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Review Paper

Complexity of adoption and diffusion of ecological sanitation technology: a review of literature

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ABSTRACT

Ecological sanitation (Ecosan) technology was introduced to improve sanitation through the reuse of excreta resources, particularly in developing countries. However, the adoption of Ecosan technology is low which makes its diffusion complex, especially in diverse spatial and socio-cultural contexts. This review of literature aimed to use the innovation theory to identify the issues that make the process of adoption of Ecosan technology complex. A total of 105 published studies were reviewed. Of these, only 34 studies were analyzed and grouped according to the complexity of the diffusion of ecological sanitation technology using the five stages of innovation diffusion conceptual model identified by Everett Rogers namely: knowledge, persuasion, decision, implementation, and confirmation. The studies revealed the existence of diverse complexities of adoption, such as lack of sanitation policy, phobia against the use of Ecosan by-products, lack of technical support, and safety issues. In addition, poor practical knowledge, illiteracy, high capital cost, disgust with human excreta, religious taboos, and cultural boundaries were also found to hinder the smooth diffusion of Ecosan technology in various geographical settings. The scale-up of Ecosan technology, therefore, needs to focus on addressing these barriers and adopting implementation best practices.

Key words: adoption, complexity, diffusion, Ecosan technology, sanitation

HIGHLIGHTS

- This paper highlights stages of adoption of Ecosan in diverse social settings.
- This paper contextualizes the socio-cultural, financial constraints, and sanitation policies gaps in the transfer of Ecosan.
- This paper applies the technology diffusion theory to evaluate the current situation of adoption of Ecosan.
- This paper sets strategies to scale up Ecosan coverage beyond the organization and country level.

INTRODUCTION

Ecological sanitation (Ecosan) is a resource-oriented technology, which is able to promote productive sanitation through excreta reuse in areas with inadequate systems for the evacuation of human excreta (Abarghaz *et al.* 2013). The same technology applies the 'sanitize-and-reuse' model through on-site treatment of urine and faeces (Nawab *et al.* 2006). The Ecosan model is being implemented in diverse communities in response to environmental sanitation and agricultural issues (Banamwana *et al.* 2022). The diffusion of Ecosan innovation is widely recognized as crucial to improving health conditions and quality of life. However, despite the benefits of Ecosan, several barriers continue to slow down the process of adoption in the areas of implementation. These barriers appear in form of 'complexities' varying from one country to another and make Ecosan diffusion worldwide a challenge. Many Ecosan programs in various countries have partially succeeded because of

limitations in wide social contexts beyond individual factors (Tamene & Afework 2021). In these societies, some members view Ecosan as an option for human exposure to excreta, which compromises cultural and religious values. Therefore, achieving sanitation targets remains critical despite many years of implementation of the technology in these settings.

Ecosan innovation has advanced in different geographical settings (Angelakis 2017). The period from 1800 to 1965 signified the age of sanitation alignment and technological advancement worldwide (Yannopoulos *et al.* 2017). The concept of Ecosan, however, first appeared in the 1990s as new sanitation millennium agenda (Hu *et al.* 2016). Ecosan innovation has been popular for thousands of years in the Asiatic countries of Vietnam and China (Mayo & Mubarak 2015; Cheng *et al.* 2018). In the past three decades, an effort was made to transfer Ecosan in agricultural areas prone to water scarcity as mentioned in the book 'Sanitation Without Water' published in the early seventies (1970s) by Uno Winblad (Hamburg-harburg 2008). The transfer of Ecosan technology to countries with limited resources like Africa was mostly done by non-governmental sanitation actors and United Nation agencies (Waithaka *et al.* 2007). Despite Ecosan technological advancement worldwide, nearly 40% of the world's population has no access to any appropriate sanitation facility (Ramani *et al.* 2012). Moreover, 85% of excreta wastes from households are globally discharged into sewage systems linked to water bodies without any treatment (Heppleston 2009). Although Ecosan was established to bridge the gaps in environmental sanitation and agriculture through the reuse of excreta, members of some communities are against it and fear close contact with urine and faecal matter (Kumwenda *et al.* 2016). In a bid to expand Ecosan in these communities, a campaign on the use of treated excreta in agriculture has been done (Abarghaz *et al.* 2013). Yet, a disproportionate adoption of Ecosan for sanitation and by-products for agriculture makes such technological diffusion complex in these communities.

Ecosan is not well-known worldwide. Where known, it may be surrounded by a bad reputation of fear of exposure to the excreta (Davies-colley & Smith 2012). A study on the toilet revolution in China (Cheng *et al.* 2018) indicated cost, technical capacities, and low acceptance are lagging behind the revolution of toilets. However, regarding Ecosan, such a revolution has positively affected the use of excreta in agriculture. Early adoption of Ecosan in China (Zhou *et al.* 2010) was due to ecological balance through the reuse of by-products which reduces 85–88% of water pollutants at a lower cost compared with the traditional methods of excreta treatment, whereas a late adoption was reported in countries with high illiteracy and limited resources in Africa (Tamene & Afework 2021). In these areas, Ecosan is considered a pro-poor innovation due to the agricultural income of the small household farmers. However, convincing poor people to install Ecosan remains a challenge in these areas (Chunga *et al.* 2016). Post-implementation studies on Ecosan in Malawi (Chunga *et al.* 2016), Tanzania (Mayo & Mubarak 2015), and Kenya (Waithaka *et al.* 2007) indicated low acceptability and behavioral change toward Ecosan were time-consuming which resulted in the late adoption to some extent of rejection. The sanitation actors need to understand the socio-economic complexities that could hinder the adoption of Ecosan for effective interventions.

Avvannavar & Mani (2007) indicated that sanitation-related practices of any community are closely linked to socio-cultural and religious values and therefore, it becomes hard to change such practices for a new sanitation approach. The rejection of Ecosan by Muslims was due to the existing disgust of fresh faeces which induces a phobia of exposure (Lamichhane & Babcock 2013). Although, treated Ecosan by-products, such phobia remains until Ecosan promoters convince the people about Ecosan technology. Despite the promotion of Ecosan in Pakistan (Strande *et al.* 2018), there was an increase of mistrust among Ecosan users and their neighbors to the extent of shunning food produced under human excreta manure (Schouten & Mathenge 2010). In addition, concerns about trust and adoption were reported in a religious community in Vietnam (Niwagaba 2016). The same study found high risks of parasitic infections among farmers due to exposure to unsanitary by-products. Both studies create a dilemma regarding adoption that needs to be seen through wide lenses of understanding the technological characteristics and associated complexities. Despite all studies done on Ecosan in the social context either presented in scientific publications or institutional reports, review literature that compares contextual findings from these studies remains scarce in the body of knowledge. By reviewing studies on Ecosan in wide socio-cultural, religious, and economic contexts, diverse complexities were identified as barriers to global diffusion of Ecosan. Therefore, understanding such contextual complexities could support implementation strategies of Ecosan for achieving the desired sanitation coverage and sustainable use.

Conceptualizing the adoption and diffusion of Ecosan technology

Innovation adoption and diffusion are inter-related and complementary terminologies. Rogers (2003) defined '*adoption*' as a process by which a technology user decides to start to implement an innovation based on acquired knowledge and persuasion, whereas '*diffusion*' is a process by which an emerging technology in the community is promoted through

communication channels and then adopted by members of that community over time. In this context, diffusion measures the rate of adoption of innovation from one society to another, and the '*Social system*' is an interpersonal network regarding the learning process of Ecosan innovation through interpersonal communication and generalization to the individual belonging groups. '*Complexity*' is a degree of uncertainties beyond individual factors about the emergency of Ecosan technology, which makes it difficult to understand and use, and negatively correlates with the rate of adoption in the social system.

As an innovation technological, Ecosan scale-up is embedded in Everett Rogers' theory, which first appeared in 1962, explaining technology diffusion in society, by focusing on the innovation-decision process (Heppleston 2009). The same theory was applied in this literature review to understand why Ecosan technology is more widely accepted and adopted in some countries than others. Using concepts from this theory, we formulated the study question: What are the barriers to the process of integration of Ecosan technology in a social system? This question sets the basis for conducting a review of the literature to understand the phenomena of adoption of Ecosan as well as the obstacles to the diffusion process worldwide. The literature search involved five aspects namely: stages of knowledge, persuasion, decision, implementation, and confirmation.

REVIEW METHODOLOGY

The literature review on the complexities of adoption and diffusion of Ecosan technology was informed by the theoretical innovation model of Rogers (2003). The Rogers' model represents five stages namely: knowledge, persuasion, decision, implementation, and confirmation by which eligible studies content was reviewed and grouped. Communities' decision to either accept or reject Ecosan technology can be seen in five stages of the innovation-decision process (Figure 1) as defined in the books of Everett Rogers (2003).

Search strategy

The literature was sourced from the following electronic databases: Hinari from Science Direct, Web of Science, Google search engine, and Google scholar, Journal articles, conference proceedings, and published books were searched, using two main concepts 'Ecological sanitation' or 'Urine Diversion Dry Toilets'. We searched the literature using key terms related to the concept of 'Ecological sanitation' such as 'Ecosan' and 'Ecosan technology,' and key terms related to 'Urine Diversion Dry Toilets', such as latrine, Eco-toilet, and fossa alterna. Terms from the two concepts were paired to search study titles and abstracts as follows: Ecosan OR complexities OR adoption OR Eco-toilet OR acceptability OR diffusion AND latrine OR diversion OR technology OR adoption OR Excreta. Although the search was not limited to any geographical area, it was done according to their relevance to the developing country context. All literature sourced were English publications.

Search selection and eligibility

The literature search of peer-reviewed studies on Ecosan published in English focused on three study themes: Ecosan in the contexts of the social system, technology, and Ecosan by-products. Studies were excluded based on the year of publication, duplication of information, and irrelevant abstracts. We only included studies on Ecosan published between 2010 and 2020

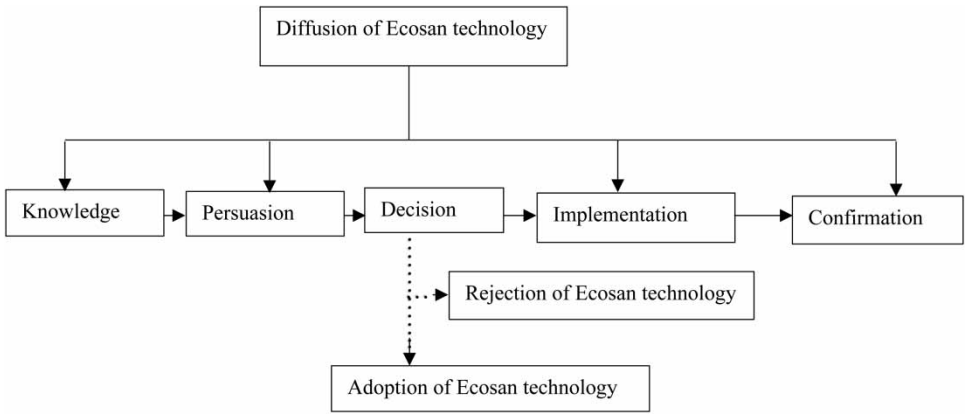

Figure 1 | Five stages of the diffusion process of Ecosan technology. Adapted from Rogers' model (Ismail 2016).

with attributes of adoption patterns at levels of individual, household, and community with the best fit in the stages of Rogers' model (Rogers 2003). Studies were grouped in these stages according to each study's outcome appropriate to the stage of technological diffusion theory of Rogers (2003), as indicated in Figure 2. Studies with a focus on knowledge were classified at the knowledge stage, studies that assessed people's attitudes and perceptions were categorized at the persuasion stage, studies on Ecosan with acceptability and rejection were considered at the decision stage, and studies on Ecosan with patterns of implementation were grouped at implementation stage and studies on Ecosan with patterns of utilization were assessed under confirmation stage of Rogers' diffusion theory (Rogers 2003). However, this review excluded the studies on Ecosan

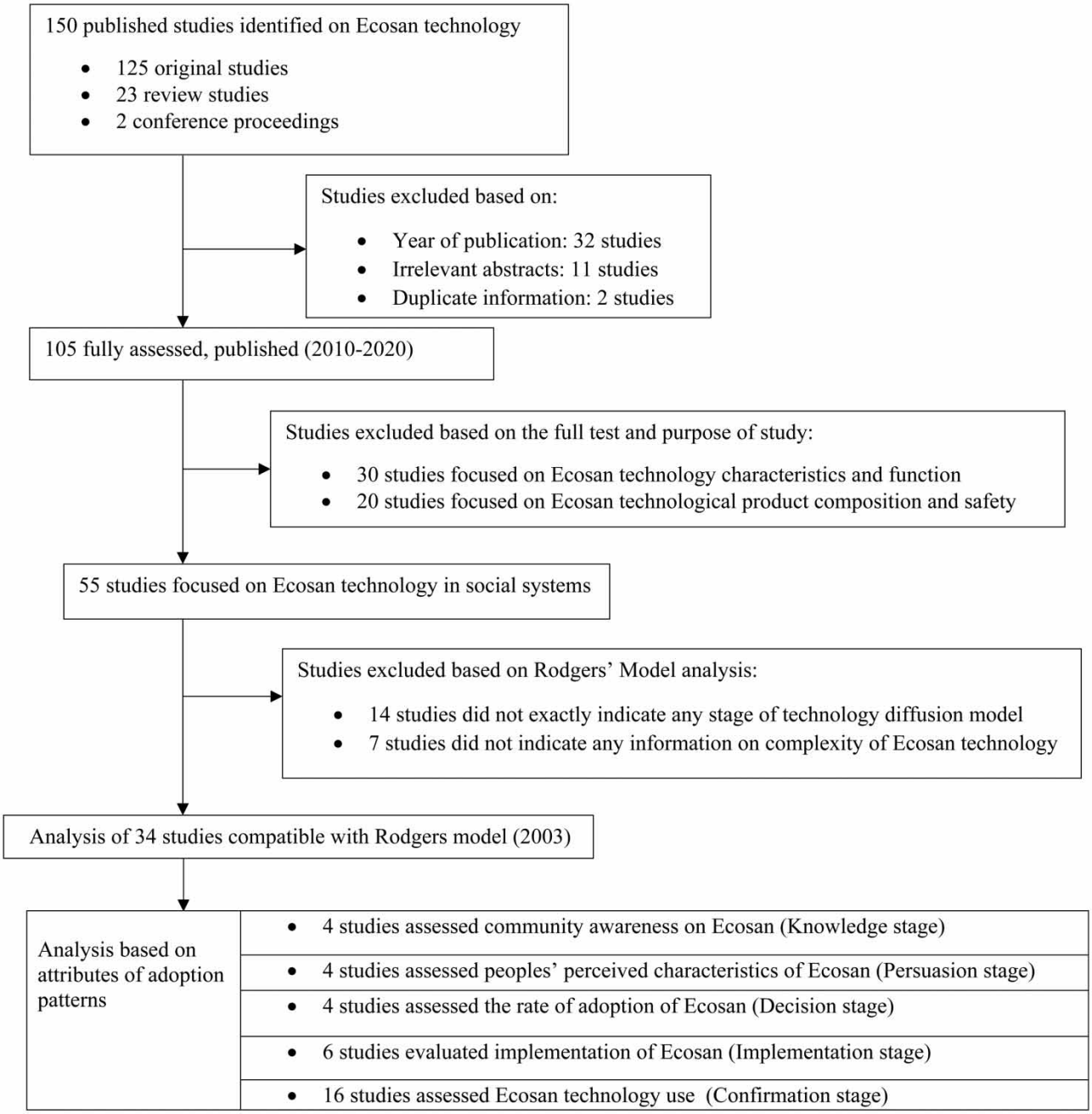

Figure 2 | Flow diagram of publications considered for the review process.

with adoption patterns at levels of individual, household, community, and society with only positive correlated attributes with the rate of adoption.

Data management and extraction

Relevant studies were saved in a folder and the purpose of the study and full texts were read. Eligible studies were organized into a matrix in MSWord according to the five stages of Rogers' framework (Rogers 2003). Two researchers participated in screening the studies. The two researchers independently read the full articles before deciding on inclusion and exclusion following the same criteria as indicated in Figure 2. The agreement was reached at the first stage of selection and the final decision on a certain disagreement was taken based on consensus.

RESULTS OF THE LITERATURE SEARCH

The search strategy yielded 150 published studies, of which 2 duplicate studies were directly removed and 32 studies were excluded due to the year of publication. Upon reading the abstracts, 11 studies presented irrelevant abstracts and were excluded. The next stage was to read the contents of the remaining 105 studies to exclude those which were not related to social systems. We excluded 30 studies on Ecosan technology characteristics and function and 20 studies on Ecosan technological product, composition, and safety. The remaining 55 studies were tested against the technology diffusion model of Rogers (2003). As a result, 14 studies did not exactly indicate any information related to the stage of the technology diffusion model and 7 studies did not present any information on the complexity of Ecosan technology. The remaining 34 studies were compatible with the stages of the innovation model of Rogers (2003) and met the eligibility criteria as the final sample of studies. All 34 reviewed studies were distributed across the same model, based on the criteria of study outcomes as follows: four studies each were presented at the knowledge, persuasion, and decision stages, six studies were considered at the implementation stage and 16 studies were eligible at the confirmation stage (Table 1).

Common characteristics of included studies

Among the final 34 studies with broader research designs, 10 review articles were included in this review process, and the remaining articles used qualitative, quantitative, and mixed methods. The majority (16) studies were conducted in countries of Africa, specifically in Malawi, Uganda, Burkina Faso, Tanzania, Uganda, Rwanda, Ghana, and South Africa, 12 studies were conducted in Asiatic countries of China, Bangladesh, India, Hong Kong, and Vietnam, and the remaining 6 studies were conducted in Sweden, France, USA, Mexico, France, and UK.

Ecosan adoption

With regard to Ecosan adoption patterns, four studies explored knowledge about Ecosan (Jana 2011; Tumwebaze & Niwagaba 2011; Kumwenda *et al.* 2016; Bhardwaj *et al.* 2017), four studies focused on persuasion (Jewitt 2011; Andersson 2015; Seleman & Bhat 2016; Simha *et al.* 2017), four studies emphasized on adaptive decision-making of Ecosan (Uddin *et al.* 2014; Fry *et al.* 2015; Mayo & Mubarak 2015; Chunga *et al.* 2016), four studies evaluated the implementation of Ecosan (Magri *et al.* 2013; Tumwebaze & Mosler 2014; Sangare *et al.* 2015; Hu *et al.* 2016; Krause *et al.* 2016), and 16 studies emphasized on Ecosan utilization as evidence of confirmation (Cofie *et al.* 2010; Zhou *et al.* 2010; Andersson *et al.* 2011; Davies-colley & Smith 2012; Haq & Cambridge 2012; Lalander *et al.* 2013; Pham-duc *et al.* 2013; Roma *et al.* 2013; Ganiron 2015; Ekane *et al.* 2016; Gao *et al.* 2017; Krause *et al.* 2016; Taseli & Kilkis 2016; Kumwenda *et al.* 2017a, 2017b; Dickin *et al.* 2018).

A final list of 34 studies was analyzed according to the adoption patterns under knowledge, persuasion, decision-making, implementation, and confirmation. Some studies presented a wide scope of analysis for more than one stage, but none covered all the stages. The adoption patterns and their associated attributes were generated inductively by merging the attributes of complexity identified in the review with the ones of Rogers' model (2003) at each stage. The conceptualized similarities of complexities were classified into three groups: Entry process of Ecosan, action process of Ecosan, and impact action of Ecosan.

Entry process of Ecosan

The entry process of Ecosan was described in eight studies (Jana 2011; Jewitt 2011; Tumwebaze & Niwagaba 2011; Andersson 2015; Kumwenda *et al.* 2016; Seleman & Bhat 2016; Bhardwaj *et al.* 2017; Simha *et al.* 2017) with a highlight of individual factors of knowledge (Jana 2011; Tumwebaze & Niwagaba 2011; Bhardwaj *et al.* 2017), attitudes and practice

Table 1 | Literature analysis of the complexity of diffusion of Ecosan following five stages of innovation

Authors and year	Country	Study methods	Knowledge stage	Persuasion stage	Decision-made stage	Implementation stage	Confirmation stage	Complexity
Jewitt (2011)	UK	Systematic review	[a]	Ecosan threats and opportunities	[a]	[a]	[a]	Spatial and cultural boundaries
Andersson (2015)	Uganda	Participatory action research	[a]	Participation of Ecosan users	[a]	[a]	[a]	Unclear user guidelines
Simha *et al.* (2017)	India	Quantitative	[a]	Drivers and hinders of Ecosan uptake	[a]	[a]	[a]	Religious taboos
Seleman & Bhat (2016))	Tanzania	Mixed	[a]	Feasibility and sustainability of Ecosan	[a]	[a]	[a]	Negative attitude on human faeces
Cofie *et al.* (2010)	Ghana	Quantitative	[a]	[a]	[a]	[a]	Perceptions and economic benefits	Lack supporting supervision
Krause *et al.* (2016)	China	Quantitative	[a]	[a]	[a]	[a]	Crop production	Poor application practice of Ecosan products
Andersson *et al.* (2011)	South Africa	SWAT model	[a]	[a]	[a]	[a]	Failure to maximize Ecosan demand	Insufficiency of Ecosan products
Ganiron (2015)	Hong Kong	Review	[a]	[a]	[a]	[a]	Ecosan system must be regularly monitored	Phobia against the reuse of excreta
Haq & Cambridge (2012)	Sweden	System review	[a]	[a]	[a]	[a]	The co-benefits of Ecosan	Unsafe Ecosan product
Zhou *et al.* (2010)	China	Review	[a]	[a]	[a]	[a]	Ecosan benefits	Excreta exposure
Gao *et al.* (2017)	China	Review	[a]	[a]	[a]	[a]	Ecosan acceptability	Environmental constraints
Lalander *et al.* (2013)	France	Quantitative	[a]	[a]	[a]	[a]	Hygienic quality	Safety issues
Taseli & Kilkis (2016)	USA	Review	[a]	[a]	[a]	[a]	Ecosan closing the loop	Diversification of Ecosan options
Pham-duc *et al.* (2013)	India	Quantitative	[a]	[a]	[a]	[a]	Ecosan model	On-site contamination
Roma *et al.* (2013)	South Africa	Quantitative	[a]	[a]	[a]	[a]	Ecosan challenges	Malfunctioning of the pedestal

(*Continued.*)

Table 1 | Continued

Authors and year	Country	Study methods	Knowledge stage	Persuasion stage	Decision-made stage	Implementation stage	Confirmation stage	Complexity
Ekane *et al.* (2016)	Rwanda & Uganda	Quantitative	[a]	[a]	[a]	[a]	Low use of Ecosan/ UDDTs	Lack of stake holding
Kumwenda et al. (2017a)	Malawi	QMRA	[a]	[a]	[a]	[a]	Health risks	Microbial risks
Kumwenda et al. (2017b)	Malawi	Quantitative	[a]	[a]	[a]	[a]	Infections	*Ascaris lumbricoides*
Dickin *et al.* (2018)	Burkina Faso	Quantitative	[a]	[a]	[a]	[a]	Post-implementation	Menstrual pads management
Davies-colley & Smith (2012)	Mexico	Case study	[a]	[a]	[a]	[a]	A bad reputation on Ecosan	Technical support
Tumwebaze & Mosler (2014)	Uganda	Intervention study	[a]	[a]	[a]	Sharing Ecosan toilets	[a]	Privacy and security
Magri *et al.* (2013)	Vietnam	Experimental design	[a]	[a]	[a]	Inactivation of faecal pathogens	[a]	Long excreta decomposition time
Sangare *et al.* (2015)	Burkina Faso	Experimental setup	[a]	[a]	[a]	Ecosan product on the farms	[a]	Functionality issues
Krause *et al.* (2016)	Tanzania	Experimental setup	[a]	[a]	[a]	Ecosan as a soil fertility improver	[a]	Pollution facts
Hu *et al.* (2016)	China	Systematic review	[a]	[a]	[a]	Ecosan affordable	[a]	Cleaning and reparation of slabs hard
Simha & Ganesapillai (2016)	India	Systematic review	[a]	[a]	[a]	Ecosan as nutrient recovery	[a]	Diversification of fertilizers
Chunga *et al.* (2016)	Malawi	Mixed	[a]	[a]	Ecosan choices	[a]	[a]	High capital costs
Mayo & Mubarak (2015)	Tanzania	Mixed	[a]	[a]	Ecosan adoption	[a]	[a]	Misuse of ash
Fry *et al.* (2015)	Ethiopia	Mixed	[a]	[a]	Ecosan Adoption and values	[a]	[a]	Hard excreta emptying
Uddin *et al.* (2014)	Bangladesh	Mixed	[a]	[a]	Socio-cultural acceptance	[a]	[a]	Anal washing

(*Continued.*)

Table 1 | Continued

Authors and year	Country	Study methods	Knowledge stage	Persuasion stage	Decision-made stage	Implementation stage	Confirmation stage	Complexity
Jana (2011)	India	Review	Traditional knowledge on Ecosan	[a]	[a]	[a]	[a]	Large scope
Tumwebaze & Niwagaba (2011)	Uganda	Quantitative	Knowledge about Ecosan	[a]	[a]	[a]	[a]	Knowledge gaps
Bhardwaj *et al.* (2017)	India	Qualitative	Female literacy	[a]	[a]	[a]	[a]	Illiteracy
Kumwenda *et al.* (2016)	Malawi	Qualitative	Knowledge, attitudes and practices	[a]	[a]	[a]	[a]	Stranger technology

[a]No available suitable information.

(Kumwenda *et al.* 2016; Seleman & Bhat 2016), community awareness (Andersson 2015), and perceptions on Ecosan (Jewitt 2011; Simha *et al.* 2017). These studies complied with the stages of knowledge and persuasion of Rogers' model (2003). All these individual factors are interconnected and influenced by other external factors such as awareness made by innovators of Ecosan or other external sanitation agents through different communication channels.

Action process of Ecosan

The action process was identified in four studies (Uddin *et al.* 2014; Fry *et al.* 2015; Mayo & Mubarak 2015; Chunga *et al.* 2016). It comprises actions of piloting Ecosan in households (Mayo & Mubarak 2015) and options of acceptability (Uddin *et al.* 2014; Fry *et al.* 2015; Chunga *et al.* 2016). These studies grouped in this category were all focused on Ecosan at the household level which informed the level of analysis at the household. All these studies focused on the household beneficiaries of Ecosan either received by hand or install for themselves.

Impact action of Ecosan

The impact action of Ecosan was evaluated in 22 studies including 6 studies on implementation (Magri *et al.* 2013; Tumwebaze & Mosler 2014; Sangare *et al.* 2015; Hu *et al.* 2016; Krause *et al.* 2016) and 16 studies on confirmation (Cofie *et al.* 2010; Zhou *et al.* 2010; Andersson *et al.* 2011; Davies-colley & Smith 2012; Haq & Cambridge 2012; Lalander *et al.* 2013; Pham-duc *et al.* 2013; Roma *et al.* 2013; Ganiron 2015; Ekane *et al.* 2016; Gao *et al.* 2017; Krause *et al.* 2016; Taseli & Kilkis 2016; Kumwenda *et al.* 2017a, 2017b; Dickin *et al.* 2018). These studies aimed to evaluate the implementation of Ecosan in the community. The analysis of relevant studies generated vast findings, which were categorized into the five stages of the innovation diffusion model. Basic data from each study: author and publication date, study country, study methods, and key findings, including Ecosan complexities, are presented in Table 1.

DISCUSSION

Ecosan technology's scale-up requires broad contextual adoption and diffusion characteristics (Davies-colley & Smith 2012). Ecosan diffusion characteristics have been widely discussed: relative advantages (Benetto *et al.* 2008), trialability (Abarghaz *et al.* 2013), observability (Mackie Jensen *et al.* 2008), and compatibility (Grimstedt 2015). However, there is a scarcity of studies on Ecosan technology focusing on the diffusion characteristic of complexity. A few studies on Ecosan technology identified multiple complexities of adoption and diffusion; however, none of them provides a critical analysis based on the model of Rogers (2003). Therefore, there is a need for critical empirical evidence on the key complexities that continue to hamper the promotion of Ecosan technology in diverse social systems.

Altogether, 34 sourced literature were analyzed based on the Everett Rogers model (Rogers 2003). The model explains the technology diffusion theory through stages of behavior change among beneficiaries of Ecosan technology. Diffusion theory is important to understand why the adoption of Ecosan technology in some countries is still hampered and diffusion from one society to another remains slow.

Analysis of reviewed literature through the five stages of the theoretical model of Rogers (2003) has generated a typical range of complexities of Ecosan technology in diverse social systems. Complexities were grouped into three phases, namely 'entry of Ecosan technology', 'action process of Ecosan technology', and 'impact action of Ecosan technology', which are typically linked to Everett Rogers' theory of technology diffusion in society (Figure 3). 'Entry of Ecosan technology' in society involves all complexities found at the knowledge and persuasion stages. 'Action process of Ecosan technology' includes complexities in the stage of decision, while 'impact of the action on Ecosan technology' includes all complexities in the implementation and confirmation stages.

The review findings were discussed under the five stages of knowledge, persuasion, decision, implementation, and confirmation organized according to the three phases: entry of Ecosan technology, action process of Ecosan technology, and impact of the action on Ecosan technology by which major complexities were grouped.

Entry of Ecosan technology in the social system

The scale-up of Ecosan technology in society is underpinned by the same principles as other technologies. The entry of Ecosan technology in any society can be an option to respond to the existing sanitation problems through behavior changes. However, the rate of diffusion of such technology depends on different factors including the nature of interventions, values of technology, and social contextual factors (Davies-Colley & Smith 2012). By referring to Everett Rogers' model (Rogers 2003),

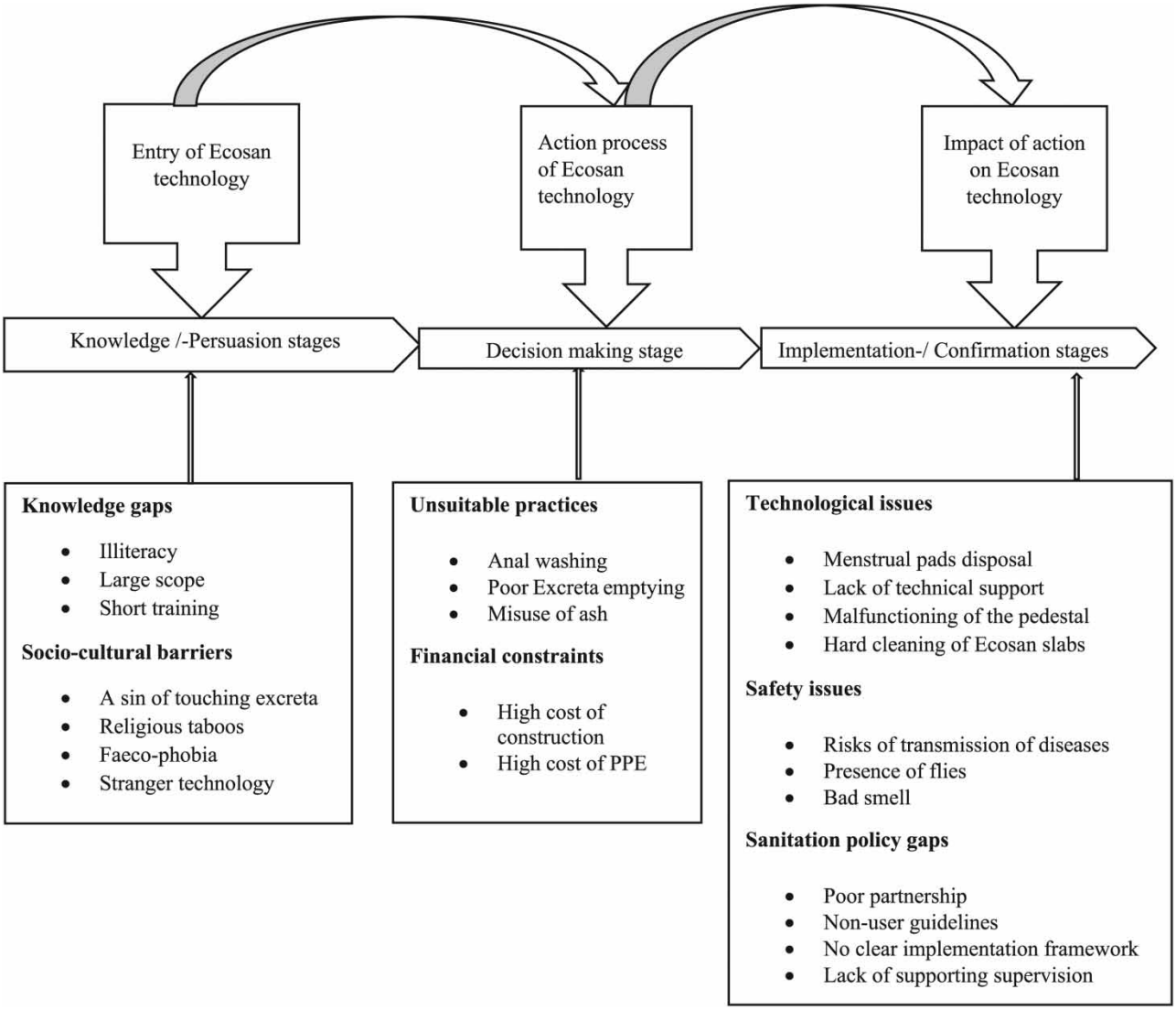

Figure 3 | Major categories of complexities alongside diffusion process of Ecosan technology.

the introduction of Ecosan technology in a new social setting evolves from the breakdown of socio-cultural taboos through technological evidence-based knowledge.

Knowledge stage

Ecosan technology is seen as novel, not popularly known in some parts of the world (Winker *et al.* 2009). As other technological innovations, the entry of Ecosan technology in society might follow the stages of the innovation diffusion model of Rogers (2003). The model describes the first stage as a knowledge outcome that responds to the questions 'how', 'what', and 'why' Ecosan technology. Analysis of the four reviewed studies assessing knowledge outcomes about Ecosan is not methodologically built on the theoretical model of innovation as cited in Hope & Jones (2014). Some studies indicated Ecosan awareness among community members on 'what about Ecosan' and 'why Ecosan in the community'. However, there is a gap in understanding the full package on 'how Ecosan technology works'. Moreover, among these studies, none of them captured all forms of complexities at the knowledge stage as vary from society to society.

Some studies indicated certain compatibility with Ecosan technology as a sanitation option through a package of training in the areas of implementation. Other studies highlighted knowledge gaps when it is about the use of Ecosan by-products (Jana 2011; Tumwebaze & Niwagaba 2011; Bhardwaj *et al.* 2017). Evidence of contradictory studies' findings as facts of

lack of analysis scheme at the knowledge stage as stipulated in a model of Rogers (2003). According to the model, the adoption of any technology is a process; any particular technology undergoes to be accepted by members of society over time. Studies described an early extension of Ecosan projects at the implementation stage in the community by sanitation actors (Simha *et al.* 2017). Yet, the members of the community are ambiguous about technology and have no clear evidence on the level of knowledge about it (Davies-colley & Smith 2012). This resulted in the risk of discontinuance of such Ecosan projects in different parts of the world, particularly in limited resources areas (Jewitt 2011). Mapping evidence on illiterate and package of training on Ecosan technology could be relevant to inform the appropriate educational intervention on Ecosan in different social systems.

Persuasion stage

The perceived characteristics of Ecosan technology among beneficiaries determine the rate of adoption (Ismail 2016). The four studies that evaluated people's attitudes and perceptions after the entry of Ecosan technology discussed the relative advantages of Ecosan (Abarghaz *et al.* 2013; Rose *et al.* 2015) and technology compatibility with beneficiaries (Maurer *et al.* 2012; Chunga *et al.* 2016). However, none of these studies discussed in depth the characteristics of the technology for a better understanding of the likely complexities that can negatively correlate with technological adoption. Such complexities could be addressed through beneficiaries' behavior changes as cited in Rogers' theory. Evidence of diverse socio-cultural complexities in reviewed studies under the analysis of Rogers' theory decline the actual adoption of Ecosan.

Although studies presented the relative advantages and values of waterless technology and excreta resource-oriented technology in some communities, the same studies highlight taboos in some communities where touching excreta is considered as a sin and anal wipe is not a common practice (Seleman & Bhat 2016; Simha *et al.* 2017). Such correlation of findings creates scientific evidence reliable by change agents during Ecosan piloting projects in the implementation areas. A need to reduce the degree of uncertainties about Ecosan technology requires identifying and reducing faeco-phobia among household members at an early stage (Simha *et al.* 2017).

Action process of Ecosan technology

The promotion of Ecosan technology in different areas continues to be problematic at the decision-making stage of innovation diffusion in Rogers model (Rogers 2003). Most actions, such as piloting Ecosan technology through educational intervention, construction, and supply of Ecosan materials, are likely to be undermined to the extent of rejection of Ecosan technology (Mayo & Mubarak 2015). Consequently, technological uncertainty in the mind of beneficiaries continues to rise, despite the efforts made by sanitation actors as indicated in the review analysis on the decision-making stage of Rogers model (Rogers 2003).

Stage of decision-making

According to Rogers' model (Rogers 2003), the available actions and communication channels made by change agents or earl adopters can make a receiver satisfied or unsatisfied with an innovation (Proctor *et al.* 2011). It is important to note that the capability of most external change agents and their ways of communication were critical to the strong decision to adopt Ecosan technology (Jones *et al.* 1998). At the same stage, the author differentiates so-called active rejection as the later decision of rejection made by beneficiaries after a technological trial, while 'passive rejection' is a direct discontinuance of technology decision-made by beneficiaries. At the decision stage, the four studies on Ecosan adoption indicated only the active rejection of Ecosan technology as it was used for a certain time and later rejected in some parts of the world (Mugure & Mutua 2009). In such a review, both types of rejection were not distinguished with insufficient evidence in the process of diffusion of Ecosan technology in the social systems. Few available studies described the later discontinuance of Ecosan as correlating with major socio-economic complexities in areas with limited resources (Mayo & Mubarak 2015), as shown in Figure 3.

Rogers' theory articulates the economic factor of beneficiaries as a leading indicator to start implementing any innovation in the community. This could be justified by the cost and benefit analysis frame of such innovation (Rogers 1983). Concerning Ecosan, such cost and benefit analysis model was not sufficiently documented (Gao *et al.* 2017) and hence was not reliable by most sanitation actors before embarking on the next stage. There was evidence that Ecosan actors failed to make Ecosan technology affordable to the poor beneficiaries (Ekane *et al.* 2016). This review finds out a high investment cost and maintenance of Ecosan and poor sanitation practices at the stage of decision making as cited in Figure 3. Subsidizing the capital and maintenance costs of Ecosan on the parts of beneficiaries can speed up the diffusion process of Ecosan in poor societies.

Impact of action on Ecosan technology

The nature and effort of actions made by change agents determine the future commitment to using innovative technology among beneficiaries (Heppleston 2009). As the stages of diffusion of technology innovation are sequential and interconnected, it is important to evaluate the diffusion process of any technology over time among members of the community. Such action impacts can decline with new emerging technologies or existing contextual complexities in the areas of implementation.

Implementation stage

This stage is characterized by putting into practice the technology after acceptance by beneficiaries (Proctor *et al.* 2011). According to Rogers' theory, technical support and the provision of expertise are of paramount importance at this stage. However, six studies on Ecosan implementation reveal the lack of technical expertise in the operation and maintenance of Ecosan technology in China (Sangare *et al.* 2015), Burkina Faso (Dickin *et al.* 2018), and Uganda and Rwanda (Ekane *et al.* 2016). This is evidence of early implementation by change agents, without a clear understanding of the adoption rate among community members. This increases the risks of rejection of technology among beneficiaries at a later stage in the cited countries. In addition, the same studies indicated a weak package of intervention that failed to change beneficiaries' behavior and existing poor practices toward Ecosan. For example, a post-implementation study on Ecosan technology done in Uganda showed that most Ecosan agents were foreigners, their implementations were characterized by Do's and Don'ts applied approaches and a lack of active participation of community members (Tumwebaze & Niwagaba 2011). The same sanitation agents were accused of installing Ecosan technology within a short mandate under funding limitation without change in practices toward Ecosan technology (Kumwenda *et al.* 2016). A need for action research with community participation could avoid such technical dependency and make local expertise and technology user-friendly.

Confirmation stage

The confirmation of any sanitation facility depends on attributes such as the ability to provide privacy, comfort, and safety to the user. Everett Rogers' model describes the stage of confirmation as a standard level to use an innovation but always seeks to reinforce his or her decision. Nevertheless, a decision can be reversed at any time as long as the person receives conflicting information about the innovation. A total of 16 studies demonstrated complexities that conflicted with the sustainable use of Ecosan technology among users. Although some studies identified technological complexities in the use of ash additives, which are not always available, others presented Ecosan as a sustainable response to environmental sanitation and agriculture (Trimmer *et al.* 2016). It is noted that the potential adopters of Ecosan technology are always exposed to conflicting messages from non-adopters such as neighbors who accuse them to expose people to their excreta (Simha *et al.* 2017). A lack of trust among members of the community on the use of Ecosan technology continues to hamper the adoption as well as diffusion worldwide.

According to Rogers' theory, potential adopters always seek to reinforce the decision made under the stake holding framework (Rogers 1983). In contrast, studies on Ecosan threats and opportunities (Ekane *et al.* 2016) highlight a lack of clear partnership between Ecosan agents and local leaders as core complexities that weaken its proper use. In addition, lack of regular follow-up and poor sanitation policy are leading causes of rejection of Ecosan technology in some social settings (Dickin *et al.* 2018). Such reviews show that the confirmation stage does not mean the terminal stage of adoption as long as sub-standard technicity and poor sanitation policy are still present. Regular supporting supervision of Ecosan users can keep high consistency in the utilization of Ecosan in the community and hence sustainable sanitation coverage.

CONCLUSION

This paper provides a comprehensive review of the complex issues that challenge the adoption and diffusion of Ecosan worldwide. Drawing on the theoretical foundations of innovation diffusion of Rogers (2003) the technology adoption process moves from knowledge to the confirmation stage. This is evidence of depth review analysis in a wide lens of Ecosan adoption beyond individual factors, using multiple levels of analysis of attributes of adoption patterns. The findings show that the complexities of Ecosan adoption patterns are geographic and social context. A better understanding of all forms of complexities of Ecosan adoption in different geographical and social settings can inform appropriate interventions by the provision of knowledge, skills, and creation of social networks through financial support for the promotion of Ecosan worldwide. Many studies identified only a single attribute of adoption patterns; hence, the need to understand multiple concerns related to the adoption

of Ecosan in a diverse social context. Therefore, there is a need for further studies to determine the rate of adoption of Ecosan under investigation of associated attributes for prediction of the future Ecosan coverage in different parts of the world.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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