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New technology adoption in rural areas of emerging economies: The case of rainwater harvesting systems in India

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A R T I C L E I N F O

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A B S T R A C T

Technological advancements can accelerate the attainment of Sustainable Development Goals (SDGs). However, technology adoption is associated with complex, interrelated factors, even more so in the context of rural areas in emerging economies. We examine the adoption of one technology that can be crucial for resolving water scarcity issues facing countries around the world–the Rainwater Harvesting (RWH) technology and the critical success factors (CSFs) that promote its adoption in rural India. Building on an extensive literature review, focus group discussions, and field visits, this paper identifies a list of factors that promote its adoption. To derive the CSFs, the relevance of each factor is analysed using Fuzzy-Delphi, and the significance is determined using D-DEMATEL technique. The novel results presented here suggest that awareness about RWH technologies, their perceived usefulness, ease of use, and tax incentives for companies are some crucial factors that can increase RWH technology adoption. Furthermore, community-based workshops explaining the architecture and operational aspects of the RWH System as well as simplifying the RWH system architecture can accelerate its usage in rural areas. Based on these results, the paper presents a new roadmap for leveraging technology to attain SDGs in rural areas of developing countries.

1. Introduction

Sustainable Development Goals (SDGs) were formulated and agreed upon by the member states of the United Nations at the Rio + 20 conference (United Nations, 2012). Rigorous inter-governmental discussions at this conference lead to a 'text for adoption' referred to as 'Transforming our world: The 2030 agenda for sustainable development' (UN, 2015). A close observation of this 'text for adoption' reveals that the word 'technology' appears 36 times, significantly more than the occurrence of the words such as 'culture' and 'science,' indicating the explicit emphasis on technology as a catalyst for the attainment of SDGs. Technologies can boost the economic, environment, and societal benefits while accelerating the transformation for attaining SDGs (Palomares et al., 2021).

Globally, the research analysing the decision to adopt specific technologies is gaining traction across the multiple disciplines. For instance, Straub (2009) highlights the need to understand "why individuals choose and resist a technology?" Technology adoption studies usually consider adoption and diffusion theories such as Rogers theory, Concerns-Based Adoption Model (CBAM), Technology Acceptance Model (TAM), Universal Technology Adoption, and Use Theory (UTAUT) to explain technology adoption (Straub, 2009). These theories allow us to examine the individual choice to accept or reject a given technology. However, these models mainly focus on behavioural aspects and shed limited light other dimensions such as the regulatory environment (Darko et al., 2018), trust and security concerns (Gupta et al., 2008), educational qualification (Ejiaku, 2014), cultural differences (Escandon-Barbosa et al., 2021), and availability of technology infrastructure (Tortorella et al., 2020). For this reason, little is known about technology adoption in rural areas, and this poses a major challenge for policy making in emerging economies. As a consequence, striking differences mark the slow pace of SDGs attainment in rural areas (Nawab

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et al., 2022; Wang et al., 2020).

The present study focuses on SDG-6 – access to clean water and sanitation for all, a compelling goal due to significant levels of water stress around the world. The impact of water stress is high in rural settlements (Chen et al., 2016). Here, the involvement of multiple stakeholders makes technology adoption a complex problem necessitating the identification and analysis of factors that enable it. Extant studies have examined the water scarcity problem (Kingsborough et al., 2016; Nachshon et al., 2016) and the role of adopting Rainwater Harvesting (RWH) technology as a potential solution (Sheikh, 2020). Variants of this technology include Rooftop rainwater harvesting (RRWH), surface runoff collection, flood runoff harvesting, and in-situ RWH (Mati et al., 2006). Among these, the rooftop rainwater harvesting technique is commonly adopted at a domestic level by installing RWH systems (Abdulla and Al-Shareef, 2009). The underlying purpose of all these variants is to conserve water for a healthy ecosystem, socioeconomic development, and protection of human life (Mitrică et al., 2017).

RWH technologies have multiple economic (Rahman et al., 2012; Concha Larrauri et al., 2020), environmental (de Sá Silva et al., 2022), and societal benefits (de Sá Silva et al., 2022). Adopting RWH technologies can minimise the reliance on fresh water sources such as rivers, lakes and ground water (Moshfika et al., 2022). In this regard, RWH technology adoption aids in conserving water resources while minimising the detrimental effects caused by water stress. Diverting the rainwater falling on the roofs into a storage tank mitigates soil erosion as the runoff volume is controlled indirectly (Li et al., 2000). The stored sustainable source of water can be used for variety of applications such as household, landscaping, and irrigation depending on the quality of collected water (Helmreich and Horn, 2009).

Despite of the associated benefits with RWHS technology, its footprint is limited, particularly in areas such as rural India. Studies have rarely examined the Critical Success Factors (CSFs) that can help in the adoption of RWH technology in such contexts. The present study aims to bridge this gap in the literature by addressing the following research questions:

RQ1: What are the Critical Success Factors (CSFs) to promote the adoption of Rainwater Harvesting technologies in rural India?

RQ2. What are the interrelationships between the CSFs? What can be the strategy to promote the use of Rainwater Harvesting technologies in rural India?

The paper aims to identify the CSFs for adopting RWH systems in rural Indian context by addressing these questions. The initial focus group discussions involved local stake holders, scientific experts and policy makers. Following this, the survey with experts who have a minimum of 10 years' experience in implementing RWH technologies in rural India was conducted. The empirical results using Fuzzy DELPHI and D-DEMATEL highlight that eight CSFs need significant attention. These include awareness about RWHS, perceived usefulness, ease of use, tax incentives to companies, technology innovation, availability of skilled workforce, supportive regulations and guidelines, and subsidies. In the process, the study makes several contributions to the extant scholarship on rainwater harvesting (Varma et al., 2021; Ward et al., 2012) and leveraging technology to attain SDGs (Sinha et al., 2020, Abdulla et al., 2021. Chien et al., 2021. Saner et al., 2020) by offering novel insights on technology adoption in rural areas.

Firstly, to the best of our knowledge, this is the first paper that aims to identify and prioritise CSFs that impact the adoption of RWH technologies in rural areas of developing countries. The findings can serve as a reference for scholars to identify the thrust areas of research on RWH technologies. Secondly, the study aims to present a new roadmap that policymakers can use to promote the adoption of RWH technologies for resolving water scarcity problems. This roadmap helps decision makers in devising various strategies to promote RWH technologies at scale. Overall, the findings provide new insights into how technology adoption can be accelerated to attain SDGs. The rest of the paper is organised as follows. Section 2 presents an overview of water demand and concisely reviews the studies on RWH technologies. In Section 3, a summary of the identified factors is presented in a tabular format. The proposed methods to analyze the identified factors and derive the CSFs are discussed. Section 4 presents the empirical analysis and the results. Section 5 presents the discussion along with a roadmap to promote the adoption of RWH technologies. Section 6 concludes the paper and presents the limitations and future research scope.

2. Literature review

2.1. Water demand

Access to clean water is crucial for the attainment of sustainable development. In various places across the globe, the dependency on rainfall for water is increasing due to vanishing traditional wells and depleting groundwater levels. The quantity of water required to meet household, agricultural, and industrial demand is growing at an unprecedented rate and is expected to rise dramatically as the global population increases (Huang et al., 2021; Akuffobea-Essilfie et al., 2020). However, freshwater availability is limited, leading to the demand-supply gap in various parts of the globe (Kummu et al., 2016; McDonald et al., 2014). Global water demand is expected to rise by 55 %, making the naturally available water resources scarce (Haque et al., 2016). Furthermore, with the varying intensities of hydro-climatic extremities resulting from climate change, the severity of water scarcity is exponentially increasing (Van Vliet et al., 2021). Nearly half of the world's population may experience water scarcity by the end of 2030, and one-third of it is expected to face severe water stress for at least one month a year (Sheikh, 2020). Thus, the enormous demand shift and limited water resource availability are likely to pose colossal challenges globally.

Considering the future demand and the current scenario, a special emphasis on overcoming this crisis is given by formulating SDG6, which aims to “Ensure availability and sustainable management of water and sanitation for all.” The specific target is to attain equitable access to safe and affordable drinking water for all by the year 2030. Ground water exploitation, desalination of sea water, river linking projects, and reservoirs are the popular engineering and infrastructural solutions to overcome the water scarcity problem (He et al., 2021). However, these solutions are unavailable to all regions, and implementing these solutions in low and middle-income nations may not be economically viable (Larsen et al., 2016).

2.2. Rainwater harvesting (RWH) technologies

The concept of rainwater harvesting has been in practice for four thousand years (Lo and Gould, 2015). However, it gained renewed attention in view of water scarcity being faced by various urban and rural areas (Alim et al., 2020). RWH technologies adopted by a dwelling unit can augment or substitute existing water supply sources (Martinson and Thomas, 2007; Ward et al., 2012). Thus, they enable stakeholders to reduce their dependency on domestic water supplies (Alim et al., 2020). Adoption of such technologies is likely to have a positive impact on the livelihood of rural households (Smith et al., 2011), as they can be leveraged to enhance household food security, income level, and the sustainability of agriculture (Zingiro et al., 2014). Fig. 1 presents the geographical distribution of water stress levels across various nations (FAO, 2022).

It can be observed that Asian countries experience a relatively higher level of water stress compared to western countries. The severity is higher in the countries such as Algeria, Oman, United Arab Emirates, Egypt, Sudan, Libya, Saudi Arabia, Pakistan, Turkmenistan, and Uzbekistan (FAO, 2022). The quantity of water saved using RWH technologies is proportional to the amount of harvested water during the rainy season (Abdulla and Al-Shareef, 2009). The installed rainwater harvesting technologies across the globe can be classified into Centralized

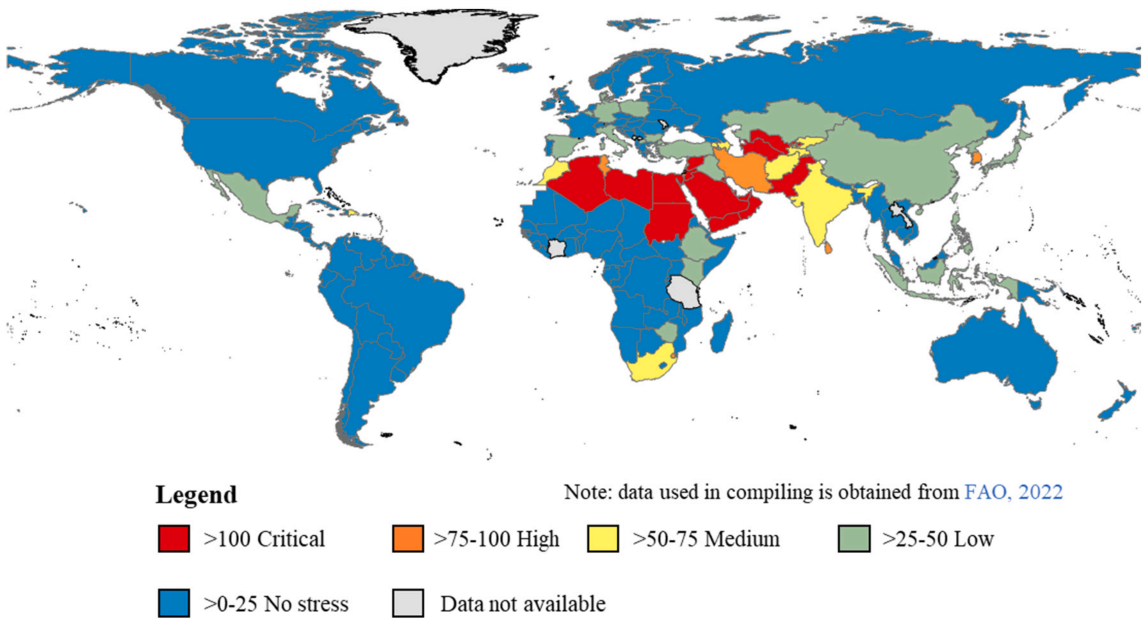

Fig. 1. Classification of countries based on level of water stress as per Food and Agricultural Organization of the United Nations.

Table 1
Incentives provided by various nations across the globe.

Country	Incentive and policy	Reference
Japan	Subsidies and low-interest loans are provided for the installation of the RWH technologies.	Furumai et al., 2008
Germany	Stormwater taxes are exempted for houses with RWH technologies.	Herrmann and Schmida, 2000
Australia	A rebate of nearly 500$ is provided to each household for the installation of RWH technologies.	Rahman et al., 2012
USA	Rebates and tax exemptions are provided for the household installing RWH technologies.	Domènech and Saurí, 2011
Taiwan	Introduced RWH technologies as a new water conservation technique and proposed guidelines.	Cheng et al., 2006
Uganda	Subsidies are provided for the materials required to construct an RWH technology.	Baguma and Loiskandl, 2010
Belgium	It is made mandatory for all buildings with rooftop areas >100 sq.m to have an installed RWH technology.	Domènech and Saurí, 2011
Brazil	A new initiative is taken up by the Ministry to install 1 million cisterns in the regions in the semi-arid category	Domènech and Saurí, 2011
Spain	Installation of RWH technologies is made mandatory for all buildings with a garden area.	Domènech and Saurí, 2011

Rainwater Harvesting (CRH) and De-centralized rainwater harvesting (DRH) technologies (Amos et al., 2018; Bashar et al., 2018).

In the case of CRH, a common storage tank is constructed for a group of dwelling units, while separate collection barrels are used in the case of DRH. Although CRH has the potential to meet a significant part of the water demand, the associated costs have made DRH technologies more popular (Gonela et al., 2020).

Water derived using both these technologies is typically free from contaminants and salinity. Moreover, the physio-chemical and bacteriological characteristics of the harvested water are usually within potable water standards (Biswas and Mandal, 2014). In the Mekong Delta of Vietnam, water harvested using RWH technologies is utilized for drinking and cooking in rural households due to various benefits arising from its smell, colour, taste, and reliability, especially in the rainy seasons (Özdemir et al., 2011). Rainwater is even directly consumed for drinking in rural areas of Australia (Van Der Sterren et al., 2013). In contrast, rainwater with large impurities is observed in various places in Australia (Eroksuz and Rahman, 2010). Collecting surfaces may induce contaminants if not maintained properly, which can consequently impact the quality of harvested water (Chidamba and Korsten, 2015).

The economic benefits are more pronounced in the areas where the water tariff is high (Farreny et al., 2011). The installed RWH systems, besides providing water security, can also aid in reducing the risk of floods (Kim and Yoo, 2009). Installation of these technologies on a large scale can delay the need to construct new infrastructure for water storage by reducing the demand for water supply (Coombes et al., 2002). As rainwater is pure, using it for domestic purposes reduces health-related risks (Baguma and Loiskandl, 2010). Utilising these technologies can help reduce peak water demand. For example, it is estimated that the installation of RWH technology in Melbourne has the potential to reduce the size of the water supply network by 18 % and bring down the operating cost by 53 % (Coombes, 2007). In view of these benefits, RWH technologies are adopted in several countries, including Bangladesh, Bermuda, Botswana, Brazil, Cambodia, Japan, Kenya, Thailand, China, and Taiwan (Lo and Gould, 2015). To promote the use of RWH technologies, various countries introduced incentives and policies, as summarized in Table.1.

In recent times, India has taken several policy initiatives to promote water harvesting. Atal Mission for Rejuvenation and Urban Transformation (AMRUT), launched in year 2015, aims to promote rainwater harvesting systems as one of the pivotal solutions to water scarcity (TCPO, 2023). Similarly, Jal Shakti Abhiyan, an initiative that commenced in 2019, promotes the construction of rainwater harvesting systems (JSACTR, 2023). In line with these initiatives, the National Water Policy 2021 was propagated to the State Governments to create state-level implementation plans to promote the implementation of rainwater harvesting systems (NWP, 2012). However, the requisite byelaws and policies are formalised by only a few states. In some cases, the byelaws are confined to few buildings as they make it mandatory only for buildings with rooftop area above 300 m^2. This threshold is substantially high for rural dwellings (TCPO, 2023) precluding their inclusion within the remit of these byelaws. Thus, an extensive investigation of various parameters that can promote the wider adoption of RWH systems can aid in formulating and refining current policy

Table 2
List of factors to promote the adoption of Rainwater Harvesting (RWHs) technologies.

Category	Factors	Description	Reference
Financial	Subsidy	Provision of financial incentives in the form of monetary support and loans help to relax the financial burden.	Woltersdorf et al., 2014
	Tax incentives to companies	A taxation policy by the state or central government authorities to propel industrial participation to manufacture the components of RWH systems.	Gonela et al., 2020
Institutional	Regulation and guidelines	A set of rules that are made in addition to the existing laws are applicable to residential units to enforce adopting RWH technologies.	Campisano et al., 2017
	Availability of skilled workforce	Installation of RWH systems requires special skills. This factor refers to the existence of skilled personnel.	Andersen, 2014
Behavioural	Image	It refers to the degree to which an individual feels adopting this technology enhances his social status.	Assayed et al., 2013
	Perceived behavioural control	It demonstrates the behavioural ease of the person in adopting the RWH system.	Marcos et al., 2021
	Perceived ease of use	It signifies the degree to which an individual believes using the RWH technologies would involve no effort.	Liu et al., 2022
	Intention to use	It refers to the subjective probability of an individual explaining if they perform a specific task or demonstrate specific behaviour.	Aliabadi et al., 2020
	Awareness about RWH	Subjective knowledge about the benefits of adopting RWH technology.	Jones and Hunt, 2010
	Subjective norms	It is a belief that an individual decision depends on the important people.	Shanmugavel and Rajendran, 2022
	Attitude towards RWH	The degree to which an individual has a favourable or unfavourable evaluation of behaviour of interest in adopting RWH technologies.	Baguma and Loiskandl, 2010
	Environmental responsibility	It infers an individual behaviour to promote sustainable use of natural resources.	Acosta García et al., 2022
	Personal moral norms	It refers to the internalised feelings of an individual towards adopting the RWH technology as a personal obligation.	Shanmugavel and Rajendran, 2022
	Perceived usefulness	It refers to the extent to which an individual believes that using this RWH technology would enhance access to water resources.	Liu et al., 2022
	Social Trust	It is a belief that people should have a positive outlook towards the quality of the water harvested using RWH technology.	Balaei et al., 2019
Technological	Technology innovation	A wide range of R&D activities to create innovative designs of RWH and technologies that can monitor the quality of collected water is the need of the hour.	Xu et al., 2018
	Ease of installation	It refers to the ease with which the RWH technology can be installed.	Villarreal and Dixon, 2005

initiatives.

Although RWH technologies can enable water conservation, several factors inhibit their adoption. For instance, people do not trust the quality of harvested water resulting in the usage being limited to cleaning and washing purposes (Leidl et al., 2010). Often due to poor operating conditions, the harvested water quality is below par which is one of the major setbacks for its widespread adoption (Fortier, 2010). Developing an in-situ technology that can monitor the harvested water quality on a real-time basis with no human intervention can help behavioural change in the users (Verma et al., 2020). As a further consideration, regulations, instead of promoting the use of RWH technologies, end up as a challenge (Parsons et al., 2010) when they do not permit the setting up of pilot projects that can create a positive outlook. As RWH has yet to become popular, the lack of a skilled workforce for installation, maintenance, and service creates further roadblocks to its adoption (Fortier, 2010). The lack of one-stop shops that can provide all the essential components required to set up the RWH technology is also a vital challenge in many regions, especially rural areas (Akuffobea-Essilfie et al., 2020). Since various architectures of RWH technology exist, a lack of awareness about various existing regulatory devices impairs adoption of RWH technology (Leidl et al., 2010).

Workshop and training sessions on the significance and installation of RWH technology can help to create a positive outlook. RWH technologies, being de-centralized, make the household responsible for carrying out operation and maintenance work (Domènech et al., 2012). The provision of tax incentives to the manufacturing industries of RWH technologies helps new stakeholders to emerge in this area which can consequently improve the availability of the components (Fewkes, 2012). Creating awareness among the people using community-based workshops can improve the adoption of RWH technologies, which can consequently help to reduce installation costs through scale economies (Akuffobea-Essilfie et al., 2020). Subsidy and soft loans to residents can boost the installation of RWH technology (Woltersdorf et al., 2014). Promoting the communication and coordination between the stakeholders involved in harnessing rainwater using RWH technologies could help to promote the adoption of this technology for wide utilization (Akuffobea-Essilfie et al., 2020).

Focusing on behavioural aspects while addressing the technical and administrative levers is also imperative. Individuals' behaviour towards adopting sustainable water resource management practices is also one of the key factors for the wide acceptance of RWH technology (Aliabadi et al., 2020). The attitude of people is identified to be a key determinant governing individuals' choice to adopt RWH technology (Akuffobea-Essilfie et al., 2020). Apart from attitude, moral norms also influence the intention of community residents to adopt RWH technology (Shanmugavel and Rajendran, 2022). Adopting this RWH technology can be encouraged by conducting activities affecting the resident's self-identity (Aliabadi et al., 2020). Perceived usefulness which can be reinforced by highlighting the advantages of RWH technology, is also found to be one of the determinants that can impact its adoption (Liu et al., 2022). A description of each factor influencing the adoption of RWH technologies is provided in Table.2.

Thus, this section reviews past research work emphasizing the impediments to adopting RWH technologies to identify various factors that can promote adoptability. In addition to the research articles, reports published by various government (CPCB, 2016; CPWD, 2002) and non-governmental (IEP, 2023) organizations are reviewed, resulting in a total of 17 factors that are grouped under financial, institutional, technological, and behavioural categories are identified.

Several countries have developed policies to encourage the implementation of RWH technologies. However, multiple financial, technical, institutional, and behavioural factors have inhibited the wide use of RWH technologies. The relevance and significance of these factors also tend to be region specific. Therefore, identifying Critical Success Factors (CSFs) specific to rural areas helps understand the prominence of each CSF which the policymakers can subsequently use to design strategies that aid in adopting RWH technologies. This can provide a new roadmap that can facilitate federal government agencies to promote the adoption of rainwater harvesting technologies.

3. Methodology

This study presents a framework to identify the critical success factors (CSFs) that can promote the adoption of RWH technologies. Fig. 2 presents the steps involved in the proposed framework.

As the flowchart in Fig. 2 suggests, the analysis starts with an extensive literature review. This is followed by a focus group discussion and a field visit that eventually help to identify the wide range of factors that can promote the adoption of RWH technologies. Since the factors identified are based on literature from the global context, the relevance of identified factors in the context of rural India is first analysed using the Fuzzy Delphi technique.

Later, the list of identified relevant factors is floated among the expert panel members to collect their perceptions on the interrelationships between the factors. These obtained responses are used to identify the CSFs.

There is an interrelation between the identified CSFs listed in Table 2. In this scenario, planning developmental activities to attain each of the identified CSF can be resource intensive. Since change in some of the CSFs can influence other CSFs, classifying the CSFs into cause-and-effect variables helps in devising strategies. Multi-criteria techniques such as Analytical Hierarchy Process (AHP) (Saaty, 2004), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Roszkowska, 2011), ELECTREE (Figueira et al., 2016), Shannon Entropy (Yazdani et al., 2020), and Analytical Network Process (ANP) (Saaty et al., 2013) can only be used to determine the significance of each variable which is CSFs in the context of current study. Since DEMATEL is the only technique that can categorize the CSFs into cause-and-effect variables, it is adopted here. The concept of D-Number theory is integrated with the DEMATEL technique in this study to handle the uncertainty associated with the responses received from decision makers. The collected responses are fused to account for the fuzziness associated with each assessment. The fused responses are further analysed using the DEMATEL technique. A detailed insight into Focus group discussion, Fuzzy Delphi, D-number theory, and DEMATEL technique extended using D-number theory is provided in the sub-sections below.

3.1. Focus group discussion

The technique of purposive sampling has been adopted in this study to select the focus group participants. In view of the study by Churchill Jr and Iacobucci (2002), Greenbaum (2000) and Fern (2001), smaller focus group size is considered in this study. The use of smaller groups ensures maximum input by all the experts by giving them equal opportunities for participation. The prepared set of questions to conduct focus group discussions are shown in Appendix-IA. The moderator prepared a discussion guide and informed each group in the same manner about the nature of the focus group, and the same questions were addressed in each focus group discussion.

3.2. Fuzzy Delphi technique

The relevance of each identified factor from the literature review is analysed using Fuzzy Delphi Technique. The identified list of factors is tabulated and floated among the experts. Each expert is asked to determine the relevance of factors using linguistic scale shown in Fig. 3.[1] Considering a fuzzy score of each linguistic judgment as shown in Fig. 3, the obtained linguistic judgments are translated into fuzzy numbers.

Say, S_{ij} is the fuzzy score corresponding to the linguistic scale given for a f^{th} factor by e^{th} expert of 'n' experts. Then the score can be represented using Eq. 1 (Puppala et al., 2022).

$$E_{ef} = (p_{fe}, q_{fe}, r_{fe}) \tag{1}$$

[1] Appendix-II presents the questionnaire shared among the experts.

for f = 1,2, 3, …. m and e = 1,2,3, ….. n.

The overall fuzzy weight of the f^{th} factor considering the scores given by all the 'n' experts can be computed using Eq.2.

$$E_f^{Overall} = \left[min(p_{fe}), \ \left(\prod_{e=1}^{n} q_{fe}\right)^{1/n}, \ max(r_{fe}) \right] \text{ where } f = 1,2,3..m; e = 1,2,..n \tag{2}$$

The defuzzified weight of each barrier is computed using the mean method as shown in Eq.3.

$$E_b^{df} = \left[\frac{min(p_{fe}) + \left(\prod_{e=1}^{n} q_{fe}\right)^{1/n} + max(r_{fe})}{3} \right] \text{ where } b = 1,2,3\ldots m; e = 1,2,3..n \tag{3}$$

Finally, the threshold value of the defuzzified score is set, and the barrier category and elements within each type are finalized for the second phase of analysis.

3.3. D-number theory

This theory is a generalization of evidence theory with a wide range of applications, especially in problems involving linguistic assessments (Deng et al., 2014). Capturing the perception of experts on a real-life problem using a crisp scale is challenging as it varies with the individual and is often impaired due to limited knowledge (Ning et al., 2016). Fusion of captured responses and aggregating them is also another challenge. Though evidence theory is proven to be an effective approach to dealing with linguistic responses, deriving conclusions using linguistic judgments is not credible as they are not exclusive to each decision-maker (Jiang et al., 2015). Adopting the mathematical framework of D-number theory helps to overcome the aforementioned problem (Deng et al., 2014). The benefits of using D-number theory in capturing the responses from the experts are discussed below.

3.3.1. Benefits of D-number theory over Dempster-Shafer evidence theory

The strong hypothesis of evidence theory, i.e., elements within the same frame of discernment, should be mutually exclusive, which would not be a barrier when D-number theory is adopted. This benefit aids in translating the expert's opinion and aggregating the obtained responses precisely when dealing with linguistic measurements. Fig. 4(a) and Fig. 4(b) explicitly presents the advantage of the D-number theory over the Dempster-Shafer evidence technique for better understanding.

The judgment scale shown in Fig. 4(a) and Fig. 4(b) is a linguistic scale providing flexibility to the decision maker to rate the perception using a five-point scale including Very poor, Poor, Fair, Good, and Excellent. As per the Dempster-Shafer theory, the judgment scale is mutually exclusive, which is not realistic as the perception of each scale varies with the expert.

As mentioned earlier, this problem can be overcome using D-number theory which is evident from the overlap highlighted in Fig. 4(b), indicating the fuzziness between different judgments. D-number theory also allows the judgments associated with incompleteness which is not possible when Dempster-Shafer evidence theory is adopted, where the sum of the focal elements in each assessment should be equal to 1. Owing to this, D-number theory is a reliable technique to evaluate the factors covering financial, technological, institutional, and behavioural categories. To ensure the completeness of the discussion on D-number theory, a few of the basic concepts are presented below.

3.3.2. Representation of D-number theory

Let Ψ is a problem domain and is represented by $\Psi = \{\beta_1, \beta_2, \beta_3 \ldots\ldots\ldots \beta_i, \ldots\ldots\ldots \beta_1\}$ where, $b_i \in R$ and $b_i \neq b_j$ if i$\neq$ j, a special

Fig. 2. Schematic illustration of the steps involved in evaluating the CSFs.

form of D number can be represented as.

$$D(\{\beta_1\}) = \gamma_1$$
$$D(\{\beta_2\}) = \gamma_2$$
$$\vdots$$
$$D(\{\beta_n\}) = \gamma_n$$

The simple representation of D number is as follows

$$D = \{(\beta_1, \gamma_1), (\beta_2, \gamma_2) \dots\dots\dots\dots (\beta_i, \gamma_i), \dots\dots\dots\dots (\beta_n, \gamma_n)\}$$

where $\gamma_i > 0$, and $\sum_{i=1}^{n} \gamma_i \leq 1$.

3.3.3. *Combination rule of D-numbers*

Let D1 and D2 are two D-numbers obtained from two different experts and say

$$D1 = \{(\beta_1^1, \gamma_1^1), (\beta_2^1, \gamma_2^1) \dots\dots\dots\dots\dots\dots (\beta_i^1, \gamma_i^1) \dots\dots\dots\dots (\beta_n^1, \gamma_n^1)\}$$

$$D2 = \left\{(\beta_1^2, \gamma_1^2), (\beta_2^2, \gamma_2^2) \dots\dots\dots\dots\dots\dots \left(\beta_j^2, \gamma_j^2\right) \dots\dots\dots\dots (\beta_m^2, \gamma_m^2)\right\}$$

The combination of D1 and D2, is indicated using $D = D1 \oplus D2$ and is shown in Eq. 4–6.

$$D(\beta) = \gamma$$

$$\beta = \frac{\beta_i^1 + \beta_j^2}{2} \tag{4}$$

$$\gamma = \frac{\frac{\gamma_i^1 + \gamma_j^2}{2}}{C} \tag{5}$$

$$C = \begin{cases} \sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{\gamma_i^1+\gamma_j^2}{2}\right) & \sum_{i=1}^{n}\gamma_i^1 = 1 \text{ and } \sum_{j=1}^{m}\gamma_j^2 = 1 \\ \sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{\gamma_i^1+\gamma_j^2}{2}\right) + \sum_{j=1}^{m}\left(\frac{\gamma_c^1+\gamma_j^2}{2}\right); & \sum_{i=1}^{n}\gamma_i^1 < 1 \text{ and } \sum_{j=1}^{m}\gamma_j^2 = 1 \\ \sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{\gamma_i^1+\gamma_j^2}{2}\right) + \sum_{i=1}^{n}\left(\frac{\gamma_i^1+\gamma_c^2}{2}\right); & \sum_{i=1}^{n}\gamma_i^1 = 1 \text{ and } \sum_{j=1}^{m}\gamma_j^2 < 1 \\ \sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{\gamma_i^1+\gamma_j^2}{2}\right) + \sum_{j=1}^{m}\left(\frac{\gamma_c^1+\gamma_j^2}{2}\right) + \sum_{j=1}^{m}\left(\frac{\gamma_i^1+\gamma_c^2}{2}\right); & \sum_{i=1}^{n}\gamma_i^1 = 1 \& \sum_{j=1}^{m}\gamma_j^2 < 1 \end{cases} \quad (6)$$

where, $\gamma_c^1 = 1 - \sum_{i=1}^{n}\gamma_i^2 \text{ and } \gamma_c^2 = 1 - \sum_{j=1}^{m}\gamma_j^2$

3.3.4. Integration of D number

Let the D number obtained after the combination be as follows

$D = \{(\beta_1^c, \gamma_1^c), (\beta_2^c, \gamma_2^c) \ldots\ldots\ldots\ldots\ldots\ldots (\beta_i^c, \gamma_i^c) \ldots\ldots\ldots\ldots (\beta_n^c, \gamma_n^c)\}$

Then the integration of the D number into a crisp number can be mathematically obtained using Eq.7 (Zhou et al., 2017).

$$I(D) = \sum_{i=1}^{n}\beta_i\gamma_i \quad (7)$$

The results obtained using Eq.7 will eventually be used in analysing using DEMATEL technique.

3.4. DEMATEL technique

DEMATEL technique is developed by Battelle Memorial Institute of Geneva Research Centre (Gabus and Fontela, 1972). This technique is built on graph theory and aims at analysing the interrelation between the elements within the system. These findings aid the decision-maker in categorizing the elements into cause-and-effect groups and to construct a map showing the interrelationship between the factors. From past research works, it is apparent that this technique is widely used in various disciplines of engineering and management (Si et al., 2018). Specifically, it includes Hospitality (Shieh et al., 2010), Operation management (Chang et al., 2011), Safety science (Yazdi et al., 2020), Customer choice analysis (Chen-Yi et al., 2007), and Supply chain (Govindan et al., 2015).

The steps involved in DEMATEL techniques are eluded below

(i) Construction of indirect relation matrix

In the conventional DEMATEL technique, the interrelation between

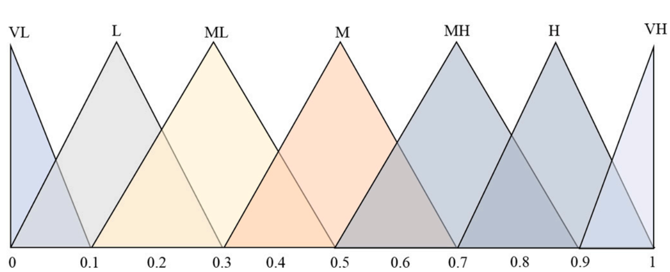

Fig. 3. Linguistic scale adopted to determine the relevance of each identified factor.

the considered parameters is collected using a Likert scale containing four levels which typically ranges between 0 and 3. A score of 0 indicates that there exist no relation and a score of 1 refers to low impact, 2 and 3 indicates moderate and high impact respectively. Unlike the conventional method, if D-number theory is integrated, the responses are collected in the form of D-number as discussed in Section 3.1.

(ii) Computation of normalized direct relation matrix

Say, if the system contains 'k' elements, the normalized matrix N corresponding to a direct relation matrix $D = [d_{ij}]_{k\times k}$ where i, j ∈ 1, 2, …, k can be represented using Eq.8.

$$N = \frac{D}{max\left(\sum_{j=1}^{n} d_{ij}, \sum_{i=1}^{n} d_{ij}\right)} \quad (8)$$

(iii) Construction of total relation matrix

Say, if the system contains 'k' elements, the total relation matrix N corresponding to a direct relation matrix $D = [d_{ij}]_{k\times k}$ where i, j ∈ 1,2…, k

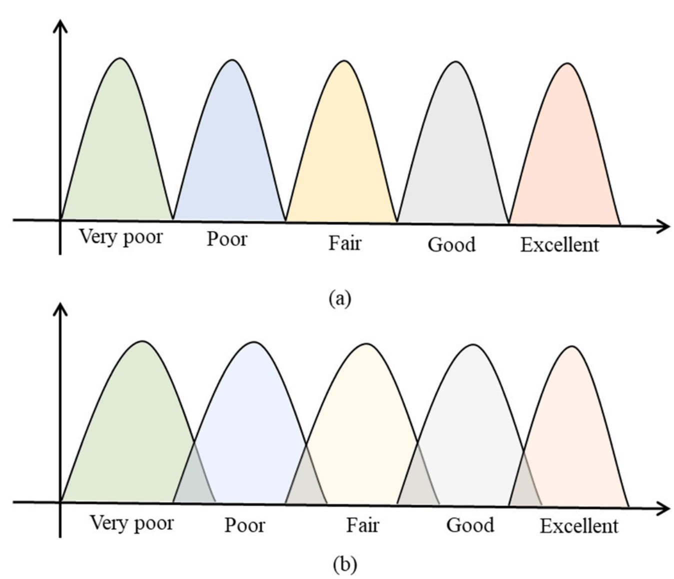

Fig. 4. Judgment scale as per different theories (a) Dempster-Shafer evidence (b) D-number.

Table 3
Demographic profile of the participants in focus group discussion.

Focus group	Participants*	Gender, Age	Highest educational qualification	Affiliated to	Experience
	P1	Male, 45	MBA	Private Sector	9
	P2	Female. 36	M.Sc	NGO	4
F1	P3	Male, 45	PhD	Academia	11
	P4	Male, 39	PhD	NGO	13
	P5	Female, 42	B·Sc	Private Sector	7
	P1	Female, 47	PhD	Academia	12
	P2	Male, 43	BSc	NGO	6
F2	P3	Male, 35	MSc	Academia	7
	P4	Male, 40	MBA	NGO	11
	P5	Female, 49	PhD	Private Sector	13
	P1	Male, 50	M.Sc	Private Sector	18
	P2	Female, 37	B.Tech	NGO	5
F3	P3	Male, 33	PhD	Academia	5
	P4	Male, 46	B·Sc	NGO	9
	P5	Female, 35	Scholar	Academia	4
	P1	Male, 49	B.Tech	NGO	15
	P2	Female, 43	B·Sc	NGO	12
F4	P3	Male, 38	PhD	Academia	3
	P4	Male, 46	M.Tech	NGO	12
	P5	Female, 50	PhD	Private Sector	11
	P1	Male, 37	M.E	Private Sector	9
	P2	Female, 39	PhD	NGO	6
F5	P3	Male, 41	PhD	Academia	13
	P4	Male, 47	MBA	NGO	11
	P5	Male, 36	PhD	Private Sector	8

* All the participants are Indian nationals.

can be represented using Eq.9.

$$T = \lim_{k\to\infty}\left(N + N^2 + \cdots + N^k\right) = N(I-N)^{-1} \quad (9)$$

where, I is the identity matrix of order k

(iv) Determining the nature of variable

The cause-and-effect relationship between the variables within the system is examined using the sum of all the rows and columns of the total-relation matrix obtained using Eq.10 and Eq.11. τ infers the effect of ith factor on the jth factor while ϕ represents the effect of jth factor on ith factor.

$$\tau = \left\{\sum_{j=1}^{n} t_{ij}\right\}_{n\times 1} \quad (10)$$

$$\phi = \left\{\sum_{i=1}^{n} t_{ij}\right\}_{n\times 1} \quad (11)$$

The significance of each indicator is examined using (τ + ϕ) while the effect of the variable can be examined using (τ - ϕ). A negative value of (τ - ϕ) regards the parameter is an effect variable while a positive value of (τ - ϕ) regards the parameter as a casual variable.

4. Analysis and results

4.1. Focus group discussion

The origin of experts participated in this study is from India where access to clean drinking water has been a challenge in rural areas. This problem has persisted despite of introducing various initiatives such as National Rural Drinking Water Programme. People living in rural communities travel long distances to collect water. In this context, there is an imminent need to tackle this pressing problem using technology-enabled interventions. Rural communities of India have witnessed a rapid increase in technology adoption, particularly those related to digital technologies, in the recent years. Similarly, adopting technologies to tackle the problem of access to clean water can significantly transform lives in rural areas.

A visit was made to an NGOs in India working on issues of water scarcity, groundwater depletion, flooding and stagnation by collaborating with corporates, civil society and research organizations. Apart from the NGOs, visits were made to the research teams in universities, working on a rainwater harvesting. One of the research teams interacted has been working on a project funded by the World Bank. The research team has installed rainwater harvesting systems in numerous villages of Rajasthan, India. These visits, complemented with the in-house contacts helped to identify 43 potential candidates who have prior experience in design, installation and implementation of rainwater harvesting systems. Preliminary e-mails and telephonic calls were made to the identified potential candidates in September 2022. After taking the consent, the possible time slots in October and November were identified using Calendly, an open access online appointment scheduling software. From the responses (n = 31), a common time slot was identified, and five different focus groups were formed based on the availability and experience. This led to 25 participants who were available at that time slot. The focus groups contained participants ranging in the age group of 35–50, with females (36 %) and males (64 %), with an average work experience of nearly 10 years in design and setup of rainwater harvesting system. Table. 3 presents the demographic profile of the participants corresponding to each focus group.

The second e-mail communication was sent to all the selected participants, sharing with them the final agenda of the discussion, and a formal invitation to block their calendars. On the scheduled day, focus group discussions were held virtually. The prepared set of questions, shown in Appendix-IB, were used for the discussion. The moderator prepared a discussion guide and informed each group in the same manner about the nature of the focus group, and the same questions were addressed in each focus group discussion. Flexibility was provided so that additional thoughts/views could be shared during the discussion. The average time taken to conduct each focus group discussion was nearly 45 min. Each focus group commenced with a discussion on the topic “what are the factors that can promote the adoption of rainwater harvesting technologies in Rural India?”. This was followed by asking questions about their thoughts about the role of government in promoting RWH technologies. The moderator used virtual collaborator whiteboards for data collection. The discussions were audio-taped to generate transcripts and the whiteboard summaries were photographed which were later converted into text using natural language processing tool bars. Later, the generated text was analyzed using the keywords-in-context method, as suggested by Creswell (2009). This activity resulted in a list of 42 sub-factors. These factors were examined to remove duplicates and overlap. In case of overlap, the items were refined, 17 such factors were removed resulting in a finalized list of 25 sub-factors which are shown in Fig. 5. The outcomes of the literature review and the focus group discussions complement each other.

4.2. A field visit to capture ground reality

Efforts were made to verify if the outcomes of focus group discussions translated the ground reality by conducting a field visit in a rural area in Haryana. A field visit was conducted in Bastapur (Ref. Fig. 6), Haryana, where access to pure drinking water is a concern throughout the year. A team comprising researchers and students was given the necessary training and deployed to interact with the villagers and understand their awareness of water stress, water conservation, and rainwater harvesting technologies. The participants of the survey comprised both genders with an age group between 25 and 50 years. The initial discussion was interaction based. Here, the research team tried to get maximum information from participants and requested them to share their experiences. The research team conducted an ice-breaking session that was found effective in a similar field visit conducted by Varma et al. (2021) to make the participants feel comfortable. Consequently, participants showed a keen interest in sharing their thoughts on the perception of RWH technologies.

A brainstorming session was then conducted with multiple groups (each group with size $n < 5$) where the prime emphasis was given to understanding the awareness level of participants about rainwater harvesting technologies. Findings suggest that the understanding level of villagers on rainwater harvesting technologies is minimal. Considering this, to take the discussion forward, a short documentary in a local language was screened as shown in Fig. 6, to explain the importance of RWH. This was followed by a brief presentation in a local language to explain the architecture of RWH technologies. This activity ensured to create awareness on RWH technologies among the rural residents of Bastpur.

As a final phase of the survey, a set of questions with the primary question as "what does it take to adopt this technology" was posed to all the participants, and their responses were noted. Appendix-IB presents the rest of the questions that were asked. The team later analysed all the obtained responses to identify the prime concerns raised by the villagers. The findings derived from the survey suggest that the concerns raised can be mapped to the identified broad factors identified from literature as shown in Table.2. The entire exercise affirmed that the outcomes of the focus group discussions reflected the ground realities.

4.3. Finalization of factors

The list of factors identified using focus group discussions are brought together along with the factors identified in the literature review to develop a list of finalized factors to be considered for the empirical analysis. The factors identified through the focus group discussions were referred to as sub-factors which can be mapped to the broad category of each identified factor derived from the literature review. The mapping of sub-factors to each of the factor is shown in Fig. 7. The nature of the factors identified using focus group discussions is a sub-part of the major factors obtained from the extensive literature review. The factors are further categorized into financial, institutional, technological, and behavioural factors to gain a deeper insight, as shown in Fig. 7.

4.4. Results from empirical evaluation of finalized factors

This section presents the critical success factors identified using the proposed empirical framework. The list of initially identified factors, as shown in Table.2**,** is shared with the expert panel, and their perception[2] on the relevance of each factor is collected using a questionnaire as shown in Table B2 of Appendix-II. The obtained linguistic judgments are later translated into Fuzzy number, and the obtained responses from all the experts are then aggregated using Eq.2. Table.4 presents the defuzzified score of each factor computed using Eq.3. A threshold values of 0.6 as suggested by Puppala et al. (2022) is used select the relevant factors and eliminate the non-appropriate list of factors. Factors with threshold value of above 0.6 are chosen for further analysis. Table.4 suggests that subjective norms, attitude towards RWHS, environmental responsibility, personal moral norms, social trust, and social image are not relevant in the context of rural India.

Although the Fuzzy Delphi technique eliminated these factors as irrelevant (7 out of 17), the significance and nature of the remaining factors in the selected category are unmapped. Therefore, in the next phase of analysis, D-DEMATEL is used to examine the nature and significance of each factor with threshold values >0.6.

The perception on the interdependency between two factors is collected in the form of D-number and is further used to create initial direct relation matrices.[3] These matrices are subsequently used to construct a fused direct relation matrix.

The following analysis exemplifies the process by considering the comparison ratings between subsidy (S) and Intention to use (IU). The same procedure is repeated to compute the fused D-numbers corresponding to all pairwise assessments.

Assessment given by Expert-1 = (C1, C2) = (0.45, 0.55)

Assessment given by Expert-2 = (C1, C2) = (0.4, 0.52)

Assessment given by Expert-3 = (C1, C2) = (0.4, 0.6)

C1 refers to the degree of direct relationship between the subsidy (S) and the Intention to use (IU), while C2 indicates the degree of having no relation between the S and IU. The assessments obtained from the experts include a positive element (C1) and a negative element (C2).

To formulate a D-number, it is imperative to convert the negative elements into positive by substituting C2 with 1-C2. The D-numbers thus formulated are shown in Table.5.

The attributes of Table.5 are used to determine the fused direct relation between S and IU using Eq.4–7, which is noted to be 0.426. Appendix-IV presents a detailed calculation involved computing a D-number with the help of an example. Similarly, the pairwise direct relation between all the factors is computed.[4] Subsequently, the summation of each row is computed, and the maximum value is used to derive the elements of normalized direct relation matrix using Eq.8. The matrix thus obtained is shown in Table.B3 of Appendix-III. Later, Eq.9 is used to formulate the total relation matrix, which is eventually used to determine the cause (τ) and effect (ϕ) using Eq.10 and Eq.11, respectively. These fields are further used to determine ($\tau + \phi$) and (τ - ϕ), as shown in Table.6.

On the basis of final results presented in Table.6, intention to use, perceived ease of use, ease of installation, and perceived usefulness are effect variables, while the rest are cause variables. Awareness about RWHS is found to be the most significant factor, while Tax incentives to companies are found last in the hierarchy. The cause-and-effect diagram of the factors is shown in Fig. 8 to illustrate the hierarchy and the nature of each factor.

The factors falling under the cause group are highly crucial, as any

[2] Collected using a linguistic scale as shown in Table.B1 of Appendix -II

[3] Sample matrix is shown in Table.B1 of Appendix-III. Equivalent matrices formulated using the ratings obtained from the other experts are also available.

[4] Table.B2 in Appendix-III presents the direct relation matrix formulated using the equivalent computations as performed for S and IU

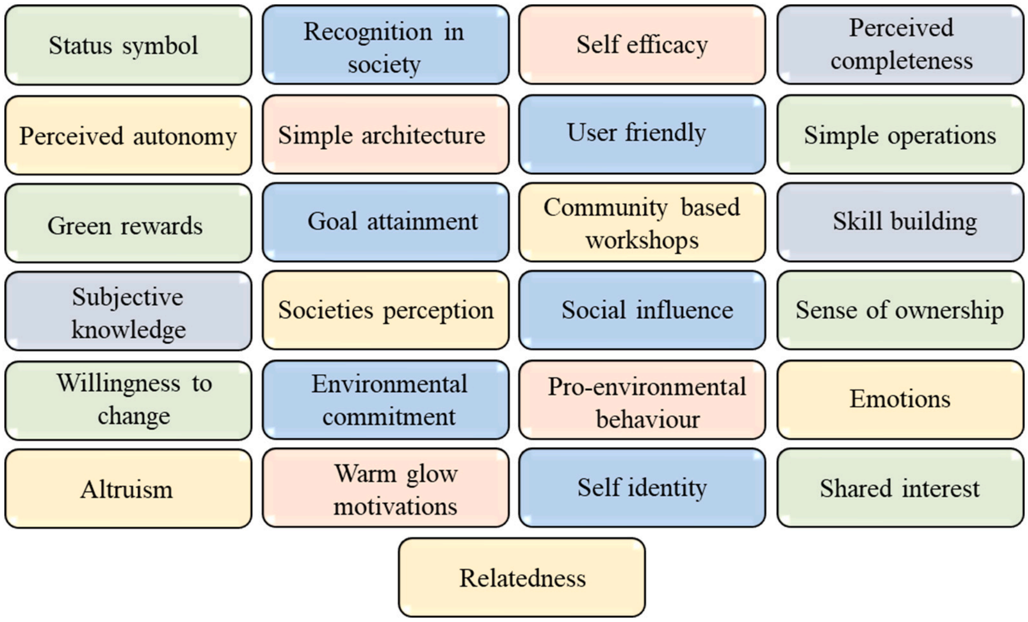

Fig. 5. List of sub-factors identified from the focussed group discussions.

Fig. 6. A field visit to Bastapur, Haryana, India (28.9624° N, 76.6470° E)

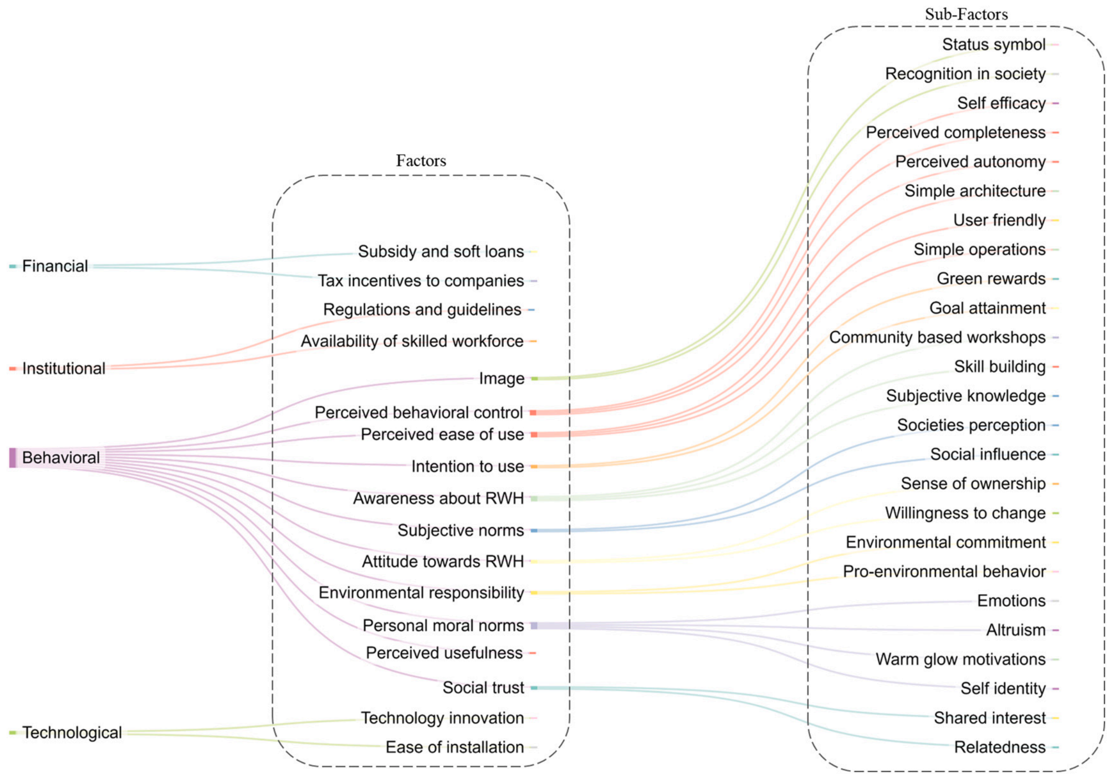

Fig. 7. Mapping of sub-factor, factors, and their categories.

Table 4
Perception on the relevance of factors on linguistic scale.

Factors	a	b	c	Defuzzified score
Subsidy and soft loans	0.70	0.97	1.00	0.888
Tax incentives to companies	0.70	0.93	1.00	0.877
Regulation and guidelines	0.50	0.70	0.90	0.700
Availability of skilled workforce	0.70	0.93	1.00	0.877
Image	0.00	0.00	0.50	0.167
Perceived behavioural control	0.00	0.29	0.70	0.331
Perceived ease of use	0.70	0.97	1.00	0.888
Intention to use	0.30	0.68	1.00	0.660
Awareness about RWH	0.70	0.93	1.00	0.877
Subjective norms	0.00	0.00	0.70	0.233
Attitude towards RWH	0.00	0.00	0.70	0.233
Environmental responsibility	0.00	0.00	0.50	0.167
Personal moral norms	0.00	0.00	0.70	0.233
Perceived usefulness	0.70	0.97	1.00	0.888
Social trust	0.00	0.21	0.50	0.236
Technology innovation	0.70	0.97	1.00	0.888
Ease of installation	0.50	0.83	1.00	0.776

Table 5
D-numbers formulated using the assessments given by Expert-1.

Nomenclature of expert	Representation of D-number	D-number
E1	$D^{E1}_{(S-IU)}$	{(0.45, 0.5), (0.45, 0.5)}
E2	$D^{E2}_{(S-IU)}$	{(0.4,0.5), (0.48, 0.5)}
E3	$D^{E3}_{(S-IU)}$	{(0.4,0.5), (0.4, 0.5)}

minor changes in these can impact the entire system. Moreover, taking the necessary steps to improve the performance of these factors can result into impact on the overall goal. Owing to this, it is widely acknowledged that the factors under the cause group should be focussed on compared to the other factors.

Instead of considering all the factors falling within the cause group as critical success factors (CSFs), a detailed analysis of the degree of importance and the attributes derived in Table.6 is performed to identify the CSFs.

Table 6
Classification and significance of Critical Success Factors.

Nomenclature	Critical Success Factor	τ	ϕ	τ + ϕ	τ - ϕ	Group
IU	Intention to use	2.957	3.163	6.119	−0.206	Effect
A	Awareness about RWH	3.787	2.954	6.740	0.833	Cause
TC	Tax incentives to companies	2.452	2.379	4.830	0.073	Cause
PE	Perceived ease of use	2.176	2.353	4.529	−0.176	Effect
TI	Technology innovation	3.404	2.352	5.755	1.052	Cause
AW	Availability of skilled workforce	2.963	2.375	5.338	0.589	Cause
E	Ease of installation	2.364	3.516	5.881	−1.152	Effect
PU	Perceived usefulness	2.800	3.962	6.762	−1.162	Effect
RG	Regulations and guidelines	3.230	3.165	6.395	0.065	Cause
S	Subsidy	2.845	2.760	5.606	0.085	Cause

Among all the factors in the cause group, technology innovation has the highest τ - ϕ indicating that this factor can influence the entire system that it being influenced by other parameters. Besides this, from the attributes of Table.6, it is apparent that the degree of influential impact corresponding to ‘technology innovation’ is 3.404, which is the second in the hierarchy. This observation indicates that variation in technology innovation can improve the performance of other variables. In this regard, conclusively, technology innovation is a CSF to promote rainwater harvesting in rural India.

Awareness about rainwater harvesting systems has the second highest τ - ϕ value which refers to the fact that it can dispatch more

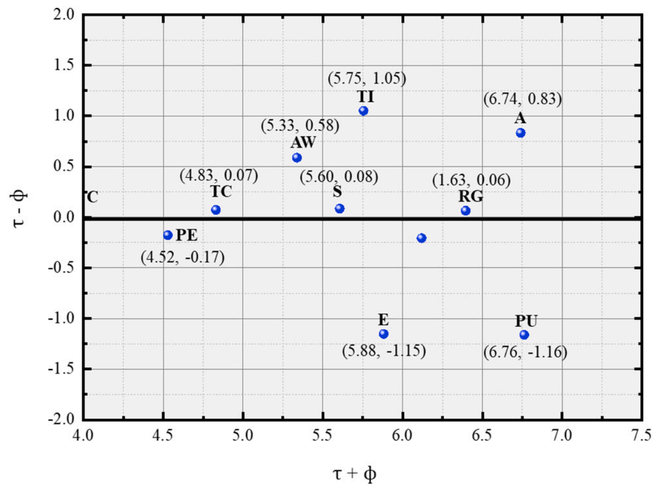

Fig. 8. Cause and effect relationship between the variables.

impact on the other factors than it receives from others. τ + ϕ values of 'Awareness about rainwater harvesting systems' is the highest among all the factors falling under the cause group, indicating that it is the most important factor. The degree of influence is also the highest among all, suggesting it to be one of the CSFs. Availability of skilled workforce follows the order in the hierarchy in terms of τ - ϕ score. The degree of importance of this parameter, i.e., τ + ϕ is comparably equal to the 'Awareness about rainwater harvesting system.' However, the degree of influential impact is relatively lower, indicating that the impact of this factor on the whole system would be relatively low. The τ - ϕ of 'Subsidy,' 'Tax incentives to companies', and 'Regulations and guidelines' follow the hierarchy. From the attributes of Table.6, it may be noted that the magnitude of τ - ϕ is comparable. τ + ϕ of 'Regulations and guidelines' is notable among the category which refers to the importance of this factor. The degree of the influential impact of this factor is pronounced with a magnitude of 3.2, inferring that this factor has a remarkable impact on the other factors of the system. The τ - ϕ score of 'perceived ease of use' and 'intention to use' is slightly below the reference line, i.e., the line indicating τ - ϕ =0. This observation indicates that these factors are slightly net affected by the other factors, and at the same time, these factors can have a considerable impact on the system. Therefore, besides considering the factors falling under the cause group as critical success factors, it is imperative to consider 'perceived ease of use' and 'intention to use' while devising the strategies, as these factors can also have a considerable effect on the goal.

5. Discussions and preparation of roadmap

The empirical analysis has identified eight critical success factors (CSFs) that promote the adoption of RWH technologies in rural India. These include awareness about RWH technologies, perceived usefulness and ease of use, tax incentives to companies, technological innovation, regulations and guidelines, availability of skilled workforce, and subsidies. Among the identified CSFs, six factors belong to the cause group, and two factors to the effect group.

Creating awareness about RWH technologies is one of the prime motivators that enables rural community residents to understand the need for installing the RWH system. Earlier studies found this factor to be crucial for adopting photovoltaic technology (Irfan et al., 2021), solar lamps (Sharma et al., 2021), solar stills (Sharon et al., 2021), GHG reduction (Kathuria, 2002), and biogas for cooking (Talevi et al., 2022). The results suggest that the 'perceived ease of use' influences RWH technology adoption, in line with findings drawn in studies investigating the factors that can promote technology adoption (Kamble et al., 2021; Zalat et al., 2021). Intuitively, if individuals find using RWH systems easy, they are more likely to adopt RWH technology.

Similarly, 'technology innovation' as a CSF demonstrates that the robustness and benefits of new technology can substantially impact its adoption in rural areas, consistent with earlier studies (Abdul-Rahaman et al., 2021). Creating a skilled workforce who can install a RWH system is an advantage in this industry, as their availability builds trust in the services. Liang et al. (2022) drew a similar inference when analysing the adoption of solar technology in rural India. Similarly, the results suggest that drafting constructive regulations and guidelines can act as a catalyst for the adoption of RWH technologies. The role of such regulations is widely acknowledged in the case of new cooking technology adoption (Kim et al., 2011).

Furthermore, the results suggest that 'tax incentives to companies' and 'subsidies' have an influential role in promoting the adoption of RWH technology in rural areas. These results are in line with the case of the adoption of solar technologies in rural India (Bansal, 2021).

While the validated empirical results shed light on the significance of individual CSFs, the availability of a comprehensive practice-oriented framework that explains activities that enable the systematic attainment of identified CSFs is a significant gap in the extant literature. Therefore, we develop a new roadmap (ref Fig. 9), as an action plan to promote the adoption of RWH technologies in rural areas. The sequence of activities that aid the attainment of identified CSFs and their corresponding timeframe are presented in Fig. 9**.** The proposed roadmap includes critical components that are derived from the CSFs.

The activities under the first component, 'Explore and Investigate', aim to create the database and tools required to translate the theory into practice. For this component, the creation of a think tank composed of experts, academicians, government officials, and industry personnel with significant experience in implementing rainwater harvesting and water conservation techniques is proposed. In its initial phase, the think-tank can identify various parameters such as access to water resources, normal annual rainfall, and demand-supply water gap to determine regions that experience water-stress. This identification can enable targeted promotion of RWH technologies. Furthermore, generating thematic maps of governing variables and geospatial databases of villages can facilitate the identification of target regions. Following this, interventions such as providing rainwater harvesting calculators to the residents of the identified target regions can create a positive outlook on RWH technology to increase its adoption.

Based on the CSF 'Creating Awareness', the second component of the roadmap involves creating awareness about RWH technology. For this, conducting workshops and seminars for community residents at schools and villages with primary emphasis on (i) the current ground water level scenario and (ii) sources of the water supply, can be beneficial. These workshops can subsequently develop a positive attitude towards the adoption of RWH technologies. In a similar manner, producing short films and distributing manuals explaining the design aspects are likely to have a significant impact on the attitude of people towards these technologies.

Emphasizing the attainment of 'perceived usefulness' and 'perceived ease of use,' the activities in the third component of the proposed roadmap, involve 'Behavioural Assessment'. Planning activities that can explain the architecture and the working principles of this system may further enhance the understanding of the operating procedures leading to a change in the perception on ease of use. Here, creating perceptual maps as a part of this component helps to understand their behavioural willingness to accept RWH technologies. Alternatively, attitudinal surveys using well-designed questionnaires, behavior-specific interviews, focus group discussions with stakeholders, and field visits can provide rich insights. These discussions also allow the community residents to participate and share their perceptions.

The fourth component of the proposed roadmap, 'Training & Support,' aims to realise the CSFs 'availability of skilled workforce' and 'technology innovation.' Creating a skilled workforce that can install these unconventional systems will encourage wider adoption of RWH

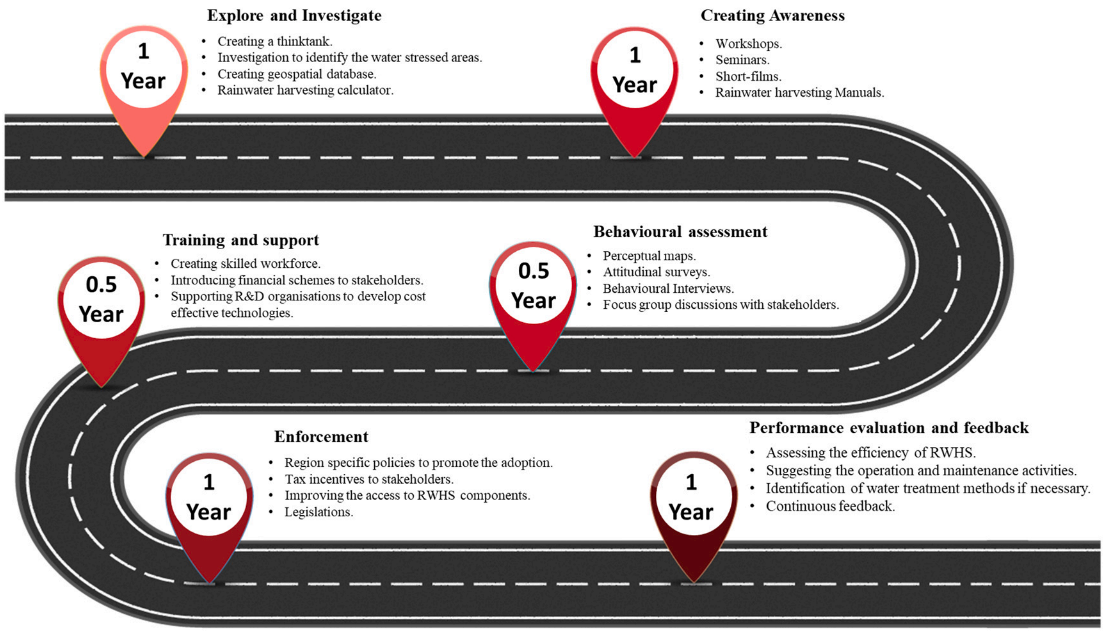

Fig. 9. Schematic illustration of the roadmap to promote the adoption of RWH technology.

systems. Introduction of schemes that can provide subsidies are also beneficial. In this phase, the roadmap also suggests that support for R&D activities can enable the adoption of such technologies to rural areas considering the income level and the initial investment cost involved. In the context of the current study, it is believed that innovation in terms of novel and simplistic architecture of RWH systems can promote its widespread adoption. Furthermore, technological innovation to overcome the problem of distrust on harvested water quality can become a catalyst in promoting its adoption.

Attainment of the CSFs 'tax incentives to companies,' 'regulations and guidelines,' and 'subsidies' is the prime objective of the activities in the fifth component of the proposed roadmap, which is 'Enforcement.' Initiating schemes that promote the participation of manufacturing companies and creating one-stop shops for the components of RWH technologies can improve perceptions on their user-friendliness. Depending on the condition of the water availability, regulations can be formulated and enforced by law, as in the case of a major cities in India.[5]

The last component of the proposed roadmap is 'performance evaluation and feedback'. The elements of this component are designed explicitly to evaluate the existing RWH technologies, their performance evaluation, and feedback. Here, advances in complementary technologies, such as Unmanned Aerial Vehicles (UAV) and remote sensing, can be harnessed to monitor and assess the performance of the RWH systems. With the recent advancements in UAV technologies, periodic RWH systems inspections can be taken up effectively with low cost, minimal human resources, and time consumption. Upon inspection, the required timely operation and maintenance works can be suggested to improve the efficiency of existing RWH systems in line with the study of Lee et al. (2016). If the desired water quality is not met, remedial cost-effective treatment techniques can also be suggested in this phase of the roadmap. Nevertheless, there is a need to take continuous feedback from the community residents to understand their experiences and challenges to iterate on strategies for the successful adoption of this technology in rural areas.

[5] http://jalshakti-dowr.gov.in/

6. Conclusions

Nearly half of the world population is likely to experience water scarcity by the end of 2030, and one-third of the population is expected to face severe water stress. Therefore, there is a significant need to promote water conservation techniques. Rainwater harvesting technology is one of the most compelling alternatives available. It involves storing the precipitated water for future use. Although this technology has gained popularity in several parts of the world, its usage in rural India is significantly limited.

This study identifies critical success factors that need attention to promote rainwater harvesting technology adoption in rural India. A hybrid multi-criterion framework by integrating Fuzzy DELPHI and D-DEMATEL techniques is developed, which is more relevant for the context where the list of factors is region specific. The list of factors identified from the studies conducted in a global context may not be fully relevant to a study emphasizing a specific region. Thus, adopting the proposed technique enables the identification of the relevant factors for the rural Indian context, where more than two-thirds of the Indian population subsists.

An exhaustive list containing 17 factors was first created with the help of a literature review, and the relevance of each factor was then analyzed with the help of the Fuzzy DELPHI technique, for which responses were obtained from focus group discussions. The results suggest that 10 out of 17 parameters are more relevant in the context of rural areas. Subsequently, the D-DEMATEL technique is adopted to analyze the selected ($n = 10$) factors resulting in eight Critical Success Factors that can promote the diffusion of RWH technology. Decision makers and planners can utilize the identified list to devise strategies that can promote the adoption of Rainwater Harvesting technologies.

The novel findings presented here suggest that community-based workshops, training sessions, field visits, and research on various architectures, along with the intervention of IoT devices in water quality assessments, will positively impact technology diffusion. The paper presents a new roadmap for policy makers for devising strategic plans to increase the adoption of the RWH technology in rural areas. Future research can specifically identify effective strategies for such technology adoption at a macro level.

Many of the identified CSFs in each category are relevant to the adoption of a range of new technologies in emerging economy contexts.

For instance, subsidy and soft loans, tax incentive to companies, awareness, attitudes, intentions, and subjective norms can be considered when analysing the adoption of new technologies in the rural areas of emerging nations. Nevertheless, it is recommended that the proposed approach is followed prior to finalizing the list of CSFs when analysing each technology. This approach not only aids in evaluating the relevance of identified CSF but also helps to ensure the completeness of CSFs from expert suggestions. Furthermore, to verify if the data collected from experts translated the ground realities, a field study was conducted in a rural region of Haryana in the context of this study. Conducting such field studies before finalizing the parameters and performing the analysis is useful as the perception of residents may change with demographics and location.

CRediT authorship contribution statement

Harish Puppala: Conceptualization, Methodology, Formal analysis, Data curation, Writing- Original draft preparation, Writing- Original draft preparation, Validation. Jaya Ahuja: Conceptualization, Data curation, Writing- Original draft preparation, Validation. Jagannadha Pawan Tamvada: Conceptualization, Data curation, Writing- Original draft preparation, Validation, Supervision, Project Management Pranav R T Peddinti: Conceptualization, Data curation, Writing- Original draft preparation, Validation, Project Management.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix I

IA: Questions used to conduct focus group discussion

- What are the critical factors for the adoption of rainwater harvesting technology in rural India?
- What is the role of government agencies in implementing the adoption of rainwater harvesting systems?
- Why do people resist the adoption of Rainwater harvesting technologies?
- How can people be motivated to adopt Rainwater harvesting technologies?
- How do we change the attitude of people towards the adoption of Rainwater harvesting technologies?
- What are the ways in which awareness can be created in society towards the adoption of Rainwater harvesting technologies?
- Any additional thoughts?

Appendix-IB

IB. Question used in the Field Investigation

1. What does it take to adopt Rainwater Harvesting Technology?
   वर्षा जल संचयन तकनीक को अच्छे तरह से अपनाने केलिए क्या कर सकते है?

2. How and from where do you get water for daily use? do you buy water?
   दैनंदनि उपयोग केलिए आप को पानी कैसे और कहाँ से मलिता है? क्या आप पानी को खरीदते हो?

3. With rain water harvesting technique, we can get water for free or very cheaply. Do you want to know about it and try to adopt it?
   वर्षा जल संचयन तकनीक से हमे पानी मुफ्त मे या बहुत सस्ते मे मलि सकता है। क्या आप इसके बारे में जानना
   चाहते हैं और इसे अपनाने का कोशशि करते है?

4. What kind of support do you need from the government or scientists to adopt it?
   इसे अपनाने केलिए आपको सर्कार या वैज्ञानकिो से कसि तरह का समर्थन चाहिए?

5. What do you think needs to be done to adopt rain water harvesting techniques in your locality/locality/village?
   आपके सोच से वर्षा जल संचयन तकनीक को आपके परविेश/इलाका/गांव मे अपनाने केलिए क्या करना पड़ेगा?

6. How can we bring social awareness to make this technology successful in India?
   भारत मे इस तकनीक को सफल करने केलिए सामजकि जागरण कैसे ला सकते है?

7. According to you, what current problems does this technique resolve?
   आपके अनुसार यह तकनीक कनि मौजूदा समस्याओं का समाधान करती है?

Appendix II

Dear Participant,

At the outset, we appreciate your active participation in the survey which is aimed at identifying the relevant factors that can promote the adoption of rainwater harvesting technologies in rural India.

- The table presented below enlists 17 different factors that are identified by the research group.
- Kindly use the following linguistic judgment scale to rate the relevance of each factor.

Table B1
Linguistic scale for rating.

Linguistic scale	Score
Very low relevance (VL)	1
Low relevance (L)	2
Medium low relevance (ML)	3
Medium relevance	4
Medium high relevance	5
High relevance	6
Very high relevance	7

Table B2
Questionnaire and sample response.

S. No	CSF	VL	L	ML	M	MH	H	VH
1	Subsidy and soft loans	☐	☐	☐	☐	☐	☒	☐
2	Tax incentives to companies	☐	☐	☐	☐	☐	☐	☒
3	Regulation and guidelines	☐	☐	☐	☐	☒	☐	☐
4	Availability of skilled workforce	☐	☐	☐	☒	☐	☐	☐
5	Image	☒	☐	☐	☐	☐	☐	☐
6	Perceived behavioural control	☐	☒	☐	☐	☐	☐	☐
7	Perceived ease of use	☐	☐	☐	☐	☐	☒	☐
8	Intention to use	☐	☐	☐	☐	☒	☐	☐
9	Awareness about RWH	☐	☐	☐	☐	☐	☒	☐
10	Subjective norms	☐	☒	☐	☐	☐	☐	☐
11	Attitude towards RWH	☐	☐	☒	☐	☐	☐	☐
12	Environmental responsibility	☐	☐	☒	☐	☐	☐	☐
13	Personal moral norms	☐	☒	☐	☐	☐	☐	☐
14	Perceived usefulness	☐	☐	☐	☐	☐	☐	☒
15	Social Trust	☐	☒	☐	☐	☐	☐	☐
16	Technology innovation	☐	☐	☐	☐	☐	☐	☒
17	Ease of installation	☐	☐	☐	☐	☒	☐	☐

Appendix III

Table C1
Direct relationship matrix of CSFs constructed using the ratings obtained from Expert-1.

	Intention to use		Awareness about RWH		Tax incentives to companies		Perceived ease of use		Technology innovation		Availability of skilled workforce		Ease of installation		Perceived usefulness		Regulations and guidelines		Subsidy	
	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	C1	C2
Intention to use	0	0	0.25	0.75	0.5	0.85	0.5	0.65	0.35	0.55	0.45	0.55	0.6	0.25	0.65	0.25	0.2	0.7	0.35	0.65
Awareness about RWH	0.83	0.12	0	0	0.53	0.45	0.32	0.42	0.15	0.8	0.64	0.3	0.6	0.35	0.7	0.15	0.84	0.12	0.35	0.65
Tax incentives to companies	0.65	0.25	0.24	0.68	0	0	0.1	0.9	0.35	0.65	0.3	0.65	0.35	0.65	0.5	0.35	0.25	0.6	0.25	0.7
Perceived ease of use	0.2	0.75	0.3	0.6	0.15	0.85	0	0	0.32	0.65	0.1	0.72	0.25	0.75	0.2	0.7	0.35	0.55	0.2	0.72
Technology innovation	0.12	0.5	0.64	0.24	0.76	0.24	0.6	0.32	0	0	0.2	0.8	0.3	0.65	0.35	0.6	0.55	0.4	0.42	0.5
Availability of skilled workforce	0.73	0.25	0.63	0.24	0.33	0.63	0.14	0.78	0.62	0.32	0	0	0.2	0.8	0.24	0.72	0.36	0.6	0.33	0.6
Ease of installation	0.65	0.2	0.26	0.7	0.24	0.6	0.32	0.64	0.25	0.7	0.15	0.82	0	0	0.5	0.32	0.26	0.7	0.27	0.68
Perceived usefulness	0.7	0.25	0.25	0.65	0.12	0.86	0.2	0.68	0.3	0.68	0.25	0.74	0.83	0.17	0	0	0.32	0.62	0.62	0.3
Regulations and guidelines	0.24	0.64	0.5	0.4	0.14	0.7	0.24	0.66	0.28	0.64	0.38	0.54	0.72	0.24	0.72	0.26	0	0	0.32	0.54
Subsidy	0.62	0.32	0.39	0.52	0.24	0.72	0.2	0.72	0.14	0.82	0.24	0.71	0.17	0.62	0.76	0.22	0.63	0.31	0	0

Table C2
Direct relation matrix of factors obtained by the integration of fused D-number.

Critical Success Factor (CSF)	Intention to use	Awareness about RWH	Tax incentives to companies	Perceived ease of use	Technology innovation	Availability of skilled workforce	Ease of installation	Perceived usefulness	Regulations and guidelines	Subsidy
Intention to use	0.000	0.250	0.325	0.425	0.400	0.450	0.675	0.700	0.250	0.350
Awareness about RWH	0.475	0.000	0.54	0.450	0.175	0.670	0.625	0.775	0.860	0.350
Tax incentives to companies	0.45	0.280	0.000	0.100	0.350	0.325	0.350	0.575	0.325	0.275
Perceived ease of use	0.475	0.350	0.150	0.000	0.335	0.190	0.250	0.250	0.400	0.240
Technology innovation	0.31	0.700	0.760	0.640	0.000	0.200	0.325	0.375	0.575	0.460
Availability of skilled workforce	0.490	0.695	0.350	0.180	0.650	0.000	0.20	0.260	0.380	0.365
Ease of installation	0.425	0.280	0.320	0.340	0.275	0.165	0.000	0.590	0.280	0.295
Perceived usefulness	0.475	0.300	0.130	0.260	0.310	0.255	0.830	0.000	0.350	0.660
Regulations and guidelines	0.440	0.550	0.220	0.290	0.320	0.420	0.740	0.730	0.000	0.390
Subsidy	0.470	0.435	0.260	0.240	0.160	0.265	0.275	0.770	0.660	0.000

Table C3
Normalized direct relation matrix of factors.

Critical Success Factor (CSF)	Intention to use	Awareness about RWH	Tax incentives to companies	Perceived ease of use	Technology innovation	Availability of skilled workforce	Ease of installation	Perceived usefulness	Regulations and guidelines	Subsidy
Intention to use	0.000	0.051	0.066	0.086	0.081	0.091	0.137	0.142	0.051	0.071
Awareness about RWH	0.097	0.000	0.110	0.091	0.036	0.136	0.127	0.158	0.175	0.071
Tax incentives to companies	0.091	0.057	0.000	0.020	0.071	0.066	0.071	0.117	0.066	0.056
Perceived ease of use	0.097	0.071	0.030	0.000	0.068	0.039	0.051	0.051	0.081	0.049
Technology innovation	0.063	0.142	0.154	0.130	0.000	0.041	0.066	0.076	0.117	0.093
Availability of skilled workforce	0.100	0.141	0.071	0.037	0.132	0.000	0.041	0.053	0.077	0.074
Ease of installation	0.086	0.057	0.065	0.069	0.056	0.034	0.000	0.120	0.057	0.060
Perceived usefulness	0.097	0.061	0.026	0.053	0.063	0.052	0.169	0.000	0.071	0.134
Regulations and guidelines	0.089	0.112	0.045	0.059	0.065	0.085	0.150	0.148	0.000	0.079
Subsidy	0.096	0.088	0.053	0.049	0.033	0.054	0.056	0.157	0.134	0.000

Appendix IV

Sample response corresponding to an assessment from 3 experts.

Obtained matrix				
	Cp	W1	Cn	W2
E1	0.6	0.5	0.1	0.5
E2	0.7	0.5	0.2	0.5
E3	0.9	0.5	0.1	0.5

Conversion of the assessment matrix into positive matrix

Converted into positive matrix				
	Cp	W1	Cp	W2
E1	0.6	0.5	0.9	0.5
E2	0.7	0.5	0.8	0.5
E3	0.9	0.5	0.9	0.5

Fusion of E1-E2 using Eq-4-7

	b	v	b	v
E1	0.6	0.5	0.9	0.5
E2	0.7	0.5	0.8	0.5

b	v
0.65	0.25
0.7	0.25
0.8	0.25
0.85	0.25

Final set of b,v	
b	v
0.65	0.25
0.7	0.5
0.85	0.25

Fusion of E12- E3

	b1	v1	b2	v2	b3	v3
E12	0.65	0.25	0.7	0.5	0.85	0.25
E3	0.9	0.5	0.9	0.5		

b	c^P	v	b	v
0.775	0.375	0.15	0.775	0.15
0.775	0.375	0.15	0.775	0.15
0.8	0.5	0.2	0.8	0.2
0.8	0.5	0.2	0.8	0.2
0.875	0.375	0.15	0.875	0.15
0.875	0.375	0.15	0.875	0.15

Evaluating the integrated value results in **0.8**

References

Abdulla, F., Abdulla, C., Eslamian, S., 2021. Concept and technology of rainwater harvesting. Handbook of water harvesting and conservation: basic concepts and fundamentals 1–16.

Abdulla, F.A., Al-Shareef, A.W., 2009. Roof rainwater harvesting systems for household water supply in Jordan. Desalination 243 (1–3), 195–207.

Abdul-Rahaman, A., Issahaku, G., Zereyesus, Y.A., 2021. Improved rice variety adoption and farm production efficiency: accounting for unobservable selection bias and technology gaps among smallholder farmers in Ghana. Technol. Soc. 64, 101471.

Acosta García, R., Aschenbrenner, M., Dürr, E., Winder, G., 2022. Re-imagining cities as ecosystems: environmental subject formation in Auckland and Mexico City. Urban Res. Pract. 15 (3), 350–365.

Akuffobea-Essilfie, M., Williams, P.A., Asare, R., Damman, S., Essegbey, G.O., 2020. Promoting rainwater harvesting for improving water security: analysis of drivers and barriers in Ghana. Afr. J. Sci. Technol. Innov. Dev. 12 (4), 443–451.

Aliabadi, V., Gholamrezai, S., Ataei, P., 2020. Rural people's intention to adopt sustainable water management by rainwater harvesting practices: application of TPB and HBM models. Water Supply 20 (5), 1847–1861.

Alim, M.A., Rahman, A., Tao, Z., Samali, B., Khan, M.M., Shirin, S., 2020. Feasibility analysis of a small-scale rainwater harvesting system for drinking water production at Werrington, New South Wales, Australia. J. Clean. Prod. 270, 122437.

Amos, C.C., Rahman, A., Gathenya, J.M., 2018. Economic analysis of rainwater harvesting systems comparing developing and developed countries: A case study of Australia and Kenya. J. Clean. Prod. 172, 196–207.

Andersen, M.K., 2014. Development of a Rainwater Harvesting System for the Village Ngumbulu, Kenya (Master's Thesis, Institutt for Produktutvikling Og Materialer).

Assayed, A., Hatokay, Z., Al-Zoubi, R., Azzam, S., Qbailat, M., Al-Ulayyan, A., Maroni, R., 2013. On-site rainwater harvesting to achieve household water security among rural and peri-urban communities in Jordan. Resour. Conserv. Recycl. 73, 72–77.

Baguma, D., Loiskandl, W., 2010. Rainwater harvesting technologies and practises in rural Uganda: a case study. Mitig. Adapt. Strateg. Glob. Chang. 15 (4), 355–369.

Balaei, B., Wilkinson, S., Potangaroa, R., Adamson, C., Alavi-Shoshtari, M., 2019. Social factors affecting water supply resilience to disasters. International Journal of Disaster Risk Reduction 37, 101187.

Bansal, N., 2021. Promoting solar energy in India to meet the Country's commitment to climate change and energy security. Energy and Environmental Security in Developing Countries 545–570.

Bashar, M.Z.I., Karim, M.R., Imteaz, M.A., 2018. Reliability and economic analysis of urban rainwater harvesting: A comparative study within six major cities of Bangladesh. Resour. Conserv. Recycl. 133, 146–154.

Biswas, B.K., Mandal, B.H., 2014. Construction and Evaluation of Rainwater Harvesting System for Domestic Use in a Remote and Rural Area of Khulna, Bangladesh. International Scholarly Research Notices, p. 2014.

Campisano, A., Butler, D., Ward, S., Burns, M.J., Friedler, E., DeBusk, K., Han, M., 2017. Urban rainwater harvesting systems: research, implementation and future perspectives. Water Res. 115, 195–209.

Chang, B., Chang, C.W., Wu, C.H., 2011. Fuzzy DEMATEL method for developing supplier selection criteria. Expert Syst. Appl. 38 (3), 1850–1858.
Chen, Z., Ngo, H.H., Guo, W., Eslamian, S., 2016. Water shortages. In: Urban Water Reuse Handbook.
Cheng, C.L., Liao, M.C., Lee, M.C., 2006. A quantitative evaluation method for rainwater use guideline. Build. Serv. Eng. Res. Technol. 27 (3), 209–218.
Chen-Yi, H., Ke-Ting, C., Gwo-Hshiung, T., 2007. FMCDM with fuzzy DEMATEL approach for customers' choice behavior model. International Journal of Fuzzy Systems 9 (4).
Chidamba, L., Korsten, L., 2015. Antibiotic resistance in Escherichia coli isolates from roof-harvested rainwater tanks and urban pigeon faeces as the likely source of contamination. Environ. Monit. Assess. 187 (7), 1–15.
Chien, F., Anwar, A., Hsu, C.C., Sharif, A., Razzaq, A., Sinha, A., 2021. The role of information and communication technology in encountering environmental degradation: proposing an SDG framework for the BRICS countries. Technol. Soc. 65, 101587.
Churchill Jr., G.A., Iacobucci, D., 2002. Marketing Research – Methodological Foundations. Harcourt, Fort Worth, TX.
Concha Larrauri, P., Campos Gutierrez, J.P., Lall, U., Ennenbach, M., 2020. A City wide assessment of the financial benefits of rainwater harvesting in Mexico City. JAWRA Journal of the American Water Resources Association 56 (2), 247–269.
Coombes, P.J., 2007. Energy and economic impacts of rainwater tanks on the operation of regional water systems. Australasian Journal of Water Resources 11 (2), 177–191.
Coombes, P.J., Kuczera, G., Kalma, J.D., Argue, J.R., 2002. An evaluation of the benefits of source control measures at the regional scale. Urban water 4 (4), 307–320.
CPCB, 2016. Rainwater harvesting potential in India. In: An Appraisal, A report by Central Pollution Control Board. http://www.cpcbenvis.nic.in/.
CPWD, 2002. Rainwater Harvesting and Conservation Manual. Central Public Works Department. https://cpwd.gov.in/.
Creswell, J.W., 2009. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 3rd ed. Sage Publications, Thousand Oaks, CA.
Darko, A., Chan, A.P.C., Yang, Y., Shan, M., He, B.J., Gou, Z., 2018. Influences of barriers, drivers, and promotion strategies on green building technologies adoption in developing countries: the Ghanaian case. J. Clean. Prod. 200, 687–703.
Deng, X., Hu, Y., Deng, Y., Mahadevan, S., 2014. Supplier selection using AHP methodology extended by D numbers. Expert Syst. Appl. 41 (1), 156–167.
Domènech, L., Saurí, D., 2011. A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the metropolitan area of Barcelona (Spain): social experience, drinking water savings and economic costs. J. Clean. Prod. 19 (6–7), 598–608.
Domènech, L., Heijnen, H., Saurí, D., 2012. Rainwater harvesting for human consumption and livelihood improvement in rural N epal: benefits and risks. Water and Environment Journal 26 (4), 465–472.
Ejiaku, S.A., 2014. Technology adoption: issues and challenges in information technology adoption in emerging economies. Journal of International Technology and Information Management 23 (2), 5.
Eroksuz, E., Rahman, A., 2010. Rainwater tanks in multi-unit buildings: A case study for three Australian cities. Resour. Conserv. Recycl. 54 (12), 1449–1452.
Escandon-Barbosa, D., Salas-Paramo, J., Meneses-Franco, A.I., Giraldo-Gonzalez, C., 2021. Adoption of new technologies in developing countries: the case of autonomous car between Vietnam and Colombia. Technol. Soc. 66, 101674.
FAO, 2022. Food and Agricultural Organization of the United Nations. https://www.fao.org/home/en.
Farreny, R., Gabarrell, X., Rieradevall, J., 2011. Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods. Resour. Conserv. Recycl. 55 (7), 686–694.
Fern, E.F., 2001. Advanced Focus Group Research. Sage, Thousand Oaks, CA.
Fewkes, A., 2012. A review of rainwater harvesting in the UK. Struct. Surv. 30 (2), 174–194.
Figueira, J.R., Mousseau, V., Roy, B., 2016. ELECTRE methods. In: Multiple Criteria Decision Analysis: State of the Art Surveys, pp. 155–185.
Fortier, J., 2010. Examining the Social Acceptability of Cisterns in Rainwater Harvesting for Residenital Use in the Region of Waterloo, Ontario (Master's thesis,. University of Waterloo.
Furumai, H., Kim, J., Imbe, M., Okui, H., 2008. Recent application of rainwater storage and harvesting in Japan. In: The 3rd RWHM Workshop, 11. September.
Gabus, A., Fontela, E., 1972. World Problems, an Invitation to further Thought within the Framework of DEMATEL. Battelle Geneva Research Center, Geneva, Switzerland.
Gonela, V., Altman, B., Zhang, J., Ochoa, E., Murphy, W., Salazar, D., 2020. Decentralized rainwater harvesting program for rural cities considering tax incentive schemes under stakeholder interests and purchasing power restrictions. J. Clean. Prod. 252, 119843.
Govindan, K., Khodaverdi, R., Vafadarnikjoo, A., 2015. Intuitionistic fuzzy based DEMATEL method for developing green practices and performances in a green supply chain. Expert Syst. Appl. 42 (20), 7207–7220.
Greenbaum, T.L., 2000. Moderating Focus Groups: A Practical Guide for Group Facilitation. Sage, Thousand Oaks, CA.
Gupta, B., Dasgupta, S., Gupta, A., 2008. Adoption of ICT in a government organization in a developing country: an empirical study. J. Strateg. Inf. Syst. 17 (2), 140–154.
Haque, M.M., Rahman, A., Samali, B., 2016. Evaluation of climate change impacts on rainwater harvesting. J. Clean. Prod. 137, 60–69.
He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., Bryan, B.A., 2021. Future global urban water scarcity and potential solutions. Nat. Commun. 12 (1), 1–11.
Helmreich, B., Horn, H., 2009. Opportunities in rainwater harvesting. Desalination 248 (1–3), 118–124.
Herrmann, T., Schmida, U., 2000. Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. Urban water 1 (4), 307–316.
Huang, Z., Nya, E.L., Rahman, M.A., Mwamila, T.B., Cao, V., Gwenzi, W., Noubactep, C., 2021. Integrated water resource management: rethinking the contribution of rainwater harvesting. Sustainability 13 (15), 8338.
IEP, 2023. India Environment Portal Knowledge For Change. http://www.environmentportal.in/.
Irfan, M., Yadav, S., Shaw, K., 2021. The adoption of solar photovoltaic technology among Indian households: examining the influence of entrepreneurship. Technol. Forecast. Soc. Chang. 169, 120815.
Jiang, W., Yang, Y., Luo, Y., Qin, X., 2015. Determining basic probability assignment based on the improved similarity measures of generalized fuzzy numbers. International Journal of Computers Communications & Control 10 (3), 333–347.
Jones, M.P., Hunt, W.F., 2010. Performance of rainwater harvesting systems in the southeastern United States. Resour. Conserv. Recycl. 54 (10), 623–629.
JSACTR, 2023. Jal Shakti Abhiyan, Ministry of Jal Shakti, Department of Water Resources. RD & GR, Government of India. https://jsactr.mowr.gov.in/.
Kamble, S.S., Gunasekaran, A., Kumar, V., Belhadi, A., Foropon, C., 2021. A machine learning based approach for predicting blockchain adoption in supply chain. Technol. Forecast. Soc. Chang. 163, 120465.
Kathuria, V., 2002. Technology transfer for GHG reduction: a framework with application to India. Technol. Forecast. Soc. Chang. 69 (4), 405–430.
Kim, K., Yoo, C., 2009. Hydrological modeling and evaluation of rainwater harvesting facilities: case study on several rainwater harvesting facilities in Korea. J. Hydrol. Eng. 14 (6), 545–561.
Kim, K.H., Pandey, S.K., Kabir, E., Susaya, J., Brown, R.J., 2011. The modern paradox of unregulated cooking activities and indoor air quality. J. Hazard. Mater. 195, 1–10.
Kingsborough, A., Borgomeo, E., Hall, J.W., 2016. Adaptation pathways in practice: mapping options and trade-offs for London's water resources. Sustain. Cities Soc. 27, 386–397.
Kummu, M., Guillaume, J.H., de Moel, H., Eisner, S., Flörke, M., Porkka, M., Ward, P.J., 2016. The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. Sci. Rep. 6 (1), 1–16.
Larsen, T.A., Hoffmann, S., Lüthi, C., Truffer, B., Maurer, M., 2016. Emerging solutions to the water challenges of an urbanizing world. Science 352 (6288), 928–933.
Lee, J.Y., Kim, H., Han, M., 2016. Importance of maintenance in rainwater harvesting systems: a case study. Water Sci. Technol. Water Supply 16 (1), 97–103.
Leidl, C., Farahbakhsh, K., FitzGibbon, J., 2010. Identifying barriers to widespread implementation of rainwater harvesting for urban household use in Ontario. Canadian Water Resources Journal 35 (1), 93–104.
Li, F., Cook, S., Geballe, G.T., Burch Jr., W.R., 2000. Rainwater harvesting agriculture: an integrated system for water management on rainfed land in China's semiarid areas. AMBIO: A Journal of the Human Environment 29 (8), 477–483.
Liang, J., Irfan, M., Ikram, M., Zimon, D., 2022. Evaluating natural resources volatility in an emerging economy: the influence of solar energy development barriers. Res. Policy 78, 102858.
Liu, Y., Li, G., Zeng, P., Zhang, X., Tian, T., Feng, H., Che, Y., 2022. Challenge of rainwater harvesting in Shanghai, China: a public psychological perspective. J. Environ. Manag. 318, 115584.
Lo, A.G., Gould, J., 2015. Rainwater harvesting: global overview. Rainwater harvesting for agriculture and water supply 213–233.
Marcos, K.J., Moersidik, S.S., Soesilo, T.E., 2021, March. Extended theory of planned behavior on utilizing domestic rainwater harvesting in Bekasi, West Java, Indonesia. In: IOP Conference Series: Earth and Environmental Science, , 1st716. IOP Publishing, p. 012054.
Martinson, B., Thomas, T., 2007. Roofwater Harvesting: A Handbook for Practitioners. IRC International Water and Sanitation Centre.
Mati, B., De Bock, T., Malesu, M., Khaka, E., Oduor, A., Meshack, M., Oduor, V., 2006. Mapping the potential of rainwater harvesting technologies in Africa. A GIS overview on development domains for the continent and ten selected countries. Tech-man 6, 126.
McDonald, R.I., Weber, K., Padowski, J., Flörke, M., Schneider, C., Green, P.A., Montgomery, M., 2014. Water on an urban planet: urbanization and the reach of urban water infrastructure. Glob. Environ. Chang. 27, 96–105.
Mitrică, B., Mitrică, E., Enciu, P., Mocanu, I., 2017. An approach for forecasting of public water scarcity at the end of the 21st century, in the Timiş plain of Romania. Technol. Forecast. Soc. Chang. 118, 258–269.
Moshfika, M., Biswas, S., Mondal, M.S., 2022. Assessing groundwater level declination in Dhaka city and identifying adaptation options for sustainable water supply. Sustainability 14 (3), 1518.
Nachshon, U., Netzer, L., Livshitz, Y., 2016. Land cover properties and rain water harvesting in urban environments. Sustain. Cities Soc. 27, 398–406.
Nawab, T., Raza, S., Shabbir, M.S., Yahya Khan, G., Bashir, S., 2022. Multidimensional Poverty Index across Districts in Punjab, Pakistan: Estimation and Rationale to Consolidate with SDGs. Environment, Development and Sustainability, pp. 1–25.
Ning, X., Yuan, J., Yue, X., 2016. Uncertainty-based optimization algorithms in designing fractionated spacecraft. Sci. Rep. 6 (1), 1–8.
NWP, 2012. National Water Policy 2012. Ministry of Water Resources, Government of India. https://nwm.gov.in/sites/default/files/national%20water%20policy%202012_0.pdf.
Özdemir, S., Elliott, M., Brown, J., Nam, P.K., Thi Hien, V., Sobsey, M.D., 2011. Rainwater harvesting practices and attitudes in the Mekong Delta of Vietnam. Journal of Water, Sanitation and Hygiene for Development 1 (3), 171–177.
Palomares, I., Martínez-Cámara, E., Montes, R., García-Moral, P., Chiachio, M., Chiachio, J., Herrera, F., 2021. A panoramic view and swot analysis of artificial

intelligence for achieving the sustainable development goals by 2030: progress and prospects. Appl. Intell. 51, 6497–6527.
Parsons, D., Goodhew, S., Fewkes, A., De Wilde, P., 2010. The perceived barriers to the inclusion of rainwater harvesting systems by UK house building companies. Urban Water J. 7 (4), 257–265.
Puppala, H., Jha, S.K., Singh, A.P., Elavarasan, R.M., Campana, P.E., 2022. Identification and analysis of barriers for harnessing geothermal energy in India. Renew. Energy 186, 327–340.
Rahman, A., Dbais, J., Islam, S.M., Eroksuz, E., Haddad, K., 2012. Rainwater harvesting in large residential buildings in Australia. Urban Development 159–178.
Roszkowska, E., 2011. Multi-criteria decision making models by applying the TOPSIS method to crisp and interval data. Multiple Criteria Decision Making/University of Economics in Katowice 6 (1), 200–230.
de Sá Silva, A.C.R., Bimbato, A.M., Balestieri, J.A.P., Vilanova, M.R.N., 2022. Exploring environmental, economic and social aspects of rainwater harvesting systems: A review. Sustain. Cities Soc. 76, 103475.
Saaty, T.L., 2004. Decision making—the analytic hierarchy and network processes (AHP/ANP). J. Syst. Sci. Syst. Eng. 13, 1–35.
Saaty, T.L., Vargas, L.G., Saaty, T.L., Vargas, L.G., 2013. The Analytic Network Process. Springer, US, pp. 1–40.
Saner, R., Yiu, L., Nguyen, M., 2020. Monitoring the SDGs: digital and social technologies to ensure citizen participation, inclusiveness and transparency. Dev. Policy Rev. 38 (4), 483–500.
Shanmugavel, N., Rajendran, R., 2022. Adoption of rainwater harvesting: a dual-factor approach by integrating theory of planned behaviour and norm activation model. Water Resour. Manag. 1–19.
Sharma, R., Choudhary, D., Shiradkar, S., Kumar, P., Venkateswaran, J., Solanki, C.S., Yadama, G.N., 2021. Who is willing to pay for solar lamps in rural India? A longitudinal study. Renew. Sust. Energ. Rev. 140, 110734.
Sharon, H., Prabha, C., Vijay, R., Niyas, A.M., Gorjian, S., 2021. Assessing suitability of commercial fibre reinforced plastic solar still for sustainable potable water production in rural India through detailed energy-exergy-economic analyses and environmental impacts. J. Environ. Manag. 295, 113034.
Sheikh, V., 2020. Perception of domestic rainwater harvesting by Iranian citizens. Sustain. Cities Soc. 60, 102278.
Shieh, J.I., Wu, H.H., Huang, K.K., 2010. A DEMATEL method in identifying key success factors of hospital service quality. Knowl.-Based Syst. 23 (3), 277–282.
Si, S.L., You, X.Y., Liu, H.C., Zhang, P., 2018. DEMATEL technique: A systematic review of the state-of-the-art literature on methodologies and applications. Math. Probl. Eng. 2018.
Sinha, A., Sengupta, T., Saha, T., 2020. Technology policy and environmental quality at crossroads: designing SDG policies for select Asia Pacific countries. Technol. Forecast. Soc. Chang. 161, 120317.
Smith, R., Hildreth, L., Kimsey, S., 2011. Evaluating the economic impacts of water harvesting in Burkina Faso. Ecosystem services economics (ESE) working paper series. Division of Environmental Policy Implementation paper No 6.
Straub, E.T., 2009. Understanding technology adoption: theory and future directions for informal learning. Rev. Educ. Res. 79 (2), 625–649.
Talevi, M., Pattanayak, S.K., Das, I., Lewis, J.J., Singha, A.K., 2022. Speaking from experience: preferences for cooking with biogas in rural India. Energy Econ. 107, 105796.
TCPO, 2023. The Atal Mission for Rejuvenation and Urban Transformation – Reforms, Town and Country Planning Organisation. Government of India, Ministry of Housing and Urban Affairs. http://tcpo.gov.in/atal-mission-rejuvenation-and-urban-transformation-amrut-reforms.
Tortorella, G.L., Fogliatto, F.S., Espôsto, K.F., Vergara, A.M.C., Vassolo, R., Mendoza, D. T., Narayanamurthy, G., 2020. Effects of contingencies on healthcare 4.0 technologies adoption and barriers in emerging economies. Technol. Forecast. Soc. Chang. 156, 120048.
United Nations, 2012. Resolution Adopted by the UN General Assembly 66/288 – The Future we Want. UN Resolutions, New York, NY.
United Nations (UN), 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. Finalized text for adoption, (A/70/L.1), New York, NY, September, 25.
Van der Sterren, M., Rahman, A., Dennis, G.R., 2013. Quality and quantity monitoring of five rainwater tanks in Western Sydney, Australia. J. Environ. Eng. 139 (3), 332–340.
Varma, D.S., Nandanan, K., Raja .V., P.C, Soundharajan, B., Pérez, M.L., Sidharth, K.A., Ramesh, M.V., 2021. Participatory design approach to address water crisis in the village of Karkatta, Jharkhand, India. Technol. Forecast. Soc. Chang. 172, 121002.
Verma, G., Gupta, S., Gupta, R., 2020, October. IoT based technique for household rainwater harvesting. In: In 2020 Global Conference on Wireless and Optical Technologies (GCWOT). IEEE, pp. 1–4.
Villarreal, E.L., Dixon, A., 2005. Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden. Build. Environ. 40 (9), 1174–1184.
van Vliet, M.T., Jones, E.R., Flörke, M., Franssen, W.H., Hanasaki, N., Wada, Y., Yearsley, J.R., 2021. Global water scarcity including surface water quality and expansions of clean water technologies. Environ. Res. Lett. 16 (2), 024020.
Wang, Y., Lu, Y., He, G., Wang, C., Yuan, J., Cao, X., 2020. Spatial variability of sustainable development goals in China: A provincial level evaluation. Environmental Development 35, 100483.
Ward, S., Barr, S., Butler, D., Memon, F.A., 2012. Rainwater harvesting in the UK: socio-technical theory and practice. Technol. Forecast. Soc. Chang. 79 (7), 1354–1361.
Woltersdorf, L., Jokisch, A., Kluge, T., 2014. Benefits of rainwater harvesting for gardening and implications for future policy in Namibia. Water Policy 16 (1), 124–143.
Xu, W.D., Fletcher, T.D., Duncan, H.P., Bergmann, D.J., Breman, J., Burns, M.J., 2018. Improving the multi-objective performance of rainwater harvesting systems using real-time control technology. Water 10 (2), 147.
Yazdani, M., Torkayesh, A.E., Santibanez-Gonzalez, E.D., Otaghsara, S.K., 2020. Evaluation of renewable energy resources using integrated Shannon entropy—EDAS model. Sustainable Operations and Computers 1, 35–42.
Yazdi, M., Khan, F., Abbassi, R., Rusli, R., 2020. Improved DEMATEL methodology for effective safety management decision-making. Saf. Sci. 127, 104705.
Zalat, M.M., Hamed, M.S., Bolbol, S.A., 2021. The experiences, challenges, and acceptance of e-learning as a tool for teaching during the COVID-19 pandemic among university medical staff. PLoS One 16 (3), e0248758.
Zhou, X., Shi, Y., Deng, X., Deng, Y., 2017. D-DEMATEL: A new method to identify critical success factors in emergency management. Saf. Sci. 91, 93–104.
Zingiro, A., Okello, J.J., Guthiga, P.M., 2014. Assessment of adoption and impact of rainwater harvesting technologies on rural farm household income: the case of rainwater harvesting ponds in Rwanda. Environ. Dev. Sustain. 16 (6), 1281–1298.

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