

Internet of Things (IoT) adoption barriers of smart cities' waste management: An Indian context

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ABSTRACT

The current study is a preliminary approach to develop a structural framework of the Internet of Things (IoT) adoption barriers that exist in the waste management systems of smart cities in developing economies such as India. To attain this aim, the present study uses hybrid Multi-criteria decision-making methods (MCDM) and has identified 15 adoption IoT Barriers (IoTBs) from literature review obstructing the IoT implementation in smart cities of India. The IoTBs are further analyzed through the Total Interpretative structural modeling (TISM) approach, the Fuzzy Matriced'Impacts Croisés Multiplication Appliquée en Classement (MICMAC) model, and the Decision Making Trial and Evaluation Laboratory (DEMATEL) method. The TISM approach is used to develop a structural framework of IoTBs in smart cities' waste management (SCWM) projects. The literature shows that several bottlenecks exist. Such bottlenecks may include operational cost and payback; a lack of standardization, regulations, directions, and policy norms; incomplete technical knowledge among policymakers; internet connectivity, privacy, and security issues; or problems with mobility, transparency, and a lack of IT infrastructure; all of these issues influence IoT adoption in SCWM. The present work discloses that the lack of regulations, directions, and policy norms, and the lack of standardization and Internet connectivity are the most critical IoT barriers hindering the development of smart cities, particularly in their waste management practices. The Fuzzy-MICMAC approach is useful in calculating driving and dependence powers of the IoTBs, and the DEMATEL method helps reveal the influence/strength of IoTBs that affect SCWM. This study will help policymakers, stakeholders, and government to understand the significant IoTBs affecting waste management practices, and it will definitely assist them to undertake decisions for eradicating these barriers for a more efficient IoT implementation in SCWM projects.

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1. Introduction

The smart city in developing nations is presented as a prospective solution to the challenges triggered by the urbanization process. Smart cities have risen in importance over the last two decades and that their progressive approaches are considered a fundamental requirement for developing nations. Various researchers have tried to define the concept of a smart city (Adapa,

2018; Albino et al., 2015; Zanella et al., 2014); most have conceptualized it as a multifaceted system that aims to build sustainable cities (Gubbi et al., 2013). Smart cities need the amalgamation of ICT and internet technologies to reshape their architecture in such diversified forms as advanced infrastructure, transportation, environment, healthcare, governance, and other areas of concern with the ultimate goal to develop a sustainable ecosystem (Alavi et al., 2018; Marques et al., 2019). A smart city is the convergence of ICT technologies, sustainability, technical, social, and economic performance indicators (Caragliu et al., 2011; Espinoza-Arias et al., 2019); the main stakeholders are government, service providers, policy makers, citizens, and developers (Barns, 2018; Simonofski

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et al., 2019). Out of all the technological innovations, the Internet of Things (IoT) acts as a main driver in smart city initiatives across the world. IoT-enabled systems act as a catalyst in the transformation of urban cities to create a better infrastructure, waste management, transportation, and to upgrade human life (Patel, 2019; Paulchamy et al., 2019). IoT technologies in smart cities ought to provide advance services and redesign existing practices (Bibri, 2018; Chatterjee et al., 2018; Talari et al., 2017). The structure of an IoT-enabled smart city is based on different aspects of internet technologies such as network, scalability, heterogeneity, coverage, and end-user engagement (Tran Thi Hoang et al., 2019).

The United Nations estimates that approximately two-thirds of the population of the world will be urbanized by 2050 (Esmailian et al., 2018; Marques et al., 2019). Hence, infrastructural and other far-reaching services will become crucial to fulfill the necessities of the urbanized population. If the population of a city grows at a rate of 3–5% per year, the amount of waste generated will be doubled in each decade, which clearly introduces a critical situation for smart cities and an immense financial burden for the costs of collection, landfills, and recycling (Chatterjee and Kar, 2018). Previous research has revealed that managing waste is a serious issue of urban populations, and that developing a sustainable ecosystem is needed to minimize the threat to urban life (Baltac, 2019; Jagtap and Rahimifard, 2019; Shah et al., 2018; Valenzuela-Levi, 2019).

Both developed and developing nations are utilizing internet technologies to achieve sustainable growth and economic development (Macke et al., 2019; Martin et al., 2018). While many factors are in place, developing smart cities is an emerging aspect of economic development and a way of fulfilling the needs of the people (Mohanty et al., 2016; Neirotti et al., 2014). Developed nations have advanced technology, ample resources, and a robust framework with which to develop smart cities; further, the smart cities that already exist support and guide them to take actions (Gaffney and Robertson, 2018). However, the scenario of developing countries is totally different. Due to financial, technical, and economic constraints, developing countries face difficulties in implementing development projects for smart cities. Developing countries, like India, seek to develop smart cities to raise the living standards of their residents and communities (MoUD, 2015). Adapa (2018) explained that developing countries have dissimilarities in their working environments as compared to developed countries; hence, it is mandatory to develop a structural framework that could help them to smoothly initiate and implement IoT-enabled ecosystems in smart cities. Previous research exemplifies that the factors affecting smart city projects are essential to be analyzed separately in developing nations (Muvuna et al., 2019).

The challenging scenario has made IoT concepts obligatory to be implemented in smart cities, since it creates connection between the objects and communicates to humans in an intelligent way (Delgado et al., 2020; Kunst et al., 2018). One of the major IoT-based services that becomes more crucial every day is the effective waste management in smart cities. Until now, waste management utilized technologies and models such as Geographical Information System (GIS), enhanced routing & scheduling, and other methods to optimize waste collection, storage, and disposal methods. These technologies lack innovation, and only IoT technology can facilitate (Alcayaga et al., 2019; Ghose et al., 2006; Hannan et al., 2015). Previous research did not consider an integral part of IoT enabled waste management practices (the stakeholders such as policy-makers, smart cities planners, city administration, etc.); rather, they were considered independent entities (Evans et al., 2019; Kumar et al., 2009; Shekdar, 2009).

An IoT-enabled smart city is a favorable solution to cater the needs of urbanization (Keerthivasan et al., 2019; Zanella et al., 2014); it may bring numerous benefits in optimizing public

services such as transport, water management, smart buildings, healthcare, and education, and it has the potential to transform societies into smart communities (Monostori et al., 2016). Mineraud et al. (2016) discussed additional benefits such as transparency, flexibility, adaption, and virtualization from the smart cities development (Khan and Salah, 2018; Trappey et al., 2017). On the other hand, there are numerous challenges such as scalability, security issues, heterogeneity, architecture, governance etc. in the adoption of IoT technologies (Atlam et al., 2018; Reyna et al., 2018; Yahia et al., 2019). Studies conducted on IoT practices and implementation in context to waste management are limited; they mainly focus on designing and optimizing IoT technologies for waste collection methods (Keerthika and Pravalika, 2018). Apart from garbage collection, there is a need to explore the factors that influence SCWM (Al Jaid Jim et al., 2019). Therefore, this study aims at developing an understanding and analyzing the strength or intensity of IoT barriers influencing SCWM so that stakeholders may take proactive actions to seamlessly implement IoT-enabled systems. The conceptual framework of IoT and smart city is presented in Fig. 1. This study is an initiative to understand the IoT adoption scenario of smart cities in developing countries like India and the various challenges that may be encountered during IoT implementation. The structuring of an IoT network, with sound support from services and technologies, still lacks an integrated approach to control SCWM. Apart from the technical complexities, a clear, standardized policy for the adoption of the IoT and a suitable direction for smart city initiatives has not yet been presented.

The following objectives are identified on the basis of above discussion. This paper attempts to:

1. Discover the significant IoT barriers (IoTBs) and their strengths to influence the SCWM.
2. Develop a structural framework and computing driving and dependence powers of the IoTBs.

To achieve these objectives, a hybrid MCDM approach has been utilized in an Indian context. The IoTBs are explored from the existing literature and verified by the experts. Further, the relationship between barriers is examined by TISM to exhibit the multi-levels structure of adoption barriers for SCWM and intensity/strength of IoTBs influencing each other and controlling the waste management practices in smart cities; these issues are analyzed through Fuzzy MICMAC and DEMATEL methods.

TISM helps to identify the interrelationships among the IoTBs and to establish the multi-level hierarchical structure of IoTBs. The MICMAC analysis helps to identify the driving and dependence powers of the IoTBs, and it facilitates stakeholders to reach informed decisions.

2. Review of IoT application in smart city waste management

It is important to have a systematic literature review of IoTBs reported by the researchers to develop a structural framework for SCWM. This method was undertaken as it abates the errors (Pietzsch et al., 2017). It is completed in five steps: i) research objectives; ii) database selection; iii) keyword identification; iv) selection of compatible articles, and v) data extraction. For the first step, the research study frames questions related to the smart cities' challenges and the technological factors affecting the development of smart cities. This is followed by the selection of the databases, including "Web of Science" and "Scopus" in step two. The keywords were searched initially with the term "smart cities waste management"; those terms should be present in the titles, keywords, and/or abstract. "Web of Science" database was initially explored, followed by a search in "Science Direct" through the Boolean

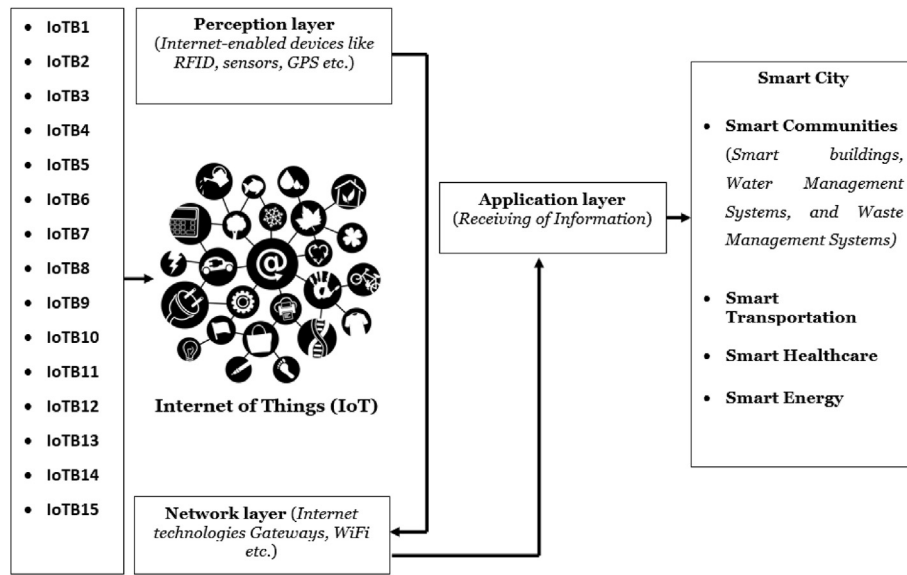


Fig. 1. IoT adoption barriers and Smart City Development.

operation (“smart cities” OR “smart waste” AND “waste management”) to validate the robustness of the search in step three.

The type of the documents included in the research was “articles” and time limits defined were from years “2016–2019.” The choice of exclusive research in the “Science Direct” database is clearly justified because all journals that contain the most selected articles in the first search are included in the database (Journal of Cleaner Production, Waste Management, Smart Cities and Society). The first search resulted in 244 articles (89 articles in “Scopus” and 155 articles in “Web of Science” database). Of the total 71 articles were chosen, 23 articles were common and, thus, 48 articles were initially selected. The second search displayed a total of 413 articles, 147 of which were finally selected.

After the omission of duplicates from both searches in the fourth step, the abstracts were read by the researcher. Only those articles that were related directly with the research questions and objectives of the study were selected. Finally, the systematic review reduced to 70 articles that effectually covered the issue (Appendix A). The process of data extraction was performed by the critical analysis of the articles in the fifth step. The challenges of IoT, and waste management in smart cities, were identified and used to summarize the conclusions of the articles under review.

2.1. IoT concept, and smart cities

IoT can be explained as an ecosystem in which a number of digitally embedded devices communicate with support through internet services (Ferrari et al., 2020). Bruneo et al. (2019) elaborated that devices are often called ‘smart objects’ and that they exist as elements in structures or vehicles or dispersed in the surroundings. The IoT evolution has advanced through many phases to reach its current state. IoT concept defines the capacity of network connectivity of several categories of objects in the environment, and it is not limited to computers (Atlam et al., 2018).

There are three layers in IoT: the personal layer, network layer, and application layer (Botta et al., 2016; Khan and Salah, 2018). The first layer comprises Internet-enabled devices, which are able to perceive, notice objects, collect and exchange information (Talari et al., 2017). Devices like RFID, sensors, and GPS are common examples of this layer. The transfer of data from the first layer to the application layer has to be under the restraints of device's

competencies, so the network and the applicant's limits is the task of the second network layer (Kamble et al., 2019). The IoT envisages this world as completely connected where all elements are competent to communicate with each other. This connectivity leads to the formation of a digital world where smart applications are implemented to form smart communities through the application of internet technologies (Reyna et al., 2018; Sarc et al., 2019). Today, the emergence of Internet technologies like cloud computing, IoT, mobile technologies are drawing attention in the smart cities to develop a sustainable ecosystem (Atlam et al., 2018; Mehmood et al., 2017). The usage of IT is encouraged by the World Foundation for smart communities in smart cities to fulfill the needs of the global economy (Kankanhalli et al., 2019). In 2010, Harrison et al. described the smart city as a passage of joining physical, social, trade, and ICT infrastructures to uplift the knowledge level of the society; he further described the urban ecosystem as one that utilizes Internet technologies to enhance operational efficiency and boasts competencies while safeguarding resource availability for current and future generations. Efficient waste management is a primary concern in India due to increases in waste generation, waste disposal, and landfills (Das et al., 2019; Marques et al., 2019).

Recently, SCWM has attracted scholarly attention and studies are conducted to elaborate models of IoT-enabled applications for waste collection processes (Kang et al., 2019; Silva et al., 2018; Shah et al., 2018) that consist of three stages of operation: waste collection, recycle, and recovery. Various devices are used to note and disseminate information such as RFID tags, sensors, Wireless Sensors network (WSNs), Near Field Communications (NFC), actuators, and GPS in waste management. Sensors are specialized to measure capacity, weight, temperature, humidity, and pressure (Nizetić et al., 2019). NFCs and WSNs are used for data transfer. These sensors are positioned so they can communicate wirelessly with each other, and actuators are used to interact with the bins (Francis and Chichebe, 2019). GPS is used for location tracking of collection trucks. Technologies have been used in waste collection methods, like intelligent waste containers that can identify the level of weight and optimization of route, and that information reduces costs and improves recycling. Being notified of the quantity of waste in bins and sending that information to the server improves the waste collection in big cities (Sowndharya and Savitha, 2019). Ghose et al. (2006) utilized a GIS optimal routing model on the

basis of population density, generation of waste, road network, garbage bins, collection vehicle and more to find the lowest cost per distance paths for transportation of waste to the landfill. LoRa is used to notify the collection system once the bins are full (Andrade and Yoo, 2019; Fataniya et al., 2019). Smart waste management systems are a desirable priority to be installed in the smart cities to manage waste efficiently (Delgado et al., 2020).

2.2. IoT adoption barriers (IoTBs) and smart cities waste management (SCWM)

Several previous studies have identified IoT adoption barriers in context to different industries (Schafer, 2014; Evans et al., 2019; Huang et al., 2019). To fulfill the need of the smart cities in developing countries it is essential to explore IoTBs, which influences SCWM (Lata and Singh, 2016; Martin et al., 2018; Kang et al., 2019; Fatimah et al., 2020).

2.2.1. Security and privacy

It is understandable that systems may meet several attacks like cross-site scripting, or having side channels that lead towards vulnerabilities. Due to multi-tenancy, security issues and data leakage may also rise. The core problem is to achieve interoperability between interconnected devices and facilitating them with the best services through adaptive behavior while maintaining security and privacy of the end-users and their personal data (Ejaz and Anpalagan, 2019). The IoT systems use network technologies such as RFID, NFC, and protocols like Zib-Bee, Z wave, and many other which may results in interoperability between communication standards (Mineraud et al., 2016; Evans et al., 2019). In 2014, Schafer proposed that data privacy and security negatively affects the competencies of IoT in SCWM as it may reveal the accessibility of individual household data to municipal corporations.

2.2.2. Reliability/lack of mobility

Reliability challenges are enhanced due to widespread participation and huge number of smart technologies. The failure risk is greater with mobility and the interconnections among them are less reliable (He et al., 2014).

2.2.3. Lack of transparency

Ambiguity and transparency in the accountability of facilities to be delivered could be in IoT enabled system. It enhances the risk of isolation of people with the smart city technology (Rana et al., 2018; Evans et al., 2019).

2.2.4. Operational cost and extended payback period

Costs are the main concern of the stakeholders in IoT implementation because of high cost of professionals, smart devices, installation, maintenance, and training cost for imparting knowledge to the laborers (Ejaz and Anpalagan, 2019; Huang et al., 2019).

2.2.5. Standardization

Standardization is essential for bi-directional communication and exchange of information among smart devices, environments, smart objects, and other systems. It ensures the smooth integration among stakeholders and data. Standards such as identification, communication, and security are required in successful implementation of IoT (Pang et al., 2015; Li et al., 2015). In previous research, the lack of standardization has been identified as the most common IoTBs (Kamble et al., 2019).

2.2.6. Lack of regulatory norms, Policies and directions

When a lack of regulatory norms and policies exist, that will lead to insecure standards and faulty guidance to perform actions. A

legal framework needs to be robust to support IoT implementation (Hannan et al., 2015). Researchers have shown that a proper legal framework contributes positively to the SCWM while the absence of regulations is harmful for the system (Asase et al., 2009; Moghadam et al., 2009).

2.2.7. Lack of common information system

These barriers hinder in ensuring end to end visibility in SCWM. Previous researches are confined to smart bins and sensors as the main focus in IoT-enabled infrastructure but there is a need to configure an integrated platform of information systems like DSS, PLM, and geo-spatial technology among the devices, applications, and service providers for real time sharing of data and information exchange (Farmanbar et al., 2019; Villa Arrieta and Sumper, 2019).

2.2.8. Lack of integration among IT networks

Due to heterogeneity, integration among the networks is an issue while adopting IoT implementation (Pang et al., 2015; Lokshina et al., 2017). For the successful implementation of IoT in SCWM there is a need of integrated infrastructure to collect waste, handling, and segregation. Al-Hader and Rodzi (2009) proposed that an Enterprise Resource Planning (ERP) application should be incorporated in which existing interfaces and legacy systems are integrated to perform as a single application. Talavera et al. (2017) discussed the compatibility among hardware, software, vehicle, and equipment for which their integration is essential.

2.2.9. Limited skilled workforce

The IoT implementation needs trained, technical professionals (Hussain et al., 2015). For providing an user-friendly and easy accessibility in services, the workforce associated must be efficient and a technical and skilled workforce will be required. Literature suggests that a lack of technical skills among the workforce influences the system adversely (Talavera et al., 2017; Hazra and Goel, 2009).

2.2.10. Lack of technical knowledge among planners

The authorities and policymakers may lack in organizational capabilities and professional skills, which will affect the waste management system (Chung and Lo, 2008; Deore et al., 2019; Israilidis et al., 2019).

2.2.11. Inadequate internet connectivity

Due to weak internet connectivity there may be issues in IoT implementation in waste management practices (Sun et al., 2010).

2.2.12. System failure issues/integrity

Data can be distorted by the various factors that are beyond individual's control like a server crash or failure. Data integrity signifies the shielding of data as well as of the system. The data is continuously updated and remains in its original form whenever accessed by the end-users (Farooq et al., 2015).

2.2.13. Data availability

Immediate access to information to users is ensured by the immediate availability of data. The IoT-enabled system aims to provide data whenever required by the users. The flow of information may be blocked with poor data availability (Liono et al., 2019).

2.2.14. High energy consumption

The power consumption of the IoT devices is a serious concern. Devices with the RFID but without power source will be preferred for an IoT implementation (Borgia, 2014). With growing demand of the IoT devices, it is expected the energy cost of the value chains

will be continuously increasing.

2.2.15. IT infrastructure/architecture

The IT infrastructure need to be developed as per the need of the smart cities. The upgraded technology can only be adopted with the proper architecture (Barbierato et al., 2018; Pasolini et al., 2019).

The IoT adoption barriers (IoTBs) are identified from the previous literature. Table 1 elaborates adoption barriers and segregates into three categories: a) Smart city governance (SCG); b) Smart City Technology and Infrastructure (SCT); and c) Smart City Legal and Ethical Issues (SCL&E).

Previous studies discussed smart cities concepts but challenges or barriers encountered by the smart cities in IoT-enabled waste

management systems are yet untouched. Moreover, the researchers have proposed new technologies used in waste management particularly in waste collection methods and but only a few studies are conducted for developing nations. The scenario in developing countries is entirely different from developed countries because waste generation is the main issue growing in urban areas. The possible solution is IoT adoption to manage waste efficiently; hence, the IoT barriers may act as obstacles and need to be identified and analyzed.

3. Research methodology

Qualitative studies provide the knowledge of novel or complex

Table 1
List of IoT Adoption barriers.

Categories	S.No	Barriers	Details	References
Smart City Governance (SCG)	1	Operational cost and extended payback period (IoTb1)	The cost related to the sensors, actuators and other devices employed in IoT application and its payback period will be a crucial factor.	Adapa (2018); Huang et al., (2019); Ejaz and Anpalagan (2019); Fataniya et al. (2019) Li et al. (2019); Nizetic et al. (2019); Ferrari et al. (2020)
Smart City Governance (SCG)	13	Lack of transparency (IoTb13)	Lack of transparency could be a concern for smart cities.	Evans et al. (2019); Gaffney and Robertson (2018)
Smart City Technology and Infrastructure (SCT)	2	Limited skilled workforce (IoTb2)	According to Labour Bureau Report (2014), the number of skilled force is very limited in India.	Umachandran et al. (2019); Ani et al. (2019)
Smart City Technology and Infrastructure (SCT)	3	High energy consumption (IoTb3)	Number of devices are connected to IoT smart cities network which need will consumer more energy.	Bibri (2018); Ejaz and Anpalagan (2019); O'Dwyer et al. (2019); Stoyanova and Monti (2019)
Smart City Technology and Infrastructure (SCT)	4	Lack of common Information system (IoTb4)	Lack of common Information system model for end-to-end visibility.	Ani et al. (2019); Ismagilova et al. (2019); Kamble et al. (2019)
Smart City Technology and Infrastructure (SCT)	5	Lack of IT infrastructure (IoTb5)	Lack of IT infrastructure in the Indian cities may lead to problems in smart cities.	Barbierato et al. (2018); Kankanhalli et al. (2019); Wirtz et al. (2019); Bruneo et al. (2019); Idwan et al. (2020).
Smart City Technology and Infrastructure (SCT)	6	Lack of standardization (IoTb6)	Every day changes in standardization is difficult to be implemented.	Silva et al. (2018); Rana et al. (2018)
Smart City Technology and Infrastructure (SCT)	7	Lack of mobility (IoTb7)	Mobility is an important challenges as most of the services are linked with mobile phones.	Kamble et al. (2019)
Smart City Technology and Infrastructure (SCT)	8	Inadequate internet connectivity (IoTb8)	Internet connectivity across the nation is one of the major challenges for IoT adoption.	Bruneo et al. (2019); Zeb et al. (2019)
Smart City Technology and Infrastructure (SCT)	10	System failure issues (IoTb10)	The system failure to any of the internet technology or devices need to be considered.	Ahanger and Aljumah (2018); Zeb et al. (2019)
Smart City Technology and Infrastructure (SCT)	11	Lack of integration among IT networks (IoTb11)	Convergence of IT networks are need to be addressed for IoT Smart cities.	Kamble et al. (2019); Deore et al. (2019)
Smart City Legal and Ethical Issues (SCL&E)	12	Lack of regulatory norms, policies and directions (IoTb12)	There is lack of data and corresponding scalable methods in smart city development.	Borgia (2014); Rana et al. (2018)
Smart City Technology and Infrastructure (SCT)	14	Poor data availability (IoTb14)	Lack of regulatory laws, regulations for smart cities development.	Liono et al. (2019); Khan and salah (2018); Huang et al. (2019)
Smart City Technology and Infrastructure (SCT)	15	Lack of technical knowledge among planners (IoTb15)	The level of knowledge required in planners for IoT smart cities planning is not available.	Ikävalko et al. (2018); Lokshina et al. (2017)
Smart City Legal and Ethical Issues (SCL&E)	9	Security and Privacy issues (IoTb9)	Data ownership is critical concern as the object and devices can be easily traced.	Sfar et al. (2019); Wirtz et al. (2019)

Table 2
SSIM.

		IoT15	IoT14	IoT13	IoT12	IoT11	IoT10	IoT9	IoT8	IoT7	IoT6	IoT5	IoT4	IoT3	IoT2	IoT1
IoT1	Operational cost and extended payback period	A	A	A	A	O	O	O	A	O	A	A	A	A	A	
IoT2	Limited skilled workforce	A	A	V	O	V	V	V	O	O	A	O	A	O		
IoT3	High energy consumption	A	A	O	O	A	O	O	A	V	A	A	A			
IoT4	Complex Architecture	X	V	V	A	A	A	A	A	V	A	A				
IoT5	Lack of IT infrastructure	A	A	V	A	V	V	V	A	V	A					
IoT6	Lack of standardization	A	A	V	A	V	V	V	A	V						
IoT7	Lack of mobility	X	A	V	A	A	A	A	A							
IoT8	Inadequate internet connectivity	O	O	V	V	V	V	V								
IoT9	Security and Privacy issues	A	A	A	A	A	A									
IoT10	System failure issues	A	O	V	A	V										
IoT11	Lack of integration among IT networks	A	A	V	A											
IoT12	Lack of regulatory norms, policies and directions	A	A	V												
IoT13	Lack of transparency	A	A													
IoT14	Poor data availability	A														
IoT15	Lack of technical knowledge among planners															

phenomenon through detailed information. This is also supported by Tewksbury and Scheufele in 2009, that information acquired through qualitative study is more informative and enriched. In order to develop a holistic model, the study has undertaken semi-structured interviews of experts, comprehensive reviews of smart cities development plans, and waste management reports and databases. The present study aims to build a new research framework of IoT adoption barriers in SCWM on the basis of experts' knowledge and previous studies and thus a qualitative research approach is applied.

3.1. Need of hybrid MCDM approach

Multi-criteria decision-making methods are applied to solve the complex problems involving huge number of factors (Sharma et al., 2020). The issues related to smart cities are discussed in literature and analyzed through MCDM approaches like Analytical Hierarchical Process (AHP), Analytical Network Process (ANP), and Interpretative Structural modeling (ISM) (Rana et al., 2018). The MCDM approach selection is done as per the problem and the action/decision to be taken by the researcher. If the requirement of research study is to calculate the importance or priorities or weightage and the best alternative selection then AHP (Govindan et al., 2016a; Zarbakhshnia et al., 2020), TOPSIS (Rostamzadeh et al., 2018; and ANP (Govindan et al., 2016b) are used.

In case of the intensity, influence or strength of the factors affecting the system, the causal and effect factors group, and the structural levels of variables, then ISM (Bouzon et al., 2015), TISM (Sushil, 2018), Fuzzy MICMAC (Bhar, 2019), and DEMATEL (Govindan et al., 2020 a,b; Sharma et al., 2020) are utilized. The present work needs two objectives to be fulfilled: a) Identification of IoT barriers in SCWM and b) The analysis of IoT barriers to develop a structural framework and to calculate the intensity of the variables resulting in the identification of most critical barriers of the SCWM. For these two purposes, the hybrid TISM, Fuzzy MICMAC, and DEMATEL are the best methods to be applied. The research is conducted into two phases. The IoT adoption barriers (IoTBs) are identified from the secondary data. For this, the pool of the journals is extracted from the databases like Scopus, Web of Science, Emerald Insight, and Google Scholar.

3.2. Experts selection

We assembled a panel of nine experts in the relevant domains and asked these experts to assist in validating the IoT adoption barriers for developing the hierarchical structure (Appendix B). Three experts are from an IT domain, two experts from smart cities

development project, two experts from waste management, and two scientists validated the identified adoption barriers. The experts from IT domain are working in a smart city project, Mussorie Dehradun Development Authority (MDDA), Uttarakhand under the national cleanliness campaign with an experience of more than 10 years; they have contributed in the IT enabled governance system in Uttarakhand, India. The experts are engaged in developing the smart cities project and building infrastructure. Two professors from the department of environment, Govt. University, and two scientists with an experience of 10 years are requested for validating the barriers and working in a smart city development project for waste management practices in cities.

3.3. Hybrid MCDM methods

After the validation and responses from all the experts, the hierarchical structure is developed using TISM in phase I. To identify the strength of adoption barriers, fuzzy MICMAC and DEMATEL method are applied in Phase II.

3.3.1. Total interpretive structural matrix (TISM) method

This method is to infer difficult associations in nodes and links forms (Sushil, 2017). This process helps to assimilate numerous pair-wise comparisons in hierarchical structure form through interpretive structural modeling (Warfield, 1974). The method is divided into six steps, which are elaborated as follows:

Step 1: Structural self-interaction matrix (SSIM) is formed, exhibiting pair-wise relationships amongst IoT adoption barriers. Four symbols are used for representing the relationships between variables *i* and *j*.

- V: *i* will ameliorate *j*;
- A: *i* will ameliorate *j*;
- X: *i* and *j* will ameliorate each other; and
- O: *i* and *j* are unrelated.

Step 2: From SSIM, initial reachability matrix (IRM) is formed and tested for transitivity. The IRM is binary in nature since the entries V, A, X, and O of the SSIM are 0 and 1 on the basis of following rules.

- i) if entry of (*i, j*) in SSIM table is V, then (*i, j*) entry in the IRM becomes 1, and (*j, i*) entry becomes 0;
- ii) if entry of (*i, j*) in SSIM table is A, then (*i, j*) entry in the IRM becomes 0, and (*j, i*) entry becomes 1;
- iii) if entry of (*i, j*) in SSIM table is X, then (*i, j*) entry in the IRM becomes 1 and (*j, i*) entry also becomes 1; and
- iv) if the entry of (*i, j*) in SSIM table is O, then (*i, j*) entry in the IRM becomes 0 and (*j, i*) entry also becomes 0.

For checking the transitivity and developing final reachability matrix (FRM), the following rule is applicable: if a barrier 'X' is related to 'Y' and 'Y' is related to 'Z' then 'X' is similar to 'Z.'

Step 3. The FRM is divided into multiple levels.

Step 4. The contextual relationships forms the directed graph (diagraph) and transitive links are ignored.

Step 5: Statements are substituted with nodal elements.

Step 6: The resultant digraph is transformed into a TISM model by replacing element nodes into statements and links into interpretations.

3.3.2. Fuzzy MICMAC methodology

This analysis is based on the principle of multiplication properties of matrices (Diabat and Govindan, 2011). The strength of the relationship among the variables is not identified by the TISM method, and the binary digits are only considered in TISM model, which denotes the linkage between the variables. However, the relationship amongst any two variables may be weak, very weak, strong, very strong, or no relationship. The steps for TISM-fuzzy MICMAC are elaborated in following 4 steps:

Step 1: Establishing Binary Direct reachability matrix (BDRM) from TISM variables: The diagonal values are converted to 0 and transitivity is overlooked in the final reachability matrix.

Step 2: Developing Fuzzy BDRM: Converting the diagonal values to zero develops the correlation matrix, and ignores transitivity. The additional interactions among the variables are constructed on the scale 0–1 with specifications such as negligible –0.1, low – 0.3, medium – 0.5, high – 0.7, very high – 0.9 and complete –1. Using Fuzzy set theory, the experts are asked to provide the values.

Step 3: Developing Fuzzy-MICMAC stabilized matrix: The two fuzzy matrices are multiplied till the product matrix is stabilized.

3.3.3. DEMATEL method

Decision Making Trial and Evaluation Laboratory (DEMATEL) is used to analyze the causal relationship factors (Sharma et al., 2020). The relationship among the variables is quantified on a scale of 0–4 where 0 indicates that variable "X" does not have any influence on variable "Y" and 4 indicates that variable "X" influences variable "Y" significantly.

Step 1: Direct-influence matrix:

On a scale of 0–4, each expert is asked to respond for the influence of i on j variable. For n number of variables, the matrix will be in the form shown below.

$$D = \begin{bmatrix} 0 & d_{12} & d_{13} & \dots & d_{1n} \\ D_{21} & 0 & d_{23} & \dots & d_{2n} \\ D_{31} & d_{32} & 0 & \dots & d_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & d_{n3} & \dots & 0 \end{bmatrix}$$

Step 2: Normalize the direct-influence matrix: The normalized direct-influence matrix N is obtained by using Eqs. (1) and (2).

$$m = \min \left[\frac{1}{\max \sum_{j=1}^n dij}, \frac{1}{\max \sum_{i=1}^n dij} \right] \quad (1)$$

$$N = \frac{D}{m} \quad (2)$$

Step 3: Deriving total Influence Matrix: The total-influence matrix T is arrived by using Eq. (3)

$$\begin{aligned} T &= N + N^2 + N^3 + N^4 + N^5 + \dots \\ &+ N^q = NI + N + N^2 + N^3 + N^4 \\ &+ \dots + N^{q-1} \left[I - N \right] \left(I - N \right)^{-1} \} \\ &= N \left(I - N^q \right) \left(I - N \right)^{-1} \end{aligned} \quad (3)$$

$$\text{Then } T = N(I - N)^{-1}$$

Where I = Identity Matrix.

4. Model application

The TISM-Fuzzy MICMAC and DEMATEL are used step by step to identify the intensity of the IoT adoption barriers. The analysis is divided into three parts: TISM Application, Fuzzy MICMAC Application, and DEMATEL application.

4.1. TISM application

4.1.1. Structural self-interaction matrix (SSIM) is developed on the basis of expert responses, exhibited in Table 2

Tables 2 and 3 are derived from step 1, 2 of section 3.1 (i.e., TISM methodology).

4.1.2. Level segmentation

The iterations are performed for levels segmentation. A total of nine iterations are performed and ten levels are formed shown in Table 4. The TISM based model for IoT adoption barriers for SCWM is developed from Table 4. The nodes in the diagram are replaced with interpretations of the IoTs barriers. The TISM based structure for SCWM is exhibited in Fig. 2 followed by the interpretations in Table 5.

4.2. Fuzzy MICMAC application

The fuzzy MICMAC analysis is used to calculate the driving and dependence power of the IoT adoption barriers.

4.2.1. Developing BDRM and FDRM

It is obtained from the reachability matrix of ISM table and the diagonal entries replaced with zero.

From the steps 2, 3, and 4 of section 3.2 elaborating MICMAC methodology, the stabilized FDRM is developed and exhibited in Table 6.

The IoT adoption barriers are divided in three clusters as per their dependence and driving powers computed from MICMAC analysis and shown in Fig. 3. Fig. 3 exhibits that all the fifteen adoption barriers are placed in only three clusters.

The ISM-MICMAC methods are applied to categorize the IoTBs and to identify the interrelationships among them. The study has categorized all fifteen variables in three clusters, shown in Fig. 3.

4.3. DEMATEL analysis

The causal and effect relationship among the 15 IoT Adoption

Table 3
Transitivity table.

	IoT1	IoT2	IoT3	IoT4	IoT5	IoT6	IoT7	IoT8	IoT9	IoT10	IoT11	IoT12	IoT13	IoT14	IoT15
IoT1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IoT2	1	1	*1	*1	0	0	*1	0	1	1	1	0	1	0	0
IoT3	1	0	1	0	0	0	1	0	0	0	0	0	*1	0	0
IoT4	1	1	1	1	*1	*1	1	0	*1	*1	*1	*1	1	1	1
IoT5	1	*1	1	1	1	0	1	0	1	1	1	0	1	*1	*1
IoT6	1	1	1	1	1	1	1	0	1	1	1	0	1	*1	*1
IoT7	*1	0	0	0	0	0	1	0	*1	0	0	0	1	0	1
IoT8	1	*1	1	1	1	1	1	1	1	1	1	1	1	*1	*1
IoT9	*1	*1	*1	1	0	0	1	0	1	0	0	0	*1	*1	*1
IoT10	*1	*1	*1	1	0	0	1	0	1	1	1	0	1	*1	*1
IoT11	*1	*1	1	1	0	0	1	0	1	0	1	0	1	*1	*1
IoT12	1	*1	*1	1	1	1	1	0	1	1	1	1	1	*1	*1
IoT13	1	0	0	*1	0	0	0	0	1	0	0	0	1	0	0
IoT14	1	1	1	*1	1	1	1	0	1	*1	1	1	1	1	0
IoT15	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1

barriers (IoTbs) was established and their degree of influence on each other is calculated. From the steps 1, 2, and 3 in the previous section of DEMATEL methodology, the direct influence matrix, normalized direct influence matrix, total relation matrix, and degree of influences are developed and exhibited in Table 7.

5. Results and discussion

The objective of TISM–Fuzzy MICMAC methodology was to calculate the hierarchical levels for the barriers for exploring their relationships. The TISM results have exhibited 10 hierarchical levels demonstrating that lack of regulations, policy and directions, internet connectivity, and lack of standardization are the key drivers in IoT applications in smart cities' waste management. Adoption barriers for the smart cities' waste management systems have been categorized into three quadrants depending upon their dependence and driving powers. The representation clusters are presented in Fig. 3.

5.1. TISM-fuzzy MICMAC results

The **first quadrant (Autonomous IoT Adoption Barriers)** contains autonomous variables with low driving and dependence power. These barriers are not connected to any other variables and thus do not influence the system. This cluster is autonomous. No barrier is present in this cluster. Without barriers, the first quadrant proves that the identified barriers are substantial (Kamble et al., 2019).

The **second quadrant (Dependent IoT Adoption Barriers)** has dependent variables. These barriers have high dependence power and low driving power. There are six dimensions in this cluster. Operational cost and extended payback period (IoT1) has highest dependence power and low driving power and, thus, it is highly dependent on other variables. The operational cost and payback period are highly dependent on other variables like System failure issues, Poor data availability, Lack of integration, and others. Lack of common Information system (IoT4), Security and Privacy issues (IoT9), and Lack of transparency (IoT13) also have high dependence powers, which indicate that other barriers will affect these variables. Highest dependence of Operational cost and extended payback period (IoT1) on other 14 variables is shown in Fig. 6 (Influence diagram of IoT1). Lack of mobility (IoT7) and High-energy consumption (IoT3) has dependence powers, which indicate that other barriers will affect these variables. These barriers are highly volatile which may change according to the other adoption barriers.

The **third quadrant (Linkage IoT adoption barriers)** consists of

linkage barriers with high dependence and driving powers. The barriers act as linkage barriers to the other variables. In this study, this cluster has six barriers with high dependence and driving powers. Linkage factors are highly unstable, and any change happening to these factors will influence the other factors. This study positions six dimensions in this cluster– Limited skilled workforce (IoT2), Lack of integration among IT networks (IoT11), System failure issues (IoT10), Poor data availability (IoT14), Lack of IT infrastructure (IoT5), and Lack of technical knowledge among planners (IoT15).

The **fourth quadrant** is comprised of driving variables. Lack of standardization (IoT6), Lack of Inadequate internet connectivity (IoT8), and Lack of regulatory norms, policies, and directions (IoT12) are the driving barriers which have highest driving barriers and, thus, are driving the other barriers. The intensity of Lack of Inadequate internet connectivity (IoT8) and Lack of regulatory norms, policies, and directions (IoT12) is shown in Figs. 5 and 6 which shows that these barriers are the key drivers and that they influence all other barriers. These driving variables are generally found on the lowest level of the TISM hierarchical levels.

5.2. DEMATEL results

The results from the TISM application exhibit IoTbs but the intensity of dependency is still unknown. The degree of influences shown in Table 7 and diagram in Figs. 4–6 provides valuable insights for implications. The D + R and D-R values elucidate the cause and effect relationships respectively. The causal group factors drive the effect group variables, which implies that these factors are independent whereas the effect group factors are driven and influenced by them.

Table 7 exhibits D + R values in the same range with the least value (2.311) of IoT4 and the highest value (2.91) of IoT15. The similar range values displays that all the IoT adoption barriers are closely associated and interdependent to each other. Lack of technical knowledge among planners (IoT15) is at the top of the group, which indicates that IoT15 is the strongest factor followed by Operational cost and payback period (IoT1). The values of D-R exemplifies that IoT5, IoT6, IoT8, IoT10, IoT12, IoT14, and IoT15 constitute the net causal group factors and IoT12 is the strongest causal barrier. IoT1, IoT2, IoT3, IoT4, IoT7, IoT9, IoT11, IoT13 are the net receiver group factors, which are affected by the causal barriers.

5.2.1. Causal group factors

Table 7 demonstrates the direct and the indirect influences of the fifteen IoT adoption barriers. From Table 7, the causal factors can

Table 4

Iterations.

Level Partitioning: Iteration 1				
Reachability Set	Antecedent Set	Intersection	Level	
1	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1	I	
1,2,3,4,7,9,10,11,13	2,4,5,6,8,9,10,11,12,14,15	2,4,9,10,11		
1,3,7,13	2,3,4,5,6,8,9,10,11,12,14,15	3		
1,2,3,4,5,6,7,9,10,11,12,13,14,15	2,4,5,6,8,9,10,11,12,13,14,15	2,4,5,6,9,10,11,12,13,14,15		
1,2,3,4,5,7,9,10,11,13,14,15	4,5,6,8,12,14,15	4,5,14,15		
1,2,3,4,5,6,7,9,10,13,14,15	4,6,8,12,14,15	4,6,14,15		
1,7,9,13	2,3,4,5,6,7,8,9,10,11,12,14,15	7,9		
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1	1		
1,2,3,4,7,9,13,14,15	2,4,5,6,7,8,9,10,11,12,13,14,15	2,4,7,9,13,14,15		
1,2,3,4,7,9,10,11,13,14,15	2,4,6,8,10,12,14,15	2,4,10,14,15		
1,2,3,4,7,9,11,13,14,15	2,4,5,6,8,10,11,12,14,15	2,4,11,14,15		
1,2,3,4,5,6,7,9,10,11,12,13,14,15	4,8,12,14,15	4,14,15		
1,4,9,13	2,3,4,5,6,7,8,9,10,11,12,13,14,15	4,9,13		
1,2,3,4,5,6,7,9,10,11,12,13,14	4,5,6,8,9,10,11,12,14,15	4,5,6,9,10,11,12,14		
1,2,3,4,5,6,7,9,10,11,12,1,3,14,15	4,5,6,8,9,10,11,12,15	4,5,6,9,10,11,12,15		
Level Partitioning: Iteration 2				
Reachability Set	Antecedent Set	Intersection	Level	
2,3,4,7,9,10,11,13	2,4,5,6,8,9,10,11,12,14,15	2,4,9,10	II	
3,7,13	2,3,4,5,6,8,9,10,11,12,14,15	3		
2,3,4,5,6,7,9,10,11,12,13,14,15	2,4,5,6,8,9,10,11,12,13,14,15	2,4,5,6,9,10,11,12,13,14,15		
2,3,4,5,7,9,10,11,13,14,15	4,5,6,8,12,14,15	4,5,14,15		
2,3,4,5,6,7,9,10,11,13,14,15	4,6,8,12,14,15	4,6,14,15		
7,9,13	2,3,4,5,6,7,8,9,10,11,12,14,15	7,9		
2,3,4,5,6,7,8,9,10,11,12,13,14,15	8	8		
2,3,4,7,9,13,14,15	2,4,5,6,7,8,9,10,11,12,13,14,15	2,4,7,9,13,14,15		
2,3,4,7,9,10,11,13,14,15	2,4,5,6,8,10,12,14,15	2,4,10,14,15		
2,3,4,7,9,11,13,14,15	2,4,5,6,8,10,11,12,14,15	2,4,11,14,15		
2,3,4,5,6,7,9,10,11,12,13,14,15	4,8,12,14,15	4,12,14,15		
4,9,13	2,3,4,5,6,7,8,9,10,11,12,13,14,15	4,9,13		
2,3,4,5,6,7,9,10,11,12,13,14,	4,5,6,8,9,10,11,12,14,15	4,5,6,9,10,11,12,14		
2,3,4,5,6,7,9,10,11,12,13,14,	4,5,6,8,9,10,11,12,15	4,5,6,9,10,11,12,14		
Level Partitioning Iteration 3				
Reachability Set	Antecedent Set	Intersection		Level
2,3,4,7,10,11	2,5,6,8,10,11,12,14,15	2,10,11	III	
3,7	2,3,5,6,8,10,11,12,14,15	3		
2,3,5,7,10,11,14,15	5,6,8,12,14,15	5,14,15		
2,3,5,6,7,10,11,14,15	6,8,12,14,15	6,14,15		
7	2,3,5,6,7,8,9,10,11,12,14,15	7		
2,3,5,6,7,8,10,11,12,14,15	8	8		
2,3,7,10,11,14,15	2,5,6,8,10,12,14,15	2,10,14,15		
2,3,7,11,13,14,15	2,5,6,8,10,11,12,14,15	2,11,14,15		
2,3,5,6,7,9,10,11,12,14,15	8,12,14,15	12,14,15		
2,3,5,6,7,10,11,12,13,14,	5,6,8,10,11,12,14,15	5,6,10,11,12,14		
2,3,5,6,7,10,11,12,14,15	5,6,8,10,11,12,15	5,6,10,11,12,15		
Level Partitioning Iteration 4				
Reachability Set	Antecedent Set	Intersection	Level	
2,3,10,11	2,5,6,8,10,11,12,14,15	2,10,11	IV	
3	2,3,5,6,8,10,11,12,14,15	3		
2,3,5,10,11,13,14,15	5,6,8,12,14,15	5,14,15		
2,3,5,6,10,11,14,15	6,8,12,14,15	6,14,15		
2,3,5,6,10,11,14,15	6,8,12,14,15	6,14,15		
2,3,5,6,8,10,11,12,14,15	8	8		
2,3,10,11,14,15	2,5,6,8,10,12,14,15	2,10,14,15		
2,3,11,14,15	2,5,6,8,10,11,12,14,15	2,11,14,15		
2,3,5,6,10,11,12,14,25	5,6,8,10,11,12,14,15	5,6,10,11,14,15		
2,3,5,6,10,11,12,14	5,6,8,10,11,12,14,15	5,6,10,11,12,14		
2,3,5,6,10,11,12,14,15	5,6,8,10,11,12,15	5,6,10,11,12,15		
Level Partitioning Iteration 5				
Reachability Set	Antecedent Set	Intersection	Level	
2,10,11	2,5,6,8,10,11,12,14,15	2,10,11	V	
2,5,10,11,14,15	5,6,8,12,14,15	5,14,15		
2,5,6,10,11,14,15	6,8,12,14,15	6,14,15		
2,3,5,6,8,10,11,12,14,15	8	8		
2,10,11,14,15	2,5,6,8,10,12,14,15	2,10,14,15		
2,11,14,15	2,5,6,8,10,11,12,14,15	2,11,14,15	V	

(continued on next page)

Table 4 (continued)

Level Partitioning: Iteration 1			
Reachability Set	Antecedent Set	Intersection	Level
Level Partitioning Iteration 6			
5,10,14,15	5,6,8,12,14,15	5,14,15	VI
5,6,10,14,15	6,8,12,14,15	6,14,15	
10,14,15	5,6,8,10,12,14,15	10,14,15	
5,6,10,12,14,15	8,12,14,15	12,14,15	
5,6,10,12,14	5,6,8,10,12,14	5,6,10,12,14	VI
5,6,10,12,14,15	5,6,8,10,11,12,15	5,6,10,12,15	
Level Partitioning Iteration 7			
5,15	5,6,8,12,15	5,15	VII
5,6,15	6,8,12,15	6,15	
5,6,8,12,15	8	8	
5,6,12,15,	8,12,15	12,15	
5,6,12,15	5,6,8,12,15	5,6,12,15	VII
Level Partitioning Iteration 8			
6	6,8,12	6	VIII
6,8,12	8	8	
6,12	8,12	12	
Level Partitioning Iteration 9			
8,12	8	8	IX
12	12	12	X

be arranged in the following order: IoTB12>IoT8>IoT6>IoT5>IoT15 > IoT14>IoT10. In causal IoT adoption barriers, IoT12 has the highest value, which signifies that Lack of regulatory norms, policies, and directions (IoT12) is the strongest causal factor and it is further followed by IoT8 and IoT6. This indicates that Lack of regulatory norms, policies, and directions is the main causal variable affecting all the other variables followed by lack of internet connectivity (IoT8) and lack of standardization (IoT6). These results were discussed with the experts and they accepted that lack of regulatory norms, policies, and directions (IoT12) is a major IoT adoption barrier. In a developing country like India, lack of standardization and policy is an elementary problem, which instigates other problems (Kamble et al., 2019; Yenneti et al., 2019).

It is visible from Table 7 and Fig. 4 IoTB12 is influencing all other IoT adoption variables except IoT8, and not affected by any variable; therefore, it is the most important adoption barrier to be managed by the government and the policymakers. This also indicates the government and policymakers need to develop a robust regulatory system with clear policy and directions for effective waste management implementation in smart cities. Moreover, IoT8 and IoT6 are also influencing all the other variables except IoTB12, which proves that both these IoT barriers also influence all other variables. Alpha threshold value of 0.833 was used to represent the influence of IoTBs graphically, as presented in Figs. 4 and 5 showing the influence diagram of IoTB12 and IoT8. This implies that lack of regulatory norms, policies, and directions, lack of connectivity issues, and lack of standardization are the important concerns to be managed by the government and policymakers for smart cities' development in India. All three causal factors (IoTB12, IoT8, and IoT6) have stronger driving forces and influence the entire IoT implementation framework for waste management in smart cities. This indicates that improvements in these variables may lead to amelioration of the entire IoT implementation and will positively influence waste management practices.

5.2.2. Receiver group factors

From Table 7 the receiver group factors can be arranged in the following order:

IoT1>IoT13>IoT9>IoT7>IoT4>IoT3>IoT11>IoT2. This indicates that Operational cost and payback period (IoT1) is the

most dependent barrier and is influenced by all other variables. More specifically, Fig. 6 displays that the relationship of IoTB1 barrier with the other variables confirms that IoTB1 does not influence any other variable; rather, it is affected by all the fourteen variables.

During the rounds of discussion, the experts advocate that the lack of regulations in the country is the most crucial bottleneck in the IoT implementation of smart city waste management. "I believe that our country is facing challenges in managing waste as we lack in regulations and governance and unable to provide the transparency in information sharing, security and type of technology to be employed" (Expert 2). The experts also characterize that the potential of IoT implementation in waste management is an integrated responsibility of the public authorities, business representatives, citizens, and other stakeholders. "Most of the stakeholders presently have their legacy systems and procedures, thus making integration among sub-systems highly challenging" (Expert 1). Expert 3 elaborated that "India is standing at fifth place in e-waste generation: 2 million metric tons per annum and only 5% of total waste is recyclable." Experts were of the opinion that currently, the electronics industry is the fastest growing industry and due to excessive e-products consumption, disposal, and recycling issues, developing countries like India are struggling to deal with the increasing waste generation. Two experts raised concerns on weak government policies and traditional methods for managing waste and suggested that "There should be new initiatives to reform the waste management policies and the examples from developed nations would be considered" (Expert 5). Numerous developed nations have realized the significance of the regulations (legislations) and formulated policies to manage waste; hence, the same must be followed in developing nations. "The conventional methods for waste management are removing the waste from living environment and processing it, but developing nations need to implement strict policies, regulations, and standardization to manage waste" (Expert 9). Expert 4 suggested to implement waste taxes and fines to make stakeholders concerned about waste generation. The widespread usage of internet technologies and social networks can be excellent ways to actively involve citizens and other stakeholders for creating awareness towards reducing waste and adopting methods for segregations & recycling. "India should

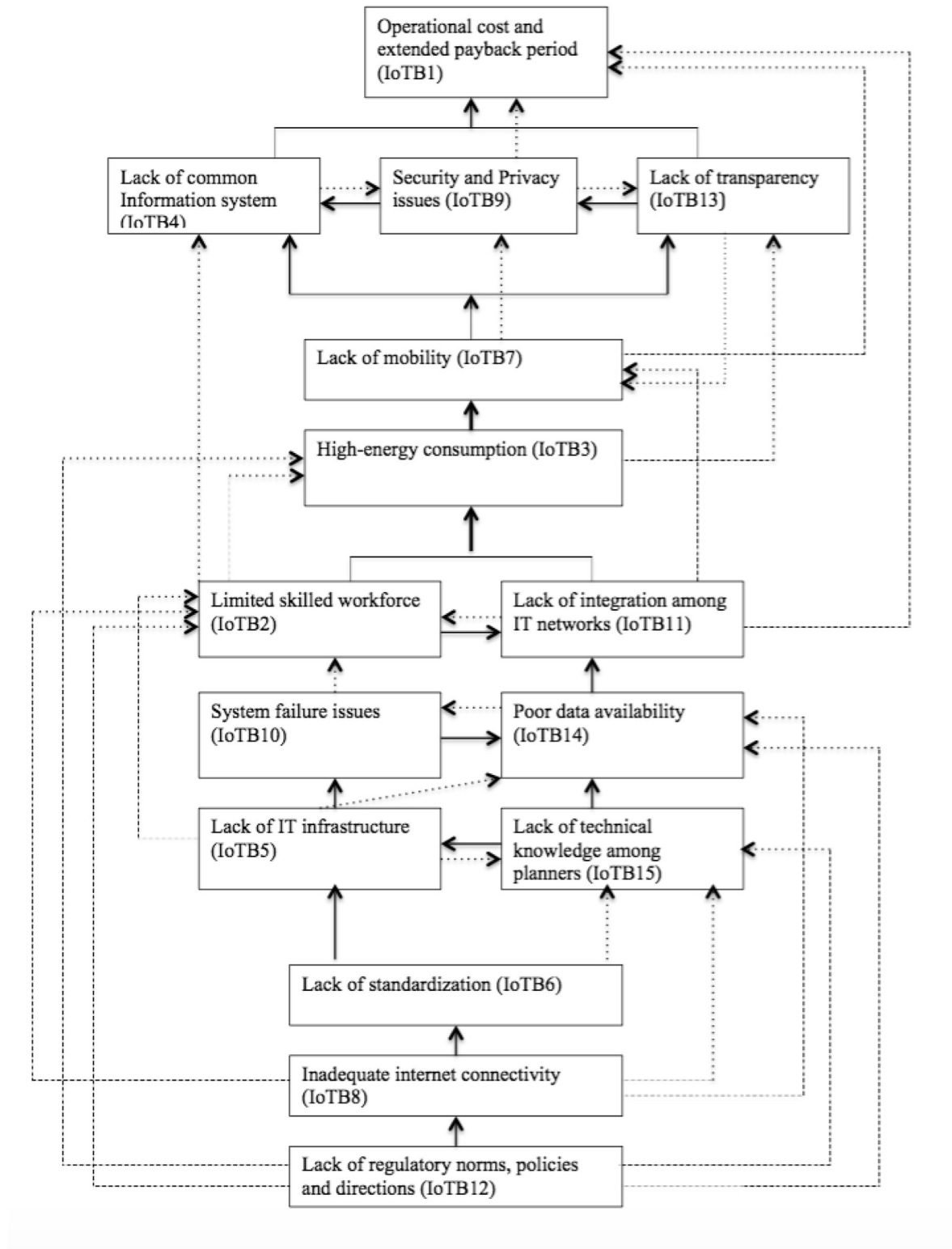


Fig. 2. Tism diagram.

use digital technologies to enhance participation among stakeholders" (Expert 6).

It is apparent from this study that implementation of an integrated approach, strict legislations, infrastructural development, technologies and community participation in waste management process will shape the structure of the smart cities in India. In India,

currently waste management demands a change among people to reconsider waste as a product and contribute towards becoming a sustainable circular economy (Kannan et al., 2020). The collaboration is required among the policymakers, stakeholders including manufacturers, and government officials for developing sustainable societies.

Table 5
TISM interpretation.

Link	Relation	Interpretation
1	B12–B2	The workforce remains low motivated, less focused and lack career paths, and without adequate training, remain less skilled.
2	B12–B15	Decisions related to training, skilling and knowledge management as adversely affected and therefore skewed the technical knowledge among top level Managers.
3	B12–B3	Lack of a strong regulation framework to account high-energy consumption may show compromised concern towards the environment.
4	B12–B14	Efficacy of Data, reusability, and analytic reproducibility is adversely affected.
5	B8–B2	Lack or limited technological skills or inadequate technical skills at executive level, can be caused by low or inadequate internet connectivity.
6	B8–B14	For Smart functionality, data availability with sufficient bandwidth to various levels of users is important.
7	B8–B15	Lack or limited technological skills or inadequate technical skills at senior/executive level can be caused by low or inadequate internet connectivity.
8	B6–B15	Lack of standardization makes consistent knowledge upgradation, application and assessment difficult among Top Level Management.
9	B5–B2	Limited exposure to Emerging Trends and Technologies may obstruct the skilled workforce development.
10	B5–B15	Top level Decisions delays may cause less visibility towards the Strategic outlook of the business entity.
11	B5–B14	Poor or Low Data Availability is caused due to lack of IT Infrastructure.
12	B11–B2	Disintegration among IT Networks affects the availability of Skilled Workforce.
13	B2–B4	Lesser number of skilled Workforce will not be sufficient to maintain integrated information system.
14	B2–B3	Due to less skilled workforce the energy consumption will be higher.
15	B11–B7	Lack of Mobility may occur due to lack of integration in IT networks.
16	B7–B9	Security Concerns are affected by Lack of Mobility in the system.
17	B7–B1	Due to Lack of Mobility, the Operational Cost and Extended Payback Period will be likely to increase.
18	B13–B7	Due to Transparency, lack of Mobility is happening.
19	B9–B13	Lack of robust Security Policies may adversely affect the system transparency.
20	B4–B9	Non-Availability of Integrated Information System may lead to Security and Privacy Concerns at a high level.
21	B9–B1	Lack of Security and Privacy related Policies, Operational Cost and Extended Payback Period will be likely to increase.
22	B14–B10	Due to poor data availability the system failure issues may prevail.
23	B10–B2	For newly technology based systems, System failure issues prevailed and remain unanswered due to limited skilled workforce.
24	B11–B1	Lack of consistency, demand-side options, and are particularly important in the absence of Integration, the cost of Operation and Pack-Back Period are adversely affected.
25	B3–B13	With the obligation to save energy, it becomes more challenging if the system does not support transparency.

Table 6
Stabilized FDRM.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.1	0	0	0	0	0	0	0	0.7	0.3	0.7	0	0.5	0	0	2.3
3	1	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	1.9
4	0.1	0.3	0.1	0	0	0	0.1	0	0	0	0	0	0.1	0.5	0.5	1.7
5	0.5	0	0.7	0.3	0	0	0.1	0	0.5	0.5	0.3	0	0.3	0	0	3.2
6	0.9	0.9	0.3	0.1	0.1	0	0.3	0	0.1	0.3	0.1	0	0.3	0	0	3.4
7	0.3	0	0	0	0	0	0	0	0	0	0	0	0.3	0	1	1.6
8	0.1	0	0.5	0.3	0.3	0.3	0.1	0	0.1	0.1	0.1	0.3	0.5	1	0	3.7
9	0	0	0	0.7	0	0	1	0	0	0	0	0	0	0	0	1.7
10	0	0	0	0.7	0	0	0.3	0	0.7	0	0.3	0	1	0	0	3
11	0	0	0.5	0.9	0	0	0.5	0	0.1	0	0	0	0.3	0	0	2.3
12	0.3	0	0	0.5	0.5	0.5	0.1	0	0.7	0.9	0.3	0	0.1	0	0	3.9
13	0.7	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0.7	1.7
14	0.1	0.7	0.7	0	0.3	0.1	0.1	0	0.5	0	0.3	0.1	0.3	0	0	3.2
15	0.1	0.3	0.1	0.3	1	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0.7	0	3.2
	4.2	2.2	2.9	3.8	2.2	1	3.6	0	3.8	2.2	2.2	0.5	3.8	2.2	2.2	

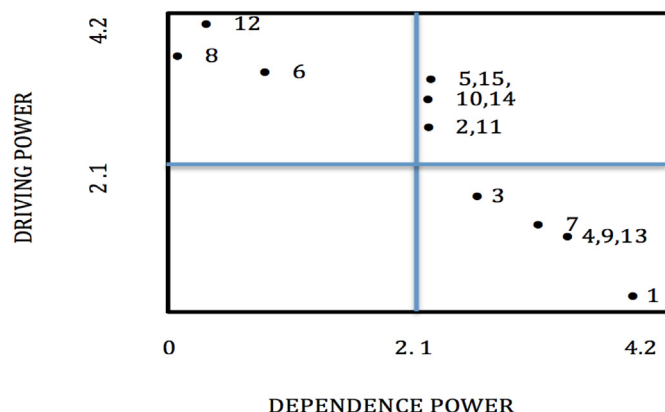


Fig. 3. Dependence and driving power of IoTs.

Table 7
Degree of relationship.

Dimension	D	R	D + R	D-R
IoTb1	0.705935	2.204392688	2.910328	-1.49846
IoTb2	1.205695	1.285400258	2.491095	-0.07971
IoTb3	1.088729	1.370181	2.45891	-0.28145
IoTb4	0.910795	1.400741	2.311536	-0.48995
IoTb5	1.569566	1.106565	2.676131	0.463001
IoTb6	1.81173	1.03275	2.84448	0.77898
IoTb7	1.065751	1.590081	2.655832	-0.52433
IoTb8	1.91878	0.753346	2.672126	1.165434
IoTb9	0.929885	1.547744	2.477629	-0.61786
IoTb10	1.412856	1.300447	2.713303	0.112409
IoTb11	1.224533	1.34783	2.572363	-0.1233
IoTb12	2.085672	0.789874	2.875546	1.295798
IoTb13	0.8954	1.620407	2.515807	-0.72501
IoTb14	1.409814	1.259378	2.669192	0.150436
IoTb15	1.649723	1.275726	2.925449	0.373997

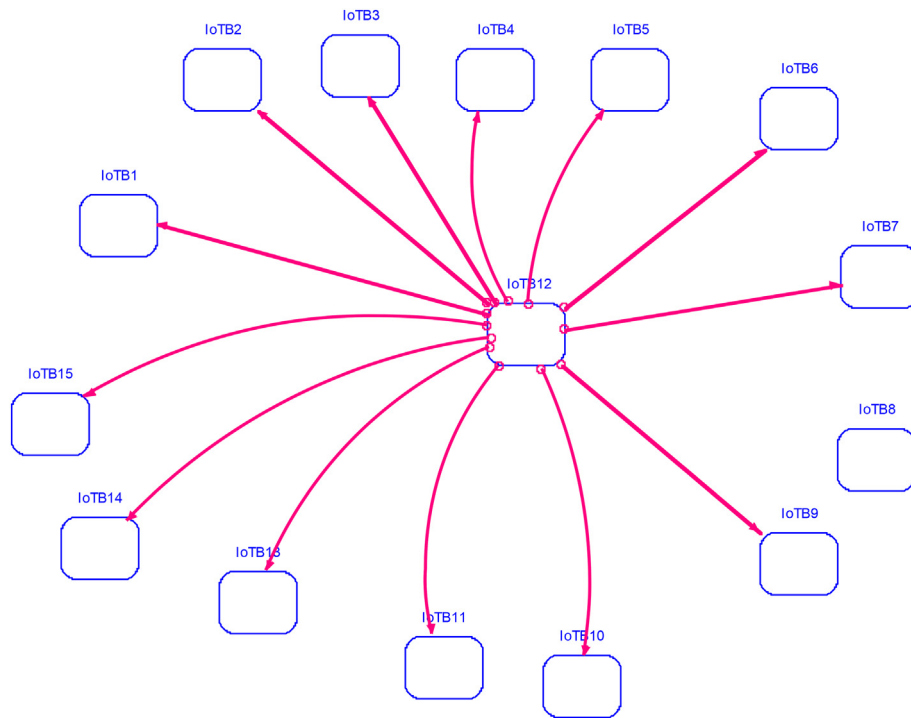


Fig. 4. Influence diagram of IoTB12.

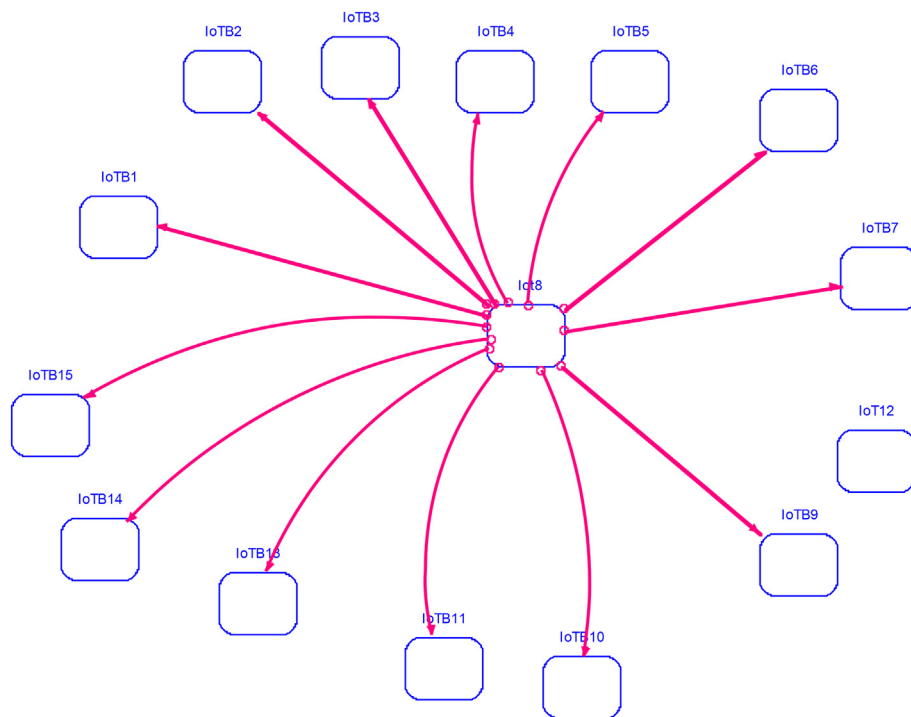


Fig. 5. Influence diagram of IoTB8.

6. Implications

The government and the policymakers should pay attention to all three causal factors (lack of regulatory norms, policies, and directions, lack of connectivity issues, and lack of standardization) rather than focusing on the receivers, operational cost, and payback period (IoTB1), Lack of common Information system (IoTB4),

Security and Privacy issues (IoTB9), and Lack of transparency (IoTB13). It implies that the IoT implementation in SCWM needs strong support systems from the government, policymakers, and practitioners in designing and managing regulatory framework, policy and directions as well as developing a robust IT-enabled system for practicing and monitoring waste management through secured data.

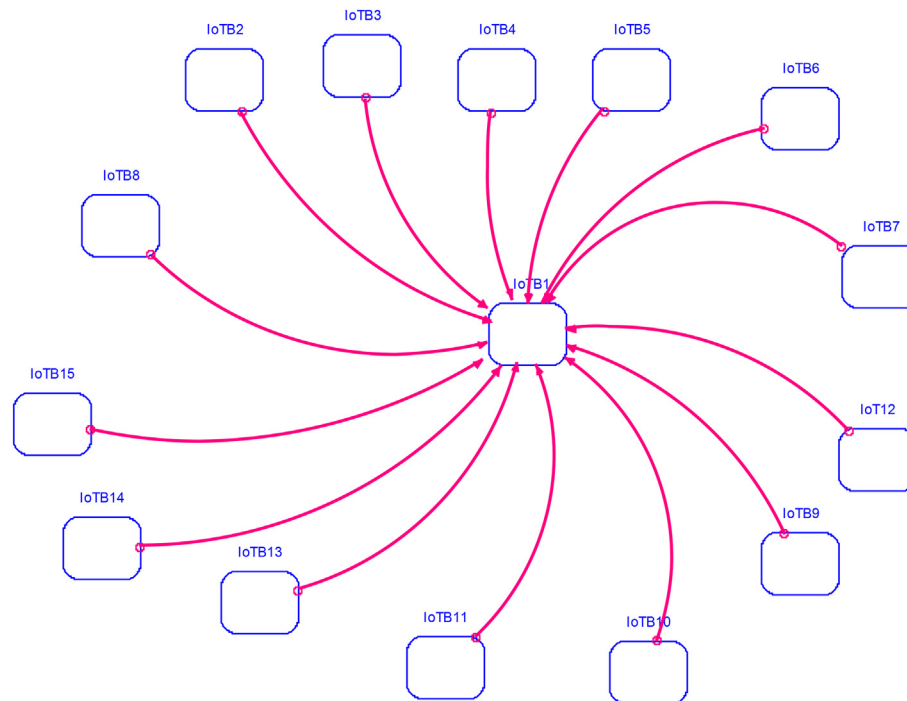


Fig. 6. Influence diagram of IoTB1.

The main objective of this research study was to identify the most prominent IoT adoption barriers for SCWM. The interdependency of the adoption barriers shows that the current system of India needs to address issues like regulatory framework, policies, internet connectivity, information systems, privacy issues, knowledge among key planners and others. In addition, all stakeholders need to work as one team for IoT implementation in smart cities for appropriate waste management practices. This is an urgent need of the country as waste management is the biggest hurdle in the development path and this study is very useful for the policy-makers who are engaged in smart cities development and effective waste management system in India. This study lays a foundation for the government to consider the main hurdles in the effective waste management issue of the smart cities development. This work helps the government to reduce complexities in the IoT adoption of smart cities waste management by proposing implications for the government and policymakers.

7. Conclusion

Waste management of smart cities is considered to be the most important issue in developing countries over the past decades. The current research identifies and prioritizes barriers in SCWM in order to improve the sustainability in Indian context. A review of existing literature revealed fifteen IoTBs of smart cities' waste management. It is apparent from TISM and DEMATEL findings that no single adoption barrier would be able to drive SCWM effectively. This study combines TISM and DEMATEL and has incorporated fifteen adoption barriers that help in decision making towards waste management practices in smart cities' development. Smart City Legal and Ethical Issues (SCL&E) is the main category for the policy makers to consider for IoT implementation in SCWM. The findings from the MCDM methods confirm that Lack of regulatory norms, policies, and directions (IoT B12) as the most dominant driving barrier in waste management of smart cities, followed by Inadequate internet connectivity (IoT B8) and lack of

standardization (IoT B6). The emerging internet technologies have the potential to improve urban waste management practices. These technologies need to be supported by the government policies, norms, and directions as well as IT-enabled infrastructure which can drive the nation to achieve sustainable waste management in smart cities of India.

This study has significant theoretical as well as practical implications. The theoretical contribution is to develop a conceptual framework of existing IoT barriers in smart cities waste management implementation in India. Methodologically, the study is confined using only two MCDM techniques; thus, further studies need to research with mixed methods approach. Moreover, the results obtained from TISM and DEMATEL are absolutely specific and hence cannot be generalized to other contexts. From the practical perspective, this study explores significant barriers driving SCWM implementation; hence, effective actions from government and policymakers may tackle the challenges associated with IoT implementation and develop smart cities in India.

This study also helps to recognize the need of increasing concentration on IoT enabled waste management systems and empowering the skilled workforce for developing IoT infrastructure.

7.1. Limitations and direction for future research

This research has limitations too, which provides a platform for the undertaking of further theoretical and empirical research in this evolving area. First, in terms of the analysis, TISM results show the hierarchical structure of the adoption barriers, which maybe extended for analysis by other methods. IoT and smart city waste management are still in a nascent stage and more novel approaches to integrate them would be welcomed in internet technologies for urbanization planning. Further research should be focused to identify the effect of IoT adoption barriers on smart communities, smart healthcare, smart transportation, and other areas of a smart city.

Second, this study has identified a limited number of IoT adoption barriers. Smart cities waste management is a broad area, which can be broken into services, and it will be more effective for the stakeholders to implement it more appropriately. Third, this was a qualitative study. This conceptual framework of the study can be extended to empirical method to test the validity of the variables.

Author contribution statement

Equally contributed by all authors.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2020.122047>.

Appendix A

Journal	Number of publications	Authors
Journal of Cleaner Production	10	Kang et al. (2019); Das et al. (2019); Delgado et al. (2020); Valenzuela-Lei. (2019); Nizetić et al. (2019); Macke et al. (2019); Li et al. (2019); Adapa, S (2018); Alcayaga et al. (2019); Ferrari et al. (2020)
Waste Management	6	Deore et al. (2019); Sarc et al. (2019); Jagtap and Rahimifard. (2019); Esmailian et al. (2018); Shah et al. (2018)
Applied Sciences	4	Pasolini et al. (2019), Villa-Arrieta et al. (2019); Andrade et al. (2019); Espinoza-Arias (2019)
Energies	4	Farmanbar et al. (2019); Laso et al. (2019); Yenenti et al. (2019); Talari et al. (2017)
International Journal of Information Management	4	Israilidis et al. (2019); Yahia et al. (2019); Simonofski et al. (2019); Ismagilova et al. (2019)
Smart cities	4	Baltac (2019); Al Jaid Jim (2019); Tran Thi Hoang (2019); Muvuna et al. (2019)
Future Generation Computing system	3	Botta et al. (2016); Khan and Salah (2018); Reyna et al. (2018)
Sustainable cities and society	2	Bibri (2018); Silva et al. (2018)
International Research Journal of Multidisciplinary Technovation	2	Sowndharya and Savitha (2019); Keerthivasan et al. (2019)
Applied energy	2	O'Dwyer et al. (2019); Stoyanova and Monti. (2019)
Journal of urban technology	2	Caragliu (2011); Gaffney and Robertson (2018)
IEEE Consumer Electronics Magazine	2	Mohanty et al. (2016); Mehmood et al. (2017)
Asian Journal of Applied Science and Technology	1	Paulchamy et al. (2019)
Engineering and Science	1	Francis and Chichebe (2019))
Indian Journal of Public Health Research & Development	1	Keerthika and Pravalika (2018)
International Journal of Electronics and Telecommunications	1	Fataniya et al. (2019)
Internet of Things	1	Bruneo et al. (2019)
Journal of Advances in Shell Programming	1	Patel, H (2019)
Journal of Computer Networks and Communications	1	Zeb et al. (2019)
Journal of Technology Construct	1	Huang et al. (2019)
International Journal of Intelligent Systems and Applications	1	Atlam et al. (2018)
City, culture and society	1	Barns (2018)
Government Information Quarterly	1	Chatterjee et al. (2018)
Journal of Science and Technology Policy Management	1	Chatterjee and Kar (2018)
Computer Networks	1	Kunst et al. (2018)
Int. J. Current Trends Engineering Research	1	Lata and Singh (2016)
Ad Hoc Networks	1	Marques et al. (2019)
Computer Communications	1	Mineraud et al. (2016)
Information Systems Frontiers	1	Rana et al. (2018)
Wireless Personal Communications	1	Idwan et al. (2020)
International Journal of Interdisciplinary Telecommunications and Networking	1	Lokshina et al. (2017)
Measurement	1	Alavi et al. (2018)
IEEE Internet of Things Journal	1	Barbierato et al. (2018)
World Journal on Educational Technology: Current Issues	1	Umachandran et al. (2019)
Journal of Systems and Information Technology	1	Ani et al. (2019)
A research agenda	1	Kankanhalli et al. (2019)
Government Information Quarterly	1	Wirtz et al. (2019)

Appendix B

Selection and expertise of experts.

#	Interview code	Expertise	Round 1 (Validation of IoT barriers)	Round 2 (Interview)
1	Expert 1	SC	✓	✓
2	Expert 2	IoT	✓	✓
3	Expert 3	WM	✓	✓
4	Expert 4	WM	✓	✓
5	Expert 5	WM	✓	✓
6	Expert 6	IoT	✓	✓
7	Expert 7	SC	✓	✓
8	Expert 8	WM	✓	✓
9	Expert 9	SC	✓	✓

* SC= Smart city, WM=Waste Management, IoT = Internet of Things.

(Questionnaire)

Following the identification and validation of the IoT adoption barriers, we prepared a questionnaire that compared each barrier against another by asking the following questions for each pair.

Factor A influences Factor B (yes/no).

OR

Factor B influences Factor A (yes/no).

The questionnaire has been circulated among nine experts in the area of in IT domain and waste management and smart city projects. The 210 combinations were made (15X14). The following responses were generated.

Elements	Paired comparison of adoption barriers	Y/N
IoT1-IoTB2	Operational cost and extended payback period will influence Limited skilled workforce	N
IoT2-IoTB1	Limited skilled workforce will influence Operational cost and extended payback period	Y
IoT1-IoTB3	Operational cost and extended payback period will influence Security issues	N
IoT3-IoTB1	Security issues will influence Operational cost and extended payback period	Y
IoT1-IoTB4	Operational cost and extended payback period will influence lack of common Information system	N
IoT4-IoTB1	Lack of common Information system will influence Operational cost and extended payback period	Y
IoT1-IoTB5	Operational cost and extended payback period will influence Lack of IT infrastructure	N
IoT5-IoTB1	Lack of IT infrastructure will influence Operational cost and extended payback period	Y
IoT1-IoTB6	Operational cost and extended payback period will influence lack of standardization	N
IoT6-IoTB1	Lack of standardization will influence Operational cost and extended payback period	Y
IoT1-IoTB7	Operational cost and extended payback period will influence Lack of mobility	N
IoT7-IoTB1	Lack of mobility will influence Operational cost and extended payback period	Y
IoT1-IoTB8	Operational cost and extended payback period will influence Inadequate internet connectivity	N
IoT8-IoTB1	Inadequate internet connectivity will influence Operational cost and extended payback period	Y
IoT1-IoTB9	Operational cost and extended payback period will influence Privacy issues	N
IoT9-IoTB1	Privacy issues will influence Operational cost and extended payback period	N
IoT1-IoTB10	Operational cost and extended payback period will influence System failure issues	N
IoT10-IoTB1	System failure issues will influence Operational cost and extended payback period	N
IoT1-IoTB11	Operational cost and extended payback period will influence Lack of integration among IT networks	N
IoT11-IoTB1	Lack of integration among IT networks will influence Operational cost and extended payback period	N
IoT1-IoTB12	Operational cost and extended payback period will influence Lack of regulatory norms, policies and directions	N
IoT12-IoTB1	Lack of regulatory norms, policies and directions will influence Operational cost and extended payback period	Y
IoT1-IoTB3	Operational cost and extended payback period will influence Lack of transparency	N
IoT13-IoTB1	Lack of transparency will influence Operational cost and extended payback period	Y
IoT1-IoTB14	Operational cost and extended payback period will influence Poor data availability	N
IoT14-IoTB1	Poor data availability will influence Operational cost and extended payback period	Y
IoT1-IoTB15	Operational cost and extended payback period will influence Lack of technical knowledge among planners	N
IoT15-IoTB1	Lack of technical knowledge among planners will influence Operational cost and extended payback period	Y
IoT2-IoTB3	Limited skilled workforce will influence Security issues	N
IoT3-IoTB2	Security issues will influence Limited skilled workforce	N
IoT2-IoTB4	Limited skilled workforce will influence lack of common Information system	N
IoT4-IoTB2	Lack of common Information system will influence Operational cost and extended payback period	Y
IoT2-IoTB5	Limited skilled workforce will influence Lack of IT infrastructure	N
IoT5-IoTB2	Lack of IT infrastructure will influence Operational cost and extended payback period	N
IoT2-IoTB6	Limited skilled workforce will influence Lack of standardization	N
IoT6-IoTB2	Lack of standardization will influence Operational cost and extended payback period	Y
IoT2-IoTB7	Limited skilled workforce will influence Lack of mobility	N
IoT7-IoTB2	Lack of mobility will influence Operational cost and extended payback period	N
IoT2-IoTB8	Limited skilled workforce will influence Inadequate internet connectivity	N
IoT8-IoTB2	Inadequate internet connectivity will influence Operational cost and extended payback period	N
IoT2-IoTB9	Limited skilled workforce period will influence Privacy issues	Y
IoT9-IoTB2	Privacy issues will influence Limited skilled workforce	N
IoT2-IoTB10	Limited skilled workforce will influence System failure issues	Y
IoT10-IoTB2	System failure issues will influence Limited skilled workforce	N
IoT2-IoTB11	Limited skilled workforce will influence Lack of integration among IT networks	Y
IoT11-IoTB2	Lack of integration among IT networks will influence Limited skilled workforce	N

(continued)

Elements	Paired comparison of adoption barriers	Y/N
IoT2-IoTB12	Limited skilled workforce will influence Lack of regulatory norms, policies and directions	N
IoT12-IoTB2	Lack of regulatory norms, policies and directions will influence Limited skilled workforce	N
IoT2-IoTB13	Limited skilled workforce will influence Lack of transparency	Y
IoT13-IoTB2	Lack of transparency will influence Limited skilled workforce	N
IoT2-IoTB14	Limited skilled workforce will influence Poor data availability	N
IoT14-IoTB2	Poor data availability will influence Limited skilled workforce	Y
IoT2-IoTB15	Limited skilled workforce will influence Lack of technical knowledge among planners	N
IoT15-IoTB2	Lack of technical knowledge among planners will influence Limited skilled workforce	Y
IoT3-IoTB4	Limited skilled workforce will influence lack of common Information system	N
IoT4-IoTB3	Lack of common Information system will influence Security issues	Y
IoT3-IoTB5	Security issues will influence Lack of IT infrastructure	N
IoT5-IoTB3	Lack of IT infrastructure will influence Security issues	Y
IoT3-IoTB6	Security issues will influence Lack of standardization	N
IoT6-IoTB3	Lack of standardization will influence Security issues	Y
IoT3-IoTB7	Security issues will influence Lack of mobility	Y
IoT7-IoTB3	Lack of mobility will influence Security issues	N
IoT3-IoTB8	Security issues will influence Inadequate internet connectivity	N
IoT8-IoTB3	Inadequate internet connectivity will influence Security issues	Y
IoT3-IoTB9	Security issues will influence Privacy issues	N
IoT9-IoTB3	Privacy issues will influence Security issues	N
IoT3-IoTB10	Security issues will influence System failure issues	N
IoT10-IoTB3	System failure issues will influence Security issues	N
IoT3-IoTB11	Security issues will influence Lack of integration among IT networks	N
IoT11-IoTB3	Lack of integration among IT networks will influence Security issues	Y
IoT3-IoTB12	Security issues will influence Lack of regulatory norms, policies and directions	N
IoT12-IoTB3	Lack of regulatory norms, policies and directions will influence Security issues	N
IoT3-IoTB13	Security issues will influence Lack of transparency	N
IoT13-IoTB3	Lack of transparency will influence Security issues	N
IoT3-IoTB14	Security issues will influence Poor data availability	N
IoT14-IoTB3	Poor data availability will influence Security issues	Y
IoT3-IoTB15	Security issues will influence Lack of technical knowledge among planners	N
IoT15-IoTB3	Lack of technical knowledge among planners will influence Security issues	Y
IoT4-IoTB5	Lack of common Information system will influence Lack of IT infrastructure	N
IoT5-IoTB4	Lack of IT infrastructure will influence Lack of common Information system	Y
IoT4-IoTB6	Lack of common Information system will influence Lack of standardization	N
IoT6-IoTB4	Lack of standardization will influence Lack of common Information system	Y
IoT4-IoTB7	Lack of common Information system will influence Lack of mobility	Y
IoT7-IoTB4	Lack of mobility will influence Lack of common Information system	N
IoT4-IoTB8	Lack of common Information system will influence Inadequate internet connectivity	N
IoT8-IoTB4	Inadequate internet connectivity will influence Lack of common Information system	Y
IoT4-IoTB9	Lack of common Information system will influence Privacy issues	N
IoT9-IoTB4	Privacy issues will influence Lack of common Information system	Y
IoT4-IoTB10	Lack of common Information system will influence System failure issues	N
IoT10-IoTB4	System failure issues will influence Lack of common Information system	Y
IoT4-IoTB11	Lack of common Information system will influence Lack of integration among IT networks	N
IoT11-IoTB4	Lack of integration among IT networks will influence Lack of common Information system	Y
IoT4-IoTB12	Lack of common Information system will influence Lack of regulatory norms, policies and directions	N
IoT12-IoTB4	Lack of regulatory norms, policies and directions will influence Lack of common Information system	Y
IoT4-IoTB13	Lack of common Information system will influence Lack of transparency	Y
IoT13-IoTB4	Lack of transparency will influence Lack of common Information system	N
IoT4-IoTB14	Lack of common Information system will influence Poor data availability	Y
IoT14-IoTB4	Poor data availability will influence lack of common Information systems	N
IoT4-IoTB15	Lack of common Information system will influence Lack of technical knowledge among planners	Y
IoT15-IoTB4	Lack of technical knowledge among planners will influence Lack of common Information system	Y
IoT5-IoTB6	Lack of IT infrastructure will influence Lack of standardization	N
IoT6-IoTB5	Lack of standardization will influence Lack of IT infrastructure	Y
IoT5-IoTB7	Lack of IT infrastructure will influence Lack of mobility	Y
IoT7-IoTB5	Lack of mobility will influence Lack of IT infrastructure	N
IoT5-IoTB8	Lack of IT infrastructure will influence Inadequate internet connectivity	N
IoT8-IoTB5	Inadequate internet connectivity will influence Lack of IT infrastructure	Y
IoT5-IoTB9	Lack of IT infrastructure will influence Privacy issues	Y
IoT9-IoTB5	Privacy issues will influence Lack of IT infrastructure	N
IoT5-IoTB10	Lack of IT infrastructure will influence System failure issues	Y
IoT10-IoTB5	System failure issues will influence Lack of IT infrastructure	N
IoT5-IoTB11	Lack of IT infrastructure will influence Lack of integration among IT networks	Y
IoT11-IoTB5	Lack of integration among IT networks will influence Lack of IT infrastructure	N
IoT5-IoTB12	Lack of IT infrastructure will influence Lack of regulatory norms, policies and directions	N
IoT12-IoTB5	Lack of regulatory norms, policies and directions will influence Lack of IT infrastructure	Y
IoT5-IoTB13	Lack of IT infrastructure will influence Lack of transparency	Y
IoT13-IoTB5	Lack of transparency will influence Lack of IT infrastructure	N
IoT5-IoTB14	Lack of IT infrastructure will influence Poor data availability	N
IoT14-IoTB5	Poor data availability will influence Lack of IT infrastructure	Y
IoT5-IoTB15	Lack of IT infrastructure will influence Lack of technical knowledge among planners	N
IoT15-IoTB5	Lack of technical knowledge among planners will influence Lack of IT infrastructure	Y

(continued on next page)

(continued)

Elements	Paired comparison of adoption barriers	Y/N
IoT6-IoBT7	Lack of standardization will influence Lack of mobility	Y
IoT7-IoBT6	Lack of mobility will influence Lack of standardization	Y
IoT6-IoBT8	Lack of standardization will influence Inadequate internet connectivity	N
IoT8-IoBT6	Inadequate internet connectivity will influence Lack of standardization	Y
IoT6-IoBT9	Lack of standardization will influence Privacy issues	Y
IoT9-IoBT6	Privacy issues will influence Lack of standardization	N
IoT6-IoBT10	Lack of standardization will influence System failure issues	Y
IoT10-IoBT6	System failure issues will influence Lack of standardization	N
IoT6-IoBT11	Lack of standardization will influence Lack of integration among IT networks	Y
IoT11-IoBT6	Lack of integration among IT networks will influence Lack of standardization	N
IoT6-IoBT12	Lack of standardization will influence Lack of regulatory norms, policies and directions	N
IoT12-IoBT6	Lack of regulatory norms, policies and directions will influence Lack of standardization	Y
IoT6-IoBT13	Lack of standardization will influence Lack of transparency	Y
IoT13-IoBT6	Lack of transparency will influence Lack of standardization	N
IoT6-IoBT14	Lack of standardization will influence Poor data availability	N
IoT14-IoBT6	Poor data availability will influence Lack of standardization	Y
IoT6-IoBT15	Lack of standardization will influence Lack of technical knowledge among planners	N
IoT15-IoBT6	Lack of technical knowledge among planners will influence Lack of standardization	Y
IoT7-IoBT8	Lack of mobility will influence Inadequate internet connectivity	N
IoT8-IoBT7	Inadequate internet connectivity will influence Lack of mobility	Y
IoT7-IoBT9	Lack of mobility will influence Privacy issues	N
IoT9-IoBT7	Privacy issues will influence Lack of mobility	Y
IoT7-IoBT10	Lack of mobility will influence System failure issues	N
IoT10-IoBT7	System failure issues will influence Lack of mobility	Y
IoT7-IoBT11	Lack of mobility influence Lack of integration among IT networks	N
IoT11-IoBT7	Lack of integration among IT networks will influence lack of mobility	Y
IoT7-IoBT12	Lack of mobility will influence lack of regulatory norms, policies and directions	N
IoT12-IoBT7	Lack of regulatory norms, policies and directions will influence lack of mobility	Y
IoT7-IoBT13	Lack of mobility will influence lack of transparency	Y
IoT13-IoBT7	Lack of transparency will influence lack of mobility	N
IoT7-IoBT14	Lack of mobility influence Poor data availability	N
IoT14-IoBT7	Poor data availability will influence Lack of mobility	Y
IoT7-IoBT15	Lack of mobility will influence Lack of technical knowledge among planners	N
IoT15-IoBT7	Lack of technical knowledge among planners will influence Lack of mobility	Y
IoT8-IoBT9	Inadequate internet connectivity will influence Privacy issues	Y
IoT9-IoBT8	Privacy issues will influence Inadequate internet connectivity	N
IoT8-IoBT10	Inadequate internet connectivity will influence System failure issues	Y
IoT10-IoBT8	System failure issues will influence Inadequate internet connectivity	N
IoT8-IoBT11	Inadequate internet connectivity lack of integration among IT networks	Y
IoT11-IoBT8	Lack of integration among IT networks will influence inadequate internet connectivity	N
IoT8-IoBT12	Inadequate internet connectivity will influence lack of regulatory norms, policies and directions	Y
IoT12-IoBT8	Lack of regulatory norms, policies and directions will influence inadequate internet connectivity	N
IoT8-IoBT13	Inadequate internet connectivity will influence lack of transparency	Y
IoT13-IoBT8	Lack of transparency will influence inadequate internet connectivity	N
IoT8-IoBT14	Inadequate internet connectivity will influence poor data availability	N
IoT14-IoBT8	Poor data availability will influence inadequate internet connectivity	N
IoT8-IoBT15	Inadequate internet connectivity will influence lack of technical knowledge among planners	N
IoT15-IoBT8	Lack of technical knowledge among planners will influence inadequate internet connectivity	N
IoT9-IoBT10	Privacy issues will influence System failure issues	N
IoT10-IoBT9	System failure issues will influence privacy issues	Y
IoT9-IoBT11	Privacy issues lack of integration among IT networks	N
IoT11-IoBT9	Lack of integration among IT networks will influence privacy issues	Y
IoT9-IoBT12	Privacy issues will influence lack of regulatory norms, policies and directions	N
IoT12-IoBT9	Lack of regulatory norms, policies and directions will influence Privacy issues	Y
IoT9-IoBT13	Privacy issues will influence lack of transparency	N
IoT13-IoBT9	Lack of transparency will influence privacy issues	Y
IoT9-IoBT14	Privacy issues will influence poor data availability	N
IoT14-IoBT9	Poor data availability will influence privacy issues	Y
IoT9-IoBT15	Privacy issues will influence lack of technical knowledge among planners	N
IoT15-IoBT9	Lack of technical knowledge among planners will influence privacy issues	Y
IoT10-IoBT11	System failure issues will influence lack of integration among IT networks	Y
IoT11-IoBT10	Lack of integration among IT networks will influence system failure issues	N
IoT10-IoBT12	System failure issues will influence Lack of regulatory norms, policies and directions	N
IoT12-IoBT10	Lack of regulatory norms, policies and directions will influence system failure issues	Y
IoT10-IoBT13	System failure issues will influence lack of transparency	Y
IoT13-IoBT10	Lack of transparency will influence system failure issues	N
IoT10-IoBT14	System failure issues will influence poor data availability	N
IoT14-IoBT10	Poor data availability will influence system failure issues	N
IoT10-IoBT15	System failure issues will influence lack of technical knowledge among planners	N
IoT15-IoBT10	Lack of technical knowledge among planners will influence system failure issues	Y
IoT11-IoBT12	Lack of integration among IT networks will influence lack of regulatory norms, policies and directions	N
IoT12-IoBT11	Lack of regulatory norms, policies and directions will influence lack of integration among IT networks	Y
IoT11-IoBT13	Lack of integration among IT networks will influence lack of transparency	Y
IoT13-IoBT11	Lack of transparency will influence lack of integration among IT networks	N
IoT11-IoBT14	Lack of integration among IT networks will influence poor data availability	N

(continued)

Elements	Paired comparison of adoption barriers	Y/N
IoT14-IoBT11	Poor data availability will influence lack of integration among IT networks	Y
IoT11-IoBT15	Lack of integration among IT networks will influence lack of technical knowledge among planners	N
IoT15-IoBT11	Lack of technical knowledge among planners will influence lack of integration among IT networks	Y
IoT12-IoBT13	Lack of regulatory norms, policies and directions will influence lack of transparency	Y
IoT13-IoBT12	Lack of transparency will influence lack of regulatory norms, policies and directions	N
IoT12-IoBT14	Lack of regulatory norms, policies and directions will influence poor data availability	N
IoT14-IoBT12	Poor data availability will influence lack of regulatory norms, policies and directions	Y
IoT12-IoBT15	Lack of regulatory norms, policies and directions will influence lack of technical knowledge among planners	N
IoT15-IoBT12	Lack of technical knowledge among planners will influence lack of regulatory norms, policies and directions	Y
IoT13-IoBT14	Lack of transparency policies and directions will influence poor data availability	N
IoT14-IoBT13	Poor data availability will influence lack of transparency	Y
IoT13-IoBT15	Lack of transparency will influence lack of technical knowledge among planners	N
IoT15-IoBT13	Lack of technical knowledge among planners will influence lack of transparency	Y
IoT14-IoBT15	Poor data availability will influence lack of technical knowledge among planners	N
IoT15-IoBT14	Lack of technical knowledge among planners will influence poor data availability	Y

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