL in the Geneva Research Centre of Battelle Memorial Institute; with its procedural merits, this method has a merit of comfortably tackling the typical societal issues. DEMATEL helps in obtaining the priority of criteria and converts the cause-effect relationship of the elements into visible structural models (Chauhan et al., 2016; Luthra et al., 2019).

Step 1. Describing scale and structure for the direct relation matrix

A direct relation matrix is developed using the reflections recorded from domain experts in terms of capturing the direct effect between a pair of considered criteria. The pair-wise comparisons among the criteria considered in the study using a DEMATEL scale ranging from *0 to 4*, where *0, 1, 2, 3, and 4* represent *"No influence," "Low influence," "equal influence" "High influence," and "Very high influence"* are used respectively. For each respondent, an initial direct relation matrix M of order n x n in which m_{ij} represents the magnitude by what element i impacts element j. Finally, this particular direct relation matrixes composed and configured as $M = [m_{ij}]_{n\times n}$ for each expert respondent. Here, the number of respondents are denoted by $g = 1, \ldots, z$.

$$M = \begin{bmatrix} m_{12} & m_{13} & \cdots & m_{1n} \\ m_{21} & m_{22} & \cdots & m_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{1n} & m_{2n} & \cdots & m_{nn} \end{bmatrix}$$

Step 2. Normalizing and making a final direct relation matrix D

This step helps in constructing a normalized initial direct relation matrix. Equations (1) and (2) are used to attain normalized direct relation matrix $D = [d_{ij}]$.

$$D_{ij} = \frac{1}{z}\sum_{g=1}^{z} M_{ij}^{g} \tag{1}$$

$$X = \frac{1}{H} * D \tag{2}$$

$$H = \max\left[\max_{1\le i\le n}\sum_{j=1}^{n} m_{ij}, \max_{1\le j\le n}\sum_{i=1}^{n} m_{ij}\right] \tag{3}$$

$$i,j \in \{1,2........n\}$$

where Eq. (1) represents the maximum value of the sums of all the rows and the sums of all the columns and Eq. (2) represents the normalized initial direct-relation matrix. All elements in matrix D follow $0 \le d_{ij} \le 1$and all principal diagonal elements are equal to 0.

Step 3. Developing a total relation matrix

The total relation matrix has been obtained using Eq. (3) where 1 to h represents the power. The matrix can converge into an identity matrix if h approaches to infinity

$$T = D^1 + D^2 + ... + D^h = D \times (1-D)^{-1} = [d_{ij}]_{n\times n}, h \to \infty \tag{4}$$

Step 4. Summation of row values and column values is performed in this step.

In Step 4 the row sum and column sum of the matrix is obtained which is denoted by *"r" and "c"* respectively. The computations for *"r" and "c"* along with *T* are as follows:

$$T = [t_{ij}]_{n\times n}, \; i,j = \{1,2........,n\}, \tag{5}$$

$$r = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [r_i]_{n\times 1} \tag{6}$$

$$c = \left[\sum_{j=1}^{n} t_{ij}\right]'_{1\times n} = [c_j]'_{n\times 1} \tag{7}$$

here the notation superscript'depictsa transpose of the matrix.

Step 5. Constructing a cause-effect diagram withr_i+c_j and r_i-$c_j$values.

In matrix *T*, r_i is the sum of row *i* and the rows show the degrees of the direct and indirect effects over the other criteria, and c_j is the sum of column *j* in *T* where the columns indicate the degrees of the influence from the other criteria. The variabler_i represents the factors that influence other variables. The termc_j represents the factors that are influenced by the other factors. The notation r_i+ $c_j$denotes the strength of relationships among the factors whiler_i-$c_j$depicts the strength of the influence among the factors. Hence, r_i+c_j and r_i-c_j represent the prominence and relation, respectively. Furthermore, Flow of the work has been provided in Fig. 1.

4. Application on smart cities

The Government of India has announced plans to develop 100 cities as smart cities. Dehradun, Saharanpur, and Moradabad are some of these cities designated to be converted to become smart cities. For this study of smart healthcare waste disposal planning, we have collected the responses of one group from each of the three cities. The respondent group contained 5–7 members from the government bodies such as the pollution control board and the urban development authority. The experts have been associated with the environment and the waste disposal related firms for the past 10–15 years and spent a major portion of their work life in planning waste disposal systems.

4.1. Results & discussions

The response matrix collected from the three expert groups, as given in Tables 1–3, of Dehradun, Saharanpur, and Moradabad cities is converted into a single matrix A i.e. Table 4. The calculation steps were carried out using Eqs. (2)–(7) in line with DEMATEL and are shown in Tables 5–10.

Based on the r + c values in Table 10, the importance of the seven criteria considered for study can be prioritized as C6>C7>C5>C1>C4>C3>C2. Criterion C6 i.e. digitally connected healthcare centres, waste disposal firms, and pollution control board is the most important with anr + c value of 2.26. Criterion C2 i.e. GPS tracking of waste collection vehicles is least important with an r + c value of 1.72. From the (r + c, r − c) values which help to identify the net causes and net effects among the seven criteria. The (r + c, r − c) values are positive for four criteria i.e. Digitally connected healthcare centres, waste disposal firms and pollution control board (C6), Providing a pollution control board's feedback App to the public and other stakeholders (C7), RFID labelling of waste (C1), and Common user interface for uploading waste generation data (C3). Thus, these four criteria are categorised as net causes. The three criteria which have received negative values of (r − c) are classified as net effects, i.e., the Direct monitoring of a hospital's temporary storage sites (C5), Digitization of chimney at a waste disposal site (C4), and GPS tracking of waste collection vehicles (C2).

Fig. 2 depicts the interactions among the seven criteria. Criterion C7 i.e. Providing a pollution control board's feedback App to public and other stakeholders and criterion C6 i.e. Digitally connected healthcare centres, waste disposal firms and pollution control board have the greatest influence on the other criteria. This is interpreted as the strongest decision making factors for developing a sustainable smart healthcare waste disposal system. In contrast, there is another set of criteria such as C4 i.e. Digitization of chimney at waste disposal site and C5 i.e. GPS tracking of waste collection vehicles which may have weak effect on the decision making regarding developing a smart healthcare waste disposal system.

Based on the net cause (C1, C3, C6, C7) and net effect (C2, C4, C5) criteria for developing a healthcare waste disposal system in projected smart cities, the decision makers can now use the outcome of the application case to pay greater attention to the net cause as these criteria are more influential than the net effect criteria in developing a better healthcare waste disposal system. Emphasising on the net causes such as criterion C7 & C8 leans on the strength and success of connecting the internal stakeholders digitally as well as enabling the external stakeholders with digital platforms. Similarly, the Direct monitoring of a hospital's temporary storage site (C5) and RFID labelling of waste (C1) help to reduce any leakage from the healthcare waste collection supply chain as well as lessen any environmental impact arising from the mishandling of hazardous and infectious healthcare wastes. Thus, focusing on C1, C5,

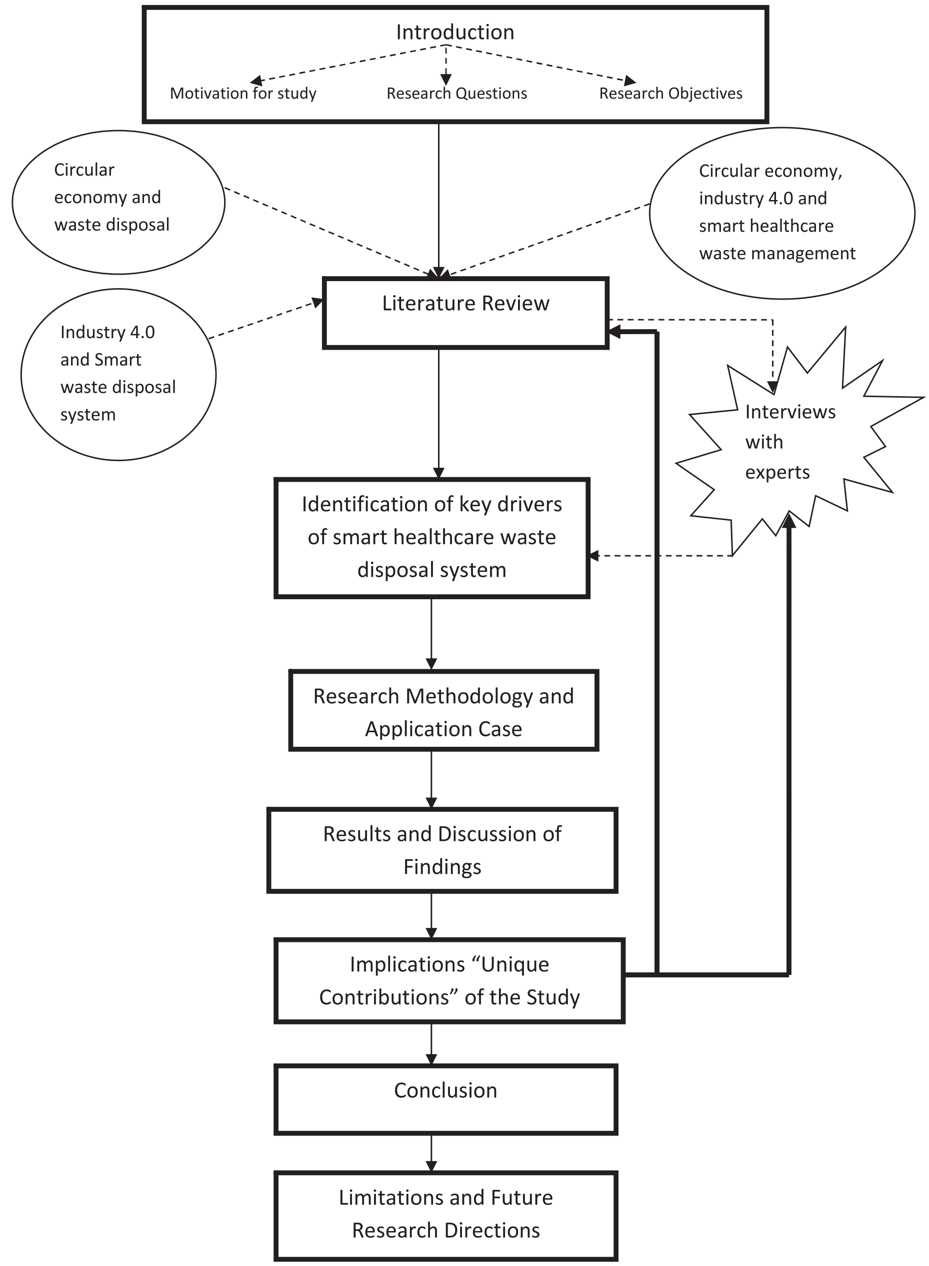

Fig. 1. Flow of the study.

Table 1
Response from group 1.

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	3.00	4.00	4.00	4.00	2.00	0.25
C2	0.33	0.00	0.33	2.00	4.00	0.25	0.25
C3	0.25	3.00	0.00	4.00	3.00	3.00	0.25
C4	0.25	0.50	0.25	0.00	1.00	0.33	0.33
C5	0.25	0.25	0.33	1.00	0.00	0.25	0.25
C6	0.50	4.00	0.33	3.00	4.00	0.00	0.25
C7	4.00	4.00	4.00	3.00	4.00	4.00	0.00

C7, and C8 will reduce information distortion and helps to develop the desired healthcare waste disposal system in the smart cities in India.

Table 2
Response from group 2.

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	1.00	3.00	0.25	4.00	0.25	0.25
C2	1.00	0.00	0.33	1.00	3.00	0.25	0.50
C3	0.33	3.00	0.00	3.00	4.00	0.25	0.25
C4	4.00	1.00	0.33	0.00	1.00	0.25	0.50
C5	0.25	0.33	0.25	1.00	0.00	0.50	0.33
C6	4.00	4.00	4.00	4.00	2.00	0.00	4.00
C7	4.00	2.00	4.00	2.00	3.00	0.25	0.00

5. Implications to practitioners and academia

5.1. Managerial implications

The exploration of relationships among the criteria identified

Table 3
Response from group 3.

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	2.00	3.00	3.00	4.00	0.25	0.33
C2	0.50	0.00	0.50	3.00	4.00	0.25	0.33
C3	0.33	2.00	0.00	4.00	3.00	0.33	0.25
C4	0.33	0.33	0.25	0.00	0.50	0.33	0.25
C5	0.25	0.25	0.33	2.00	0.00	0.25	0.33
C6	4.00	4.00	3.00	3.00	4.00	0.00	4.00
C7	3.00	3.00	4.00	4.00	3.00	0.25	0.00

Table 4
Aggregated response matrix.

	C1	C2	C3	C4	C5	C6	C7	Row Sum
C1	0.00	2.00	3.33	2.42	4.00	0.83	0.28	12.86
C2	0.61	0.00	0.39	2.00	3.67	0.25	0.36	7.28
C3	0.31	2.67	0.00	3.67	3.33	1.19	0.25	11.42
C4	1.53	0.61	0.28	0.00	0.83	0.31	0.36	3.92
C5	0.25	0.28	0.31	1.33	0.00	0.33	0.31	2.81
C6	2.83	4.00	2.44	3.33	3.33	0.00	2.75	18.69
C7	3.67	3.00	4.00	3.00	3.33	1.50	0.00	18.50
Column Sum	9.19	12.56	10.75	15.75	18.50	4.42	4.31	

Table 5
Normalized direct influence matrix D.

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	0.11	0.18	0.13	0.21	0.04	0.01
C2	0.03	0.00	0.02	0.11	0.20	0.01	0.02
C3	0.02	0.14	0.00	0.20	0.18	0.06	0.01
C4	0.08	0.03	0.01	0.00	0.04	0.02	0.02
C5	0.01	0.01	0.02	0.07	0.00	0.02	0.02
C6	0.15	0.21	0.13	0.18	0.18	0.00	0.15
C7	0.20	0.16	0.21	0.16	0.18	0.08	0.00

Table 6
Identity matrix I.

	C1	C2	C3	C4	C5	C6	C7
C1	1.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.00	1.00	0.00	0.00	0.00	0.00	0.00
C3	0.00	0.00	1.00	0.00	0.00	0.00	0.00
C4	0.00	0.00	0.00	1.00	0.00	0.00	0.00
C5	0.00	0.00	0.00	0.00	1.00	0.00	0.00
C6	0.00	0.00	0.00	0.00	0.00	1.00	0.00
C7	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 7
Matrix (I-D).

	C1	C2	C3	C4	C5	C6	C7
C1	1.00	−0.11	−0.18	−0.13	−0.21	−0.04	−0.01
C2	−0.03	1.00	−0.02	−0.11	−0.20	−0.01	−0.02
C3	−0.02	−0.14	1.00	−0.20	−0.18	−0.06	−0.01
C4	−0.08	−0.03	−0.01	1.00	−0.04	−0.02	−0.02
C5	−0.01	−0.01	−0.02	−0.07	1.00	−0.02	−0.02
C6	−0.15	−0.21	−0.13	−0.18	−0.18	1.00	−0.15
C7	−0.20	−0.16	−0.21	−0.16	−0.18	−0.08	1.00

Table 8
Matrix (I-D) inverse.

	C1	C2	C3	C4	C5	C6	C7
C1	1.05	0.18	0.22	0.24	0.33	0.08	0.04
C2	0.06	1.03	0.05	0.16	0.24	0.03	0.03
C3	0.07	0.19	1.05	0.28	0.27	0.09	0.04
C4	0.10	0.06	0.05	1.05	0.10	0.03	0.03
C5	0.03	0.04	0.03	0.10	1.03	0.03	0.02
C6	0.25	0.33	0.24	0.36	0.40	1.06	0.18
C7	0.27	0.29	0.31	0.35	0.40	0.13	1.05

Table 9
Total relation matrix T.

	C1	C2	C3	C4	C5	C6	C7	Row sum (r)
C1	0.05	0.18	0.22	0.24	0.33	0.08	0.04	1.15
C2	0.06	0.03	0.05	0.16	0.24	0.03	0.03	0.61
C3	0.07	0.19	0.05	0.28	0.27	0.09	0.04	0.99
C4	0.10	0.06	0.05	0.05	0.10	0.03	0.03	0.41
C5	0.03	0.04	0.03	0.10	0.03	0.03	0.02	0.28
C6	0.25	0.33	0.24	0.36	0.40	0.06	0.18	1.82
C7	0.27	0.29	0.31	0.35	0.40	0.13	0.05	1.79
Column sum (c)	0.84	1.13	0.94	1.53	1.78	0.44	0.40	

Table 10
Computation of row sum and column sum to identify net cause and effect.

	r	c	r + c	r - c	Nature	Rank
C1	1.15	0.84	1.99	0.31	Cause	3
C2	0.61	1.13	1.74	−0.52	Effect	5
C3	0.99	0.94	1.93	0.05	Cause	4
C4	0.41	1.53	1.94	−1.12	Effect	6
C5	0.28	1.78	2.06	−1.50	Effect	7
C6	1.82	0.44	2.26	1.38	Cause	1
C7	1.79	0.40	2.19	1.39	Cause	2

and studied in this work vividly shows the responsibility of three major stakeholders which are Healthcare waste disposal firms, Environmental Body and Government. *Healthcare waste disposal firms* need to ensure RFID labelling of waste (C1) and GPS and GIS tracking of waste collection vehicles (C2) for keeping a close track of the generated and collected waste which eventually becomes the record for effective disposal planning and achievement of an efficient circular economy goal. Common user interface for uploading waste generation data (C3), Digitization of chimneys at waste disposal sites (C4), and Direct monitoring of hospital's temporary storage sites (C5) are key for an *Environmental bodies* such as pollution control board to encourage the participation of generators of this waste and measuring the effects of disposal on environment and society. Similarly, *Government's* continuous focus on revitalizing the infrastructure helps in digitally connecting healthcare centres, waste disposal firms, and pollution control board (C6) and Pollution control board's feedback App to public and other stakeholders (C7) can be proved as a quick response to complicacies brought into the healthcare waste due to the emergence of pandemic waste COVID-19.

5.2. Theoretical implications

We have observed that the planning of smart cities and their various systems such as disposal of various kinds of waste is in nascent stage. Therefore, the seven criteria identified during literature review and thereafter studied in detail is a novel contribution of this study to the body of knowledge. Similarly, the net causes and net effects nature of drivers along with causal relationship revealed during the study can be considered as a significant contribution of this study towards theory building. Hence, incorporation of the findings of this study will strengthen the literature to support better and accurate advanced smart healthcare waste disposal planning of smart cities in developing economies.

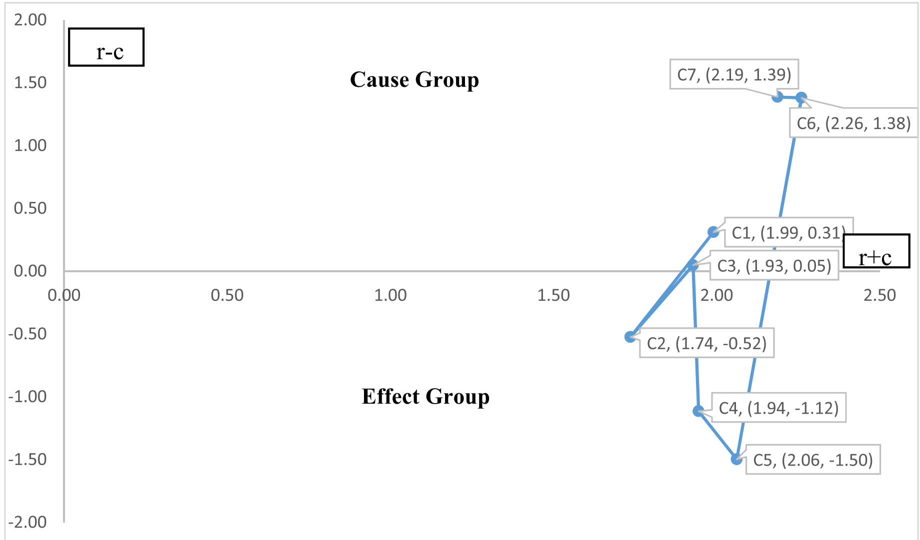

Fig. 2. Cause-effect diagram.

6. Conclusion

The 3 R's theory of circular economy perspective in terms of retrieving the material from huge amount of wasted disposable cotton, propylene and plastics (Campion et al., 2015) could be very useful and beneficial for environment, society and economy. In this paper, seven criteria were identified from the literature on Circular Economy, Industry 4.0 and smart city planning, and field experts in waste disposal planning in India. Since, the objective of this study was to analyse the criteria of smart healthcare waste disposal system and converging its output through a circular economy perspective to attain the maximum retention of material while containing its negative impact on environment and society. Therefore, a prioritisation and causal relationship structure has been developed with the help of a decision making trial and evaluation method. Using the importance which is set on the basis of the r + c values, criterion such as i.e. Digitally connected healthcare centres, waste disposal firms and pollution control board (C6), and Providing a pollution control board's feedback App to public and other stakeholders (C7) shall be given greater priority as their ability to influence the final decision is good.

The development of a smart healthcare waste disposal system using the drivers elicited from circular economy and Industry 4.0 perspective could be effective in critically planning for smart cities. Drivers such as the RFID labelling of the waste, GPS tracking of the waste collection vehicles, Direct monitoring of temporary storage sites, Digitally connecting hospitals, disposal firms and pollution control board, Common user interface for uploading data and Providing a pollution control board's feedback App to the public can determine possible leakages and improvises the waste recovery mechanism which helps in achieving the goal of maximum circularity of resources and value retention from disposable healthcare waste. Similarly, the Digitization of chimney at a waste disposal site helps in identifying the energy efficiency and emissions impact on environment. Conclusively, this study provides a causal relationship model among the intertwined drivers of industry 4.0 and circular economy for developing a smart healthcare waste disposal system enriched with the benefits of circular economy.

7. Limitations and future research directions

We have applied a multi criteria decision making method to investigate the drivers in the present study. For this study, we have incorporated the responses from the key experts of proposed smart city planning team members of northern region of India. Since, these experts may have some subjective bias during our interviews which may influence results of the study. In future, the researchers can conduct a study to compare the performance of various smart healthcare waste disposal systems across the smart cities. Additionally, future researchers can study other issues in smart city planning such as municipal solid waste disposal, transport management, establishing and monitoring industrial parks, using more sophisticated multi-criteria approaches to measure the effect of factors on the planning of the healthcare waste disposal system of a smart city.

CRediT authorship contribution statement

Ankur Chauhan: Methodology, Data curation, Formal analysis, Writing - original draft. **Suresh Kumar Jakhar:** Conceptualization, Writing - review & editing. **Chetna Chauhan:** Resources, Visualization.

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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