Published by the UFS
http://journals.ufs.ac.za/index.php/trp
© Creative Commons With Attribution (CC-BY)
How to cite: Kabundu, E., Mbanga, S., Makasa, P. & Ngema, N. 2022. User-acceptance of sanitation technologies in South Africa and Malawi. *Town and Regional Planning*, no. 80, pp. 88-104.

User-acceptance of sanitation technologies in South Africa and Malawi

Emmanuel Kabundu, Sijekula Mbanga, Paul Makasa & Noxolo Ngema

Research article

DOI: http://dx.doi.org/10.18820/2415-0495/trptrp80i1.9

Received: September 2021

Peer reviewed and revised: March 2022

Published: June 2022

**The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article*

Abstract

There is a great need for the planning and implementation of sanitation technologies (STs) to take into consideration the user-acceptance factor and, therefore, limit resource wastage. This article aims to determine whether the pattern of relative importance of the factors that affect sanitation technology user-acceptance (STUA) is similar across study areas located in South Africa and Malawi with respect to the STs rolled out. Information from the study is especially critical for resource conservation, considering the recent relatively poor performance of the South African economy (a 7% slump) in 2020. Desktop research methods, using data from previous studies, were used to perform an analysis of the significance of the underlying factors that influence STUA. These were based on a systematic review that uses a structured protocol for literature review, together with the snowball approach. The methodology proposed by the Water Research Commission (WRC) under the sanitation suitability index was used to perform the sanitation technology comparisons. This article adds value to previous research in that, unlike previous research studies, it considers several relevant researched technologies to establish whether there exist similar patterns of relative significance of factors that influence STUA. Reliability, health, user- and technical acceptability were the predominant influencers of STUA. Education, training, and technical support are necessary throughout the sanitation project life cycle.

Keywords: Reliability, sanitation index, sanitation, sanitation technologies, technical acceptance, user-acceptance, VBN-model

GEBRUIKERSAANVAARDING VAN SANITASIETEGNOLOGIE IN SUID-AFRIKA EN MALAWI

Daar is ’n groot behoefte aan die beplanning en implementering van sanitasietegnologieë (ST’e) om die gebruikeraanvaardingsfaktor in ag te neem en dus hulpbronvermorsing te beperk. Hierdie artikel bepaal of die patroon van relatiewe belangrikheid van die faktore wat sanitasietegnologie-gebruikersaanvaarding (STUA) beïnvloed, soortgelyk is oor studiegebiede in Suid-Afrika en Malawi met betrekking tot die ontplooiing van ST’e. Inligting uit die studie is veral krities vir hulpbronbewaring, in ag genome die onlangse relatief swak prestasie van die Suid-Afrikaanse ekonomie (‘n 7% vermindering) in 2020. Lessenaarnavorsingsmetodes, met behulp van data van vorige studies, is gebruik om ’n analise uit te voer van die belangrikheid van die onderliggende faktore wat STUA beïnvloed. Dit is gebaseer op ’n sistematiese literatuuroorsig wat ’n gestruktureerde protokol gebruik, tesame met die sneeubalbenadering. Die metodologie wat deur die Waternavorsingskommissie (WNR) onder die sanitasie-geskiktheidsindeks voorgestel is, is gebruik om die sanitasietegnologie-vergelykings uit te voer. Hierdie artikel voeg waarde toe tot vorige navorsing deurdat dit, anders as vorige navorsingstudies, verskeie relevante nagevorsde tegnologieë oorweeg om vas te stel of daar soortgelyke patrone van relatiewe betekenis van faktore bestaan wat STUA beïnvloed. Betroubaarheid, gesondheid, gebruikers- en tegniese aanvaarbaarheid was die oorheersende beïnvloeders van STUA. Onderwys, opleiding en tegniese ondersteuning is nodig gedurende die lewensiklus van die sanitasieprojek.

Sleutelwoorde: Betroubaarheid, gebruikersaanvaarding, sanitasie, sanitasie-indeks, sanitasietegnologieë, tegniese aanvaarding, VBN-model

Dr Emmanuel Kabundu, Researcher, Department of Building and Human Settlement Development, Nelson Mandela University, P.O. Box 77000, Gqeberha (Port Elizabeth), 6031, South Africa. Phone: 0729017550, email: kabunduemmanuel@gmail.com, ORCID: https://orcid.org/0000-0001-6201-465X

Prof. Sijekula Mbanga, Department of Building and Human Settlement Development, Chair, Sustainable Human Settlements, Nelson Mandela University, P.O. Box 77000, Gqeberha (Port Elizabeth), 6031, South Africa. Phone: 0729674093, email: sijekula.mbanga@mandela.ac.za, ORCID: https://orcid.org/0000-0001-9439-7552

Prof. Paul Makasa, Department of Architecture, Nelson Mandela University, P.O. Box 77000, Gqeberha (Port Elizabeth), 6031, South Africa. Phone: 0840948026, email: paul.makasa@mandela.ac.za, ORCID: https://orcid.org/0000-0003-3533-5276

Ms Noxolo Ngema, Researcher, Department of Building and Human Settlement Development, Nelson Mandela University, P.O. Box 77000, Gqeberha (Port Elizabeth), 6031, South Africa. Phone: 0637294330, email: s215126769@mandela.ac.za

KAMOHELO EA BASEBELISI BA THEKNOLOJI EA LIKHOEREKHOERE AFRIKA BOROA LE MALAWI

Ho na le tlhokahalo e kholo ea ho rala le ho kenya tšebetsong mahlale a tsamaiso ea likhoerekhoere (STs) ele ho ela hloko ntlha ea kamohelo ea basebelisi, ka hona, ho fokotsa tšenyo ea lisebelisoa. Sengoliloeng sena se ikemiselitse ho fumana hore na mehlala ea bohlokoa e amang kamohelo ea basebelisi ba theknoloji ea likhoerekhoere (STUA) e ea tšoana ha e bapisoa le li-ST tse phatlalalitsoeng libakeng tsa boithuto ka kakaretso linaheng tsa Afrika Boroa le Malawi. Tlhahisoleseding e tsoang phuputsong ena e bohlokoa haholo bakeng sa paballo ea moruo, haholo ha ho ipapisoa le tshebetso e mpe morao tjena ea moruo wa Afrika Borwa (ho putlama ka 7%) ka 2020. Mekhoa ea ho etsa lipatlisiso ka komporo, ho sebelisoa lintlha tse tsoang lithutong tse fetileng, e ile ea sebelisoa ho etsa tlhahlobo ea bohlokoa ba mabaka a ka sehloohong a susumetsang STUA. Tsena li ne li ipapisitse le tlhahlobo e hlophisitsoeng ea lingoliloeng, hammoho le mokhoa o ikhethileng oa ho khetha bankakarolo boithutong bona. Mokhoa o hlahisitsoeng ke Komisi ea Lipatlisiso ka Metsi (WRC) tlas'a sesupo sa ho tšoaneleha ha tsamaiso ea likhoerekhoere o ile oa sebelisoa ho etsa papiso ea theknoloji ea likhoerekhoere. Sengoliloeng sena se eketsa boleng ba lipatlisiso tse fetileng ka hore, ho fapana le boithuto ba pele, se sheba mahlale a 'maloa a bohlokoa a entsoeng ho fumana mekhoa e ts'oanang e amanang le lintlha tse susumetsang STUA. Ho tšepahala, bophelo bo botle, kamohelo ea basebelisi le tšebeliseho e ne e le tsona litšutšumetso tse ka sehlohong tsa STUA. Thuto, koetliso, le tšehetso lia hlokahala ntšetsopeleng ea merero oa tsamaiso ea likhoerekhoere.

1. INTRODUCTION

Globally, from 2015 to 2030, it is estimated that roughly 1.1 billion people would need services to end open defecation, which translates to a budget of US$6 billion annually, while 3.4 billion people, equivalent budget of US$33 billion annually, would need basic sanitation services (Mudombi, 2018:2; World Bank, 2016: 2). According to the World Bank statistical data of 2016, roughly 62% of the global sanitation-related budget between 2015 and 2030 would need to be spent, not on the above two items, but on safe management of faecal sludge (Mudombi, 2018: 2).

During the same period in South Africa, it is estimated that 18.3 million people would require basic sanitation services, equivalent to a budget of US$370 million annually, and roughly US$21 million annually, for one million people, would need to be spent on ending open defecation (Mudombi, 2018: 4). However, greater emphasis would still need to be placed on safe management of faecal sludge from all sources, including, but not limited to waste-water treatment plants, with 32 million people (annual budget of US $970 million or 69% of expenses on sanitation) requiring this service (Mudombi, 2018: 4). The annual investment by South Africa into sanitation in 2019/2020 was estimated to be R17.5 billion (NT, 2017). This was insufficient for both the backlogs and the new services (Mudombi, 2018: 6; WRC, 2019: 2). This emphasises the need to carefully plan the roll-out of sanitation technologies.

Significant progress has been made towards improving the sanitation conditions of households in South Africa. Between 2002 and 2017, the national percentage of households with improved sanitation increased from 62% to 83% (WRC, 2019: 10). By 2014, ecological sanitation toilets were slowly coming into the South African environment as alternatives to flush toilets, pit latrines, and bucket toilets. However, only 0.1%, 0.2%, and 0.1% of the households in South Africa used the ecological sanitation toilets in 2014, 2015 and 2019, respectively (SSA, 2016: 68; SSA, 2020: 43). There has been a low acceptance of the Ecosan technologies in South Africa.

In the case of Malawi, inadequate sanitation and hygiene have been major contributors to the burden of disease and child mortality, accounting for US$57 million annually, or 1.1% of national GDP, due to health costs and productivity losses (SSA, 2021; WSP, 2012: 1). In 2017, approximately 66%, 75% and 74% of households did not have access to basic sanitation services in urban areas, rural areas and nationally, respectively (UNICEF, 2019: 116). Conversely, 1% and 7% of the households practised open defecation in urban and rural areas, respectively. Because of increasing population density in Lilongwe, there has been lack of space to construct new pit latrines. Alternatively, ecological sanitation technologies could be used. The Ecosan technologies must be well managed, however, to reduce the possibility of diseases such as diarrhoea and helminthiasis (Chunga *et al*., 2016: 1; Kumwenda *et al*., 2017: 3).

WaterAid, an international non-governmental organisation that focuses on water, sanitation, and hygiene, first officially introduced ecological sanitation in Malawi in 2001. The goal of ecological sanitation in Malawi was to reduce pollution, conserve water, and promote the reuse of human waste as fertilizer. One advantage of the Ecosan sanitation in Malawi was its overall low costs, despite its correspondingly high capital costs (Chunga *et al*., 2016: 2, 12-13). Although there has always been a potential to expand ecological sanitation use in Malawi, the rate of increase in adopting these technologies has been low since their introduction in 2001. A study conducted by Zeleza-Manda (2009: 47) in the informal settlements in three cities revealed that the share of Ecosan technologies in Lilongwe was not more than 4.4%. In 2017, a study on challenges and the potential of ecological sanitation revealed that 24.7% of Malawi's rural population did not have adequate basic sanitation services (Harada & Fujii, 2020: 8). These findings indicate that, even after 16 years of operation in Malawi, the Ecosan technologies had not been successfully implemented, in rural and urban areas, to meet household needs.

This evaluation of Ecosan technologies, as an example, indicates that there is a slow uptake of new sanitation technologies (or low user-acceptance) in both Malawi and South Africa. The aim of this research is to review relevant literature, extract data on factors that influence

STUA, and then compare the findings from the different studies to determine whether there are similar patterns of relative significance in the factors that influence STUA.

2. LITERATURE REVIEW

2.1 User-acceptance and its determinants

A sanitation technology has high acceptability (or acceptance) if, through practical experience, it is acceptable by both the user and the implementing agent responsible for the supply and maintenance of the technology. Acceptability encompasses both user- and agent-acceptance, which are dependent on sub-items of sanitation indices (WRC, 2018: 57). Numerous researchers have recognised the need to determine user-acceptability of sanitation technologies (Poortvliet *et al.*, 2018; Chunga *et al.*, 2016; Tobias *et al.,* 2017; Ssemugabo *et al.*, 2020; Sutherland *et al.*, 2020; Simiyu, 2015). This, when done, enables preventative measures to be taken prior to, or even after the implementation of projects, so that the local communities may accept them better and, therefore, avoid resource wastage (Roma *et al.*, 2010: 589).

Some of the factors that influence user-acceptance of sanitation technologies include lack of training, construction quality, levels of hygiene, the accessibility by disabled, perceived maintenance problems, levels of safety for children and other age groups, internal and external perceptions of users, user involvement from planning to post-implementation phases, capital costs, operation costs, knowledge of existing adaptation strategies for users, compliance with cultural norms of users, ease of cleaning, use or adaptation to habits of users, economic benefit, business model used, and prior performance of field tests (Mlamla & Mbanga, 2020; Mkhize *et al.*, 2017: 115; Matsebe, 2011: 87, 92; Lagardien, Muanda & Benjamin, 2012; Chunga *et al.*, 2016: 7; Simiyu, 2015: 243, 253). WRC (2018: 61-70) summarise a more complete set of factors as sub-items of the sanitation technology index. There is also a great need to communicate the benefits and risks of new sanitation technologies to the potential users, and the need to educate, train and involve the users from planning to post-implementation phases (Ajzen, 1991; Tobias *et al.*, 2017; Kennedy-Walker *et al.*, 2014: 2, 4, 11; Simiyu, 2015; Sutherland *et al.*, 2020; Matsebe 2011; Lungu *et al.*, 2008).

2.2 Sanitation technologies

This subsection offers a brief background of each sanitation technology to acquaint the readers with some general facts that will enrich their understanding of the later sections.

2.2.1 Cistern flush toilets

Cistern flush toilets are mass-produced, factory-made interfaces that are made from porcelain. The water is used to clean the toilet bowl and carry away excreta. There is a mechanism to prevent the odours from coming back through the plumbing into the toilet room. These toilets require a constant supply of water and a constant local availability of connections and hardware accessories. Among their advantages are that they are safe and comfortable to use, if kept clean (Tilley *et al.*, 2014: 52). Cistern toilets include both onsite-based (using a soak pit) and sewer-based systems.

2.2.2 Pit latrines

Pit latrines consist of a pit (at least 3m deep) with a concrete slab and a toilet interface over which the user sits or squats. There are no vents. They are a form of dry-toilet technology. They are the most common basic form of improved sanitation (Banerjee & Morella, 2011: 63; Tilley *et al.*, 2014: 44). Pit latrines are characterised by low-cost, simplicity of construction, water savings, and ease of operation and maintenance. The capacity to cope with bulky diverse anal cleansing materials and flexibility for consistent upgrading of the facility make them convenient and easily accepted (Nakagiri *et al.*, 2015: 2).

2.2.3 Ventilated improved pit latrines (VIPs)

VIPs, a form of dry-toilet technology, efficiently control odours and flies whilst still permitting users to clean themselves with solid materials such as newspaper and leaves. These materials may be unsuitable for use with a pour-flush latrine. The ventilation pipes are used to control flies and odours, but they cannot control the breeding of mosquitoes (Reed, 2014: 2). Most of the VIPs in South Africa have permanent superstructures. The pits, however, tend to fill up quicker than their anticipated design life. The disinfectants that are used may negatively affect the stabilisation processes in the pit. The emptying of pit contents also poses significant health risks (WRC, 2018: 55-57). Tilley *et al.* (2014: 62-64) outline further design considerations, merits, and demerits.

2.2.4 Fossa alterna

This is a short-cycle alternating double-pit (lined pits) toilet such as the double-pit VIP, but with a shallower pit dug to about 1.5m. While the double-pit VIP may collect, store, and partially treat excreta, the fossa alterna, in its design, ensures that the excreta is transformed into an earth-like substance that acts as a soil conditioner (Tilley *et al.*, 2014: 66). While one pit is being filled by users (in roughly one year), the second full pit gradually degrades the excreta in it into useful soil conditioner. Some cover material such as soil, ash or leaves should be added to the pit after use. The fossa alterna is a typical example of a compost toilet, since it is a dry toilet that treats human waste by the composting process. It can easily be changed into a urine-diverting dry toilet (UDDT) by modifying the user interface to separate faeces from urine. Because it is double pit, its useful life is unlimited. Tilley *et al.* (2014: 66-67 outline the advantages, disadvantages, and other specifications.

2.2.5 Pour-flush latrines

Pour-flush latrines are like regular cistern flush toilets, except that the water supply is not continuous since water is poured in by the user (Tilley *et al*., 2014: 50). Pour-flush latrines can be built inside the house and are easy to clean. They are much safer to use in schools and more water efficient, due to low flush technology. They are also safe and prevent the occurrence of both flies and odours (Van Vuuren, 2014:18). Tilley *et al* (2014: 50-51) further outline design specifications. The success of the pour-flush latrines may provide a viable option to offer waterborne sanitation where laying sewers is not feasible. Pour-flush technology may be unsuitable for a public toilet facility when users fail to flush and replace flushing water (Still & Louton, 2012: 35).

2.2.6 Urine diverting dry toilet (UDDT)

A urine diverting dry toilet (UDDT) is a toilet that operates exclusive of water and has a divider so that the user can, with little effort, divert the urine away from the faeces. The urine is collected and drained from the front area of the toilet, while faeces fall through a large hole in the back. Drying material such as lime, ash or earth should be added into the same hole after defecating (Tilley *et al*., 2014: 46; Muniz, 2013:10). Tilley *et al.* (2014: 46-47) outline further design specifications for UDDTs and other details. There are other modern variants of UDDT toilets such as Blue Diversion toilets and the Blue Diversion Autarky toilets (Tobias *et al*. 2017; Sutherland *et al*., 2020). Other sanitation technologies such as the Earth Auger are hybrids of the composting toilets and UDDTs (Mlamla & Mbanga, 2020).

2.3 The sanitation technology index

The sanitation index will be used as a basis for the evaluation of sanitation technologies. The items under the sanitation technology sustainability indices (SSI) and sanitation technology suitability indices (STSI) are compared with one another in Table 1 (Hashemi, 2020: 3-5; WRC, 2018: 61-70). They are also compared with some of the factors that influence user-acceptance of sanitation technologies. Although user-acceptability affects both indices, it is also influenced by the other items, which can be taken as individual forms of acceptability, that also influence the respective indices.

While the SSI index is based on ratios derived from comparing new sanitation technologies with the most used technology in the community, the STSI index is based on a combination of field questionnaire information that is fed into scorecards, actual field life cycle cost trials, sample site faecal contact scientific assessments, and hazard risk assessment of technologies from experts or user experiences from the field. Table 1 shows that, while all the components of the SSI index are included in the STSI index, the reliability and risk assessments are not included in the SSI index. The methodology for this research will be based on the six items of the STSI when evaluating the relative influence of various factors on user-acceptance of sanitation technologies. The STSI items can also be mapped with all the factors influencing sanitation technology user-acceptability. In addition, the STSI index caters to education, training, and support, the importance of which can be illustrated using the modified values, beliefs, and norms (VBN) model.

2.4 The VBN model and its role in user-acceptance

Education and awareness should be carried out by the sanitation technology firm during all three stages of planning, implementation, and post-implementation, as recommended by Lagardien, Muanda and Benjamin (2012). Considering previous discussion, it is through education and training that communication of the benefits and risks of the sanitation technologies to the users can conveniently occur. A modification of the VBN model originally proposed by Poortvliet *et al*. (2018) is, therefore, necessary to emphasise on-going education and training throughout the three sanitation technology stages. Figure 1 illustrates this modified model.

Table 1: Comparison of items of sanitation indices and factors that influence user-acceptance

Item	SSI (Hashemi, 2020)		Item	STSI (WRC, 2018)	Relationship between STSI and SSI items	STSI and factors influencing acceptability
1a	Water efficiency (WE)		1b	Safety (hazard risk assessment-physical harm)		Levels of safety (all age groups)
2a	Energy efficiency (EE)		2b	Health (faecal contact assessment)	8a	Levels of hygiene, risks
3a	Water-recycling efficiency (WRE)		3b	Acceptability (user and technical acceptance)	7a	Construction quality; ease of use, adaptation to user habits; education, training and support
4a	Capital costs index (CCI)		4b	Environmental performance	1a, 2a, 3a	Ease of cleaning
5a	Maintenance costs index (MCI)		5b	Reliability performance		Ease of maintenance
6a	Direct economic benefits (DEB)		6b	Cost (Life cycle cost)	4a, 5a, 6a	Capital, maintenance, operational costs, economic benefits
7a	Acceptability					
8a	Public health					

Source: Hashemi, 2020; WRC, 2018

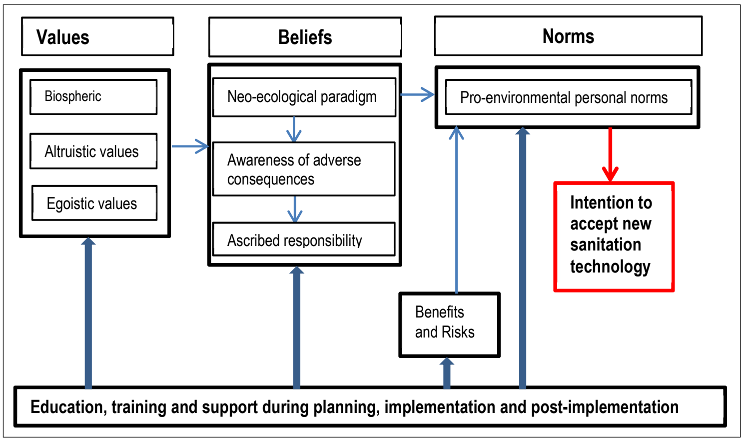

Figure 1: Modified VBN model for acceptance of new technologies
Source: Author

The model shows that biospheric (belief that it is worth protecting nature because of its intrinsic value), altruistic (dealing with the welfare of others), and egoistic (concerned with one's own welfare) values play a part in shaping the beliefs of would-be technology users. These values affect subsequent beliefs, including the new ecological paradigm that represents people's belief in the extent to which they can affect nature (Poortvliet *et al.*, 2018: 91-92; Ssemugabo *et al.*, 2020: 227), followed by people's awareness of adverse consequences of their course of action. The beliefs, in turn, affect the norms that affect or control the final intention to accept the new sanitation. The model is modified to include risks and benefits that affect the norms, separately from the beliefs and values. Appropriate on-going education and training, which re-shape the biospheric, altruistic, and egoistic values can serve to affect or influence the intention to accept the new sanitation. Creating an awareness of the benefits of the new technology when compared to the risks can also serve to re-shape the norms of intended users and hence, influence their intention to accept the new sanitation. The re-shaping process spans all three stages of the sanitation technology roll-out.

3. METHODOLOGY

3.1 Search strategy

The major factors influencing user-acceptance of sanitation technologies were adopted from the WRC (2018) sanitation index items and sub-items that were created by the WRC according to previous studies in sanitation and scientific evidence. Relevant studies dealing with user-acceptance of sanitation technologies were then searched systematically in April 2021, using Google scholar and the ScienceDirect database. Search phrases ("ecological", "sanitation", "acceptance", "Africa") joined with the "AND" Boolean search operator were used.

3.2 Inclusion and exclusion criteria

Inclusion criteria:

- The search targeted journal papers, conference proceedings, books, master's theses, organisation reports, and dissertations.
- Papers published from 2008 or later in English as the main language. Although preference was initially given to papers that were less than 11 years old since the date of publishing, the criteria was expanded to papers that were less than 13 years old since the date of publishing, to increase the sample.
- Papers that directly evaluated user-acceptance of one or more sanitation technologies after conducting field tests.
- Papers with studies done in South Africa and Malawi. As an exception, a study based on UDDT sanitation technology from Uganda was included.

Exclusion criteria:

- Papers published prior to 2008 or papers that were not published in English as the main language.
- Papers without names of author(s) or dates of publication.
- Papers with studies done outside Africa, where South Africa or Malawi is not part of the joint study at all.
- Papers that were not directly evaluating user-acceptance of one or more sanitation technologies without or after conducting field tests.

3.3 Identification of studies

A structured protocol for systematic literature review (SLR) was used, together with the snowball method (Higgins & Green, 2008: 95-150; Wohlin, 2014: 2-5). The reference lists of the searched literature were scanned, and the relevant literature was compiled in a list, including the country where the study took place. The literature was also downloaded to an appropriate folder for further examination. For each paper in the list, the title of the paper was used for initial scanning. If there was a strong likelihood of its relevance, the abstract would then be opened online. If the abstract was relevant to the search criteria, the paper would be downloaded, and its 'discussion and conclusion' sections read to confirm its relevance. It would then be saved for further analysis. The snowball method was then used to identify publications that were relevant but may not have shown up in the systematic search. This was implemented by checking the reference list of each of the sampled papers for the contents in the abstracts to verify their relevance.

3.4 Search findings

The initial search produced 879 results from both sources. After evaluating the paper titles, the results reduced to 79 relevant results. After evaluating the abstracts and discussion sections of the papers, the search results reduced to 59 studies. Therefore, 59 studies applied to STUA in Africa. The main countries where studies took place were South Africa, Kenya, Ethiopia, Uganda, Tanzania, Ghana, Namibia, Morocco, Zambia, Zimbabwe, and Malawi. The snowballing method helped identify one more study in Malawi and two more studies in South Africa. There were studies done in South Africa and Uganda for the Blue Diversion sanitation technology. Because of this similarity, the study done in Uganda for this technology was also included in the analysis.

Seven studies from South Africa, two studies from Malawi, and one study from Uganda were relevant for the analysis adopted in this research. Table 2 shows the results. However, in keeping with the recommendations to separate private sanitation user-acceptance analysis from communal sanitation user-acceptance by Seymour (2013:135), the studies (3 and 4) dealing with communal sanitation technologies were excluded from the primary analysis. It is also difficult to evaluate the health risks of communal unit-based sanitation studies (WRC, 2018: 64, 71). This left a balance of eight studies for consideration (1, 2, 5-10).

Tables 3 to 7 present the captured data in scorecard form that was obtained from the selected research papers in Table 2. This information helped provide a comparison of the various sanitation technologies in their different local contexts.

3.5 Analysis of identified literature

An evaluation spreadsheet based on the criteria of the WRC (2018) STSI was prepared for comparing the sanitation technologies. For each of the collected relevant literature (studies), the research extracted the information suitable for evaluation of the six items (six sub-indices) of the STSI. Using the spreadsheet, the research then evaluated the score (with respect to each study) for each of the six sub-items of the index based on the collected data from the study, compared all the technologies, and discussed the results. The health sub-item was simply estimated using guidance information (standard design parameters related to ‘E coli’ concentrations) from standard non-shared technologies provided by WRC (2018). The Shiga toxin-producing ‘E coli’ is a type of bacterium found in lower intestines of warm-blooded animals and can cause foodborne disease, due to faecal contamination of vegetables (WHO, 2018). WRC (2018) also indicate detailed guidelines on the evaluation of risk likelihood, severity, and scores.

The life cycle costing information was estimated from some recent relevant research (WSP, 2009; WSUP, 2018; Tobias *et al.*, 2017; Daudey, 2018; Hutton & Varughese, 2016; Burr & Fonseca, 2011; Manga, Bartram & Evans, 2020). The US$ life cycle costing data of earlier years was compounded to make it consistent with the time period of the research.

4. CATEGORICAL FINDINGS

4.1 Physical risks

The severity and likelihood risk tables for each technology were evaluated according to the WRC guidelines (2018: 60-71). These are mainly underpinned by the location of the technology (inside or outside the house) and the nature of its design, including the method of human waste storage or disposal (presence or absence of a deep pit). Tables 3 and

Table 2: Summary of the studies

	Technology (subsidies/no subsidies)	Year	Citation	Country (N=Sample size)
1	Ecosan UDT and fossa alterna vs pit latrines Shared or private sanitation No subsidies	2016	Chunga *et al.*, 2016	Urban Malawi (N=1300)
2	Blue Diversion toilet Private/Shared, commercialise No subsidies	2017	Tobias *et al.*, 2017	Uganda (N=1538)
3	Mobile communal sanitation facilities (MCSF) Subsidies	2012	Lagardien *et al.,* 2012	South Africa
4	Community ablution blocks (CAB) Subsidies	2010	Roma *et al.*, 2010	Durban, South Africa. (N1=29, N2=57, N3=50)
5	Urine diversion toilets (UDDT) UDDTs not shared Provided for free. WATSAN Subsidies	2017	Mkhize *et al.*, 2017	KwaZulu-Natal, eThekwini Municipality, South Africa
6	(Earth Auger = UDDT + compost toilet) Subsidies	2020	Mlamla and Mbanga, 2020	Ida Community, Eastern Cape, South Africa (N=100)
7	Urine diversion dry (UDD) toilets Subsidies	2011	Matsebe, 2011	Kimberley, South Africa
8	Blue Diversion Autarky toilet Field trial	2021	Sutherland *et al.*, 2020	Durban, South Africa
9	Urine diversion dehydration toilets Subsidies	2013	Roma *et al.*, 2013	eThekwini (Durban) South Africa
10	Ecological sanitation No subsidies	2020	Harada and Fujii *et al.*, 2020	Rural Malawi

Source: Author

4 show the data that were extracted from literature sources in Table 2. The VIPs, which require deep pit excavation, had, for example, a higher severity risk than UDDT toilets under the item of 'deep excavation'. Severity score and likelihood scores were multiplied to obtain the overall score (WRC, 2018: 61).

4.2 Environmental performance

This item captured how well a technology performed with respect to environmental conservation or friendliness. Matters such as recyclability of materials, water conservation, energy conservation, and reuse of waste as fertilizers were considered (Capodaglio & Olsson, 2019: 9; WRC, 2018: 68). Dry toilets such as dry pit latrines and UDDTs generally scored well on the water conservation sub-item. Ecosan toilets such as UDDTs, however, scored better than pit latrines on recyclability and recovery of both nutrients and energy. These sub-items are mainly dependent on the nature of the toilet design. Under the acceptability scorecard, further inquiry is made as to whether the technology supplier is available for support. For example, a technology may have the potential to provide benefits through nutrient recovery or energy generation, but that potential may not be tapped due to poor support, as several studies have shown (Mkhize *et al*., 2017; Matsebe, 2011; Chunga *et al*., 2016).

Table 5 shows the environmental performance data.

Table 3: Severity of risk

Item	Pit latrine (VIP)-Durban (SA)	UDDT-Durban (SA) -2017	Waste-water system-Durban (SA)	BDT-Uganda -2017	BDAT-Durban (SA) -2021	UDDT-Malawi (Urban) -2016	Pit latrine (VIP)-Malawi (Urban) -2016	UDDT-Kimberley (SA) -2011	Earth Auger-Ida EC (SA) -2020	UDDT-eThekwini (SA) -2013	UDDT-Malawi (Rural) -2020
Safe for children	Major	Moderate	Slight	Slight	Slight	Slight	Major	Slight	Slight	Moderate	Slight
Proximity to home (crime risk)	Serious	Serious	None	None	None	Serious	Serious	None	Serious	Serious	Serious
Deep excavation	Serious	None	None	None	None	None	Serious	None	None	None	None
Risk of drowning	Major	Slight	None	None	None	None	Major	None	None	Slight	None
Safe for the disabled and the elderly	Serious	Moderate	Moderate	Slight	Slight	Moderate	Serious	Moderate	Moderate	Moderate	Moderate

Major: Major-Major injury, death, or chronic medical condition; Moderate: Moderate-Resulting in absence from normal duties or activities; Slight: Slight-Minor injury; Serious: Serious-Urgent medical attention; None: No effect

Table 4: Likelihood of risk

Item	Pit latrine (VIP)-Durban (SA)	UDDT-Durban (SA) -2017	Waste-water system -Durban (SA)	BDT-Uganda -2017	BDAT-Durban (SA) -2021	UDDT-Malawi (Urban) -2016	Pit latrine (VIP)-Malawi (Urban) -2016	UDDT-Kimberley (SA) -2011	Earth Auger-Ida EC (SA) -2020	UDDT-eThekwini (SA) -2013	UDDT-Malawi (Rural) -2020
Safe for children	PHH	LHR	PHH	UNH	UNH	PHH	PHH	UNH	UNH	LHR	PHH
Proximity to home (crime risk)	LHR	LHR	INH	INH	INH	LHR	LHR	INH	PHH	LHR	LHR
Deep excavation	PHH	UNH	INH	INH	INH	UNH	PHH	INH	INH	UNH	UNH
Risk of drowning	PHH	UNH	INH	INH	INH	UNH	PHH	INH	INH	UNH	UNH
Safe for the disabled and the elderly	PHH	PHH	PHH	UNH	UNH	PHH	PHH	PHH	PHH	PHH	PHH

PHH: Possible-It is possible that it has happened; UNH: Unlikely-Has never happened yet; INH: Impossible-Cannot happen; LHR: Likely-Happens regularly

Table 5: Environmental performance

Category	Description	Pit latrine (VIP)-Durban (SA)	UDDT-Durban (SA) -2017	Waste-water system-Durban (SA)	BDT-Uganda -2017	BDAT-Durban (SA) -2021	UDDT-Malawi (Urban) -2016	Pit latrine (VIP)-Malawi (Urban) -2016	UDDT-Kimberley (SA) -2011	Earth Auger-Ida EC (SA) -2020	UDDT-eThekwini (SA) -2013	UDDT-Malawi (Rural) -2020
Water consumption	How much water is required to operate the toilet?	No water	No water	>2 and <6Litres/ Flush	No water	No water	No water	No water	No water	No water	No water	No water
Pollution control	Does effluent discharge or leachate meet the appropriate standards prescribed in the Department of Water Affairs general authorisation limits?	Effluent 20%	No effluent	Effluent municipality	No effluent	No effluent	No effluent	Effluent 20%	No effluent	No effluent	No effluent	No effluent
Resource recovery	Does the technology seek to recover resources such as energy in the form of biogas and nutrients in the form of urine or compost fertiliser as part of its design?	Design NRC	Design YRC	Design NRC	Design YRC	Design YRC	Design YRC	Design NRC	Design YRC	Design YRC	Design YRC	Design YRC
Materials	Does the technology use environmentally friendly materials that are biodegradable, or can be effectively recycled?	Materials greater 50%	Materials lesser 20%	Materials greater 50%	Materials lesser 20%	Materials lesser 20%	Materials lesser 20%	Materials greater 50%	Materials lesser 20%	Materials lesser 20%	Materials lesser 20%	Materials lesser 20%
Chemicals	Does the technology require the use of hazardous chemicals as part of its operation and maintenance?	No	No	Some hazardous chemicals are used that are contained within the technology	No	No	No	No	No	No	No	No

Effluent 20%: Effluent within 20% of general authorisation limits; No effluent: No effluent discharge; Effluent municipality: Effluent discharged to municipal facility; No water: No water (dry toilet); Design NRC: Design does not include resource recovery measures; Design YRC: Design demonstrates effective energy OR nutrient recovery; Materials greater 50%: Greater than 50% of materials are not biodegradable or recyclable; Materials lesser 20%: Less than 20% of materials are not biodegradable or recyclable

Table 6: User-acceptance of technology

Category	Description	Pit latrine (VIP)-Durban (SA)	UDDT-Durban (SA) -2017	Waste-water system-Durban (SA)	BDT-Uganda -2017	BDAT-Durban (SA) -2021	UDDT-Malawi (Urban) -2016	Pit latrine (VIP)-Malawi (Urban) -2016	UDDT-Kimberley (SA) -2011	Earth Auger-Ida EC (SA) -2020	UDDT-eThekwini (SA) -2013	UDDT-Malawi (Rural) -2020
User interface	Is the technology easy and safe to use? Suitability for both adults and children	Adults	Adults	Both	Both	Both	Adults	Adults	Both	Both	Both	Adults
	Does the technology effectively control odours? What is the level of observed odours when using this technology?	Slight	Slight	Slight	None	None	Slight	Slight	Significant	Slight	Significant	Slight
	The standard of the technology compared to other sanitation technologies supplied to neighbouring areas	Similar	Lower	Higher	Higher	Higher	Higher	Similar	Lower	Lower	Lower	Higher
	Can the technology be positioned close to people's homes?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Is there sufficient space available for the technology to be installed?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Collection and storage /treatment	Are the ground conditions suitable for the technology (*i.e.*, can the technology be installed where there is shallow rock or groundwater?)	EXCV1	EXCVN	EXCVN	EXCVN	EXCVN	EXCVN	EXCV1	EXCVN	EXCVN	EXCVN	EXCVN
	Is there sufficient space available for the technology to be installed?	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Conveyance	What is the method of transporting the waste once the collection facility is full?	Vacuum truck	Hand	Sewer	Vacuum truck	Integrated into design - Helical screw/cart	Hand	Hand	Hand	Hand	Hand	Hand
	How often does the collected waste need to be emptied?	>1 year	>6 months	Continuous (sewer)	<1 week	<1 week	>6 months	>1 year	<1 week	>6 months	>6 months	>6 months
	Does the Implementing Agent or appointed service provider have sufficient capacity to support the required operation and maintenance activities?	YES	NO	YES	YES	YES	YES	YES	NO	YES	YES	YES
Treatment	Is the necessary Infrastructure in place to support the operation of the technology (*i.e.*, Waste water treatment works)	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
	Is the treatment facility easy and safe to operate?	SN	SH	SN	SH	SH	SH	SN	SH	SH	SH	SH
	Does the treatment effectively control odours?	ON	OS	ON	OS	ON	OS	ON	OG	OG	OS	OS
Use/Disposal	Is there a demand for the use of the treated waste?	ACL	ACD	ACL	ACM	ACL	ACL	ACD	ACO	ACD	ACD	ACO
	Is there a suitable place for the disposal of the treated waste	DLN	DLN	DLN	DYD	DYD	DYD	DLN	DYD	DLN	DLN	DYD

EXCV1: Excavation greater than 1 meter; EXCVN: No excavation or infiltration required; SN: No site treatment; SH: Household operation; ON: No odours observed; OS: Slight odours; OG: Significant odour; ACL: Limited acceptance; ACO: Local acceptance; ACD: Dispose to landfill; ACM: Active market; DLN: No local disposal; DYD: Disposal in the yard

4.3 User-acceptance of technology

The information from surveys and interviews conducted with the users captured the users' experience with the use of the technology, and the possible underlying reasons that contributed to the level of user-acceptance.

Table 6 shows the user- and technical acceptability performance data for the various studies.

For example, in the Earth Auger technology survey conducted by Mlamla and Mbanga (2020: 6-7), 97% of the beneficiaries of the technology decided not to use it. Some of the underlying reasons were poor construction (50%), poor hygiene (10%), and incompatibility with the disabled and the elderly (12%). The users thus assumed the technology to be of a lower standard. This item also affects the reliability of the technology because poor construction may also imply parts that easily break and hence, are not reliable (Mkhize *et al*., 2017: 117; Mlamla & Mbanga, 2020: 7). The users do not reuse the waste as fertilizer, thus an indicator of lack of proper education and awareness of these benefits. Hence, it is disposed of to landfill. Because it poses a danger to the elderly and the disabled, this information must be appropriately captured in the risk scorecard. The other information is technical and is inherent in the way in which the technology was designed. This includes suitability of ground conditions for the technology and ability for it to be placed close to people's homes. Roughly 92% of would-be users who had used a waterborne toilet previously, preferred a waterborne toilet to a UDDT (Matsebe, 2011: 66). This same pattern was also evident in the Ida Community, in the Eastern cape. Once all information is filled in, the final score was generated according to the WRC guidelines (2018: 60-71).

4.4 Reliability of sanitation technologies

The reliability of the sanitation technologies depended on factors such as design life, historical performance, ability of supplier to offer support to users, and whether the materials used have proven durability. Table 7 shows the compiled reliability performance status of the technologies. Technologies such as the Blue Diversion toilet and the Blue Diversion Autarky toilet (Tobias *et al*., 2017; Sutherland *et al*., 2020) are relatively new on the market, so they score fairly low on the sub-item of historical performance. From the recorded field survey information of the Earth Auger technology in Ida and the UDDT technology in eThekwini, Durban, the users complained of poor workmanship and/or parts that broke easily. This indicates that the technologies were not robust. They both score low on the sub-item of robustness. There was also limited support for both technologies from the respective suppliers (Mlamla &

Table 7: Reliability

Category	Description	Pit latrine (VIP)-Durban (SA)	UDDT-Durban (SA) -2017	Waste-water System-Durban (SA)	BDT-Uganda -2017	BDAT-Durban (SA) -2021	UDDT-Malawi (Urban) -2016	Pit latrine (VIP)-Malawi (Urban) -2016	UDDT-Kimberley (SA) -2011	Earth Auger-Ida EC (SA) -2020	UDDT-eThekwini (SA) -2013	UDDT-Malawi (Rural) -2020
Historical performance	Number of functioning installations (sample verified by references)	>10000	>10000	>10000	>10	Lab Only	>1000	>10000	>10000	>100	>10000	>1000
	Duration of functional installations (excludes laboratory-based prototypes)	>10 Years	>10 Years	>10 Years	Lab Only	Lab Only	>5 Years	>10 Years	>10 Years	>10 Years	>10 Years	>10 Years
Robustness	Material durability (strength, UV stable and fire resistance)	DP	DN	DP	DT	DT	DP	DP	DP	DN	DN	DP
	Resistance to vandalism	VP	VP	VP	VT	VT	VN	VP	VN	VN	VP	VN
Maintenance	Technical support	TE	TL	TE	TE	TE	TL	TE	TL	TL	TL	TE
	Availability of spares and consumables	AL	AL	AL	AR	AR	AL	AL	AL	AR	AL	AL
Design life	Design life	>20 years	>15 years	>20 years	>5 years	>5 years	>15 years	>20 years	>10 years	>10 years	>15 Years	>15 Years

DP: Selected materials have proven durability; DN: Selected materials not suitable; DT: Selected materials have theoretical durability; VP: Proven resistance to vandalism; VT: Theoretical resistance to vandalism; VN: Selected materials prone to vandalism; TE: Supplier demonstrates effective training and good long-term support; TL: Limited support available; AL: Readily available at local stores; AR: Available from supplier on request

Mbanga, 2020: 13; Mkhize *et al*., 2017: 117-118). Once all the items were filled in, the reliability scores could be evaluated according to WRC specifications (2018).

4.5 Costing of technologies

Information on costing was obtained from multiple sources. The research opted to adopt the life cycle costing approach that considered the net present value (NPV) of both capital expenses (Capex), maintenance and operating expenses (Opex), and any financial benefits such as fertilizer use or biogas generation accrued by the household. The Ecosan toilets offered the owners the flexibility of obtaining these kinds of financial benefits. However, some of the owners in South Africa never used the benefits (WSP, 2009: 17-19). Therefore, unit cost data per capita was estimated with the help of more secondary reports that are country specific (WSP, 2009: 18-19; Hutton & Varughese, 2016: 38-42).

To arrive at the risk scores, the risk factor ratings are calculated by multiplying the risk likelihood by the risk severity (from Tables 3 and 4). The figure obtained is used together with the *risk interpretations* to arrive at the *risk score*. The life cycle cost score is obtained by first evaluating the *life cycle cost per person per day* and then reading it against the "*score*" column in Table 8. If the score is not exactly equal to the life cycle cost per person per day in Table 8, then *interpolation is used* to obtain its exact corresponding value under the "*score*" column.

Table 9: Interpretation of scores for health, environmental, reliability, technical and user-acceptance, and overall suitability index

Score	Risk interpretation *(risk factor rating)*
80-100	Excellent
60-80	Good
40-60	Average
20-40	Poor
0-20	Unacceptable

Source: WRC, 2018

The remainder of the four items on the index were obtained by interpreting Tables 5, 6, and 7 into numeric scores as outlined by WRC (2018). The numeric values obtained were directly equal to the respective final scores. The health score item was specially obtained using the interpretation of the faecal contact assessment information from WRC (2018) together with the sanitation technology-specific information. First, a score is computed according to equation 1:

$$Score = \text{"}E\text{"}\ Coli\ concentration\ X\ Frequency\ of\ contact\ X\ Likelihood\ of\ ingestion. \quad (1)$$

The frequency of contact, "E" Coli concentration, and likelihood of ingestion may depend on type of sanitation technology used (how often waste is emptied, whether waste is wet or dry, and method of emptying the waste). The number of points scored are given by equation 2:

$$points\ score\ = 100\ X\ (300 - score)/300 \quad (2)$$

Table 8: Evaluation of scores for life cycle costs and risks

Score	Risk interpretation (risk factor rating)	Lifecycle cost (per person per day) 2016 prices (2020 prices)
100	All hazards considered impossible (*0*)	R 0.5 (0.53)
75	All hazards are low risk (*1-4*)	R 1.0 (1.06)
50	Maximum of 2 hazards considered medium risk, while all other risks are low (*5-12*)	R 2.0 (2.13)
25	Three or more hazards considered medium risk, while all other risks are low (*5-12*)	R 3.0 (3.19)
0	One or more hazard is high risk (*15-25*)	>R 4.0 (> 4.25)

Source: WRC, 2018

The final suitability score is the weighted average (out of 100 [%]) (see Table 10) of all the individual scores under each of these six items. After reviewing the studies on sanitation, acceptability, reliability, and costs seemed to be the most important factors influencing the household's choice of any sanitation technology. Their weights were equal and had the highest values (25%). Environmental and health factors were also very important (weight of 10% for each), but the users did not immediately appreciate their benefits. The risk factor was not emphasised so much in the studies and was given a weight of 5%. After evaluating all the six scores, Table 9 was, again, used to interpret (poor, average, good, or excellent) both the final score and each of the individual scores for the six items of the suitability index.

4.6 Results

The final scores were tabulated, and are presented in Table 10.

4.6.1 Risk

In terms of low risk, VIPs scored the lowest, due to the higher severity and likelihoods of suffering physical harm and the incompatibility with the disabled when using them. The UDDTs in Kimberley were not located outside the dwelling units, so they scored higher on low likelihood of crime when used at night compared to other UDDTs. Pit latrines performed *poorly* (20-40) under the risk item. UDDTs in Durban (2017 and 2013 research), Malawi (2016 and 2020 research) and Earth Auger in Ida had an *average* performance under the risk item (40-60). The Blue Diversion toilet (BDT) in Uganda, the waste-water system in Durban and Blue diversion Autarky toilet (BDAT) in Durban had *good* performance (60-80). Generally, if a sanitation technology does not require the digging of pits, is located inside the main dwelling, and can be easily used by adults, children, and the elderly, then it would score well on this item.

Table 10: Final scores on the six items of the suitability index

Items	Weight (out of 100 = %)	Pit latrine (VIP)-Durban (SA)	UDDT-Durban (SA) -2017	Waste-water system-Durban (SA)	BDT-Uganda -2017	BDAT-Durban (SA) -2021	UDDT-Malawi (Urban) -2016	Pit latrine (VIP)-Malawi (Urban) -2016	UDDT-Kimberley (SA) -2011	Earth Auger-Ida EC (SA) -2020	UDDT-eThekwini (SA) -2013	UDDT-Malawi (Rural) -2020
Risks	5	25	50	75	75	75	50	25	75	50	50	50
Acceptability	25	75	0	90	91	93	82	72	0	0	0	84
Environment	10	55	85	35	95	95	85	55	85	85	85	85
Reliability	25	100	78	100	44	40	69	100	76	51	78	84
Health	10	89	68	89	57	57	68	79	57	68	68	68
Costs	25	54	38	36	100	100	100	100	38	38	38.414	100
Mean acceptability		72.8	46.9	72.7	77.7	77.2	80.6	82.6	46.6	40.2	46.9	84.8

4.6.2 Acceptability

User- and technical acceptability were highest among the Blue Diversion toilets, with the BDAT being the highest. The BDAT was improved, based on user experience survey carried out earlier in both Uganda and Kenya (Tobias, Markus & Frederik, 2016; Sutherland *et al.*, 2020). Therefore, it is expected that its performance would be higher under this item. In Malawi, most of the households in the survey done in urban areas still preferred using pit latrines over the UDDT Ecosan toilet mainly because of higher initial costs of UDDTs and the accustomed easier usage and reliability of the pit latrine. The total of initial capital costs and costs of emptying the pit (done about once every 3.9 years) was roughly US$55, compared to the initial capital costs for a UDDT that could possibly reach as high as US$ 200 (Chunga *et al.*, 2016). Although both scored very well on costing, the unit net present value costs per capita for UDDTs in the Malawian context are estimated to roughly 1.35 times those of pit latrines (excluding benefits due to generated fertilizers and/or biogas). Despite the serious shortage of land in the locality for digging more pits, due to increasing urbanisation, the STSI index average still indicates users favouring pit latrines ahead of UDDTs in Malawi. Therefore, while users still preferred pit latrines, technically the pit latrine technology would soon become unacceptable because of space constraints. This kind of user-acceptance of the pit latrine is mis-informed and is unsustainable. A good education and awareness campaign of the value of Ecosan alternatives can help alleviate unnecessary health and catastrophic ecological consequences. It requires a change in the users' values, beliefs, and norms (Poortvliet *et al.*, 2018).

UDDT users in rural Malawi had better acceptability for UDDTs because of the good support from the Nikon International Cooperation for Community Development (NICCO) that was responsible for their roll-out (Harada & Fujii, 2020). They also made good use of the UDDT waste as a source of fertilizer for agriculture. The UDDTs in South Africa scored very low because of various factors including lack of post-implementation support and problems related to strong, bad odour (Matsebe, 2011: 72-73; Mkhize, 2017: 69,165; Roma *et al.*, 2013: 308-309). The score of zero (0) under the Earth Auger acceptability item highlights both the failure of continual customer support by the agent and the non-effective marketing of the Earth Auger technology benefits to the community.

4.6.3 Environment

Ecosan sanitation options (Blue Diversion units and UDDTs) performed highest under environmental considerations, thus highlighting their potential for ensuring environmental sustainability compared to their counterparts. This depended on the research and development (R&D) that went into their design. However, no amount of R&D can influence user-acceptability once the users are not made aware of the benefits. Education and awareness must go hand in hand with good R&D (Sutherland *et al.*, 2020: 1).

4.6.4 Reliability

Generally, technologies that have been used by many people over a longer period of time tended to perform well under the reliability score, provided they were robust and had a high lifespan. The novel Ecosan technologies such as the Blue Diversion options never had proven reliability. They only had theoretical reliability since they were still laboratory products undergoing further improvements (Tobias *et al.*, 2017; Sutherland *et al.,* 2020). The Earth Auger sanitation option had poor workmanship, although it has been in operation worldwide for over 10 years. There were fewer than 1,000 units in use worldwide at the time of this research (EarthAuger, 2021; Mlamla & Mbanga, 2020).

4.6.5 Health

Generally, the frequency of handling excreta, the classification of the technology (wet or dry), and the method of handling excreta (sewer lines, by hand, mechanical, without personal protective equipment) contributed most to the scores under the health category. Ecologically friendly toilets such as the Blue Diversion toilets and UDDTs in Kimberley that had dry technology but scored *average* health-wise (40-60 points) were associated with more frequent handling of excreta and the use of hands to handle the excreta by households as they disposed of it. Pit latrines had the least frequent periods of handling excreta (more than once a year). Some UDDTs allow for handling excreta once a year (Chunga *et al.*, 2016), while others allow for handling excreta at least once a week (Matsebe *et al.*, 2011: 80, 87).

4.6.6 Mean acceptability

Table 10 also shows the weighted scores based on the assumption that the users attached greater importance to items of reliability, costs and both functional and technical acceptance. The data shows that UDDTs (or technologies utilising the urine diversion method, such as the Earth Auger) in South Africa generally performed average (all less than 50 points) in terms of acceptability. They were far outperformed by both waste-water systems (flush toilets) and VIPs, whose overall acceptance was good (between 60 and 80 points). Therefore, if users in South Africa attach more importance on reliability, costs and both functional and technical acceptance, UDDTs will continue to experience low overall user-acceptance and will favour VIPs and waste-water (flush) systems.

In Malawi, mean acceptability for UDDTs was excellent (falling in the interval of 80-100) in both urban and rural areas. However, acceptability for pit latrines in urban areas was higher than that for UDDTs, meaning that most of the households still prefer pit latrines over UDDTs. This agrees with Chunga *et al*. (2016). In rural Malawi, there was a generally better acceptance of UDDTs (higher STSI for rural compared to urban UDDTs) and the accompanying benefits from waste (Harada & Fujii, 2020: 4, 8).

5. COMPARISONS

5.1 Comparison of technologies encompassing urine diversion technologies in South Africa

Urine diversion dry technologies contribute greatly to water conservation. Figure 2 shows that sanitation technologies that have been in use in South Africa, but utilise the UDDT technology, have low user-acceptance levels (low mean acceptability, according to Table 10). This is mainly due to low technical and user interface acceptability. The exception is with the BDAT, which, when tested in field trials, showed good acceptance (Sutherland *et al*., 2020: 10). However, it was only tried with one family in Durban. Similar patterns of good scores and acceptance (except for reliability scores) were obtained with the BDT in Uganda when tested publicly against many users during a field trial survey (Tobias *et al*., 2017: 270-271). Therefore, conducting field trials and surveys to re-design or modify sanitation technologies according to user preferences seems to improve STUA.

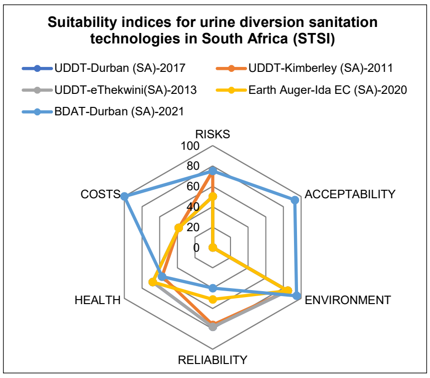

Figure 2: Urine diversion technologies in South Africa

5.2 Comparison of sanitation technologies across Durban in South Africa

Figure 3 shows that both the waste-water (toilet flush) system and, in some cases, the VIP pit latrine are still very popular, despite poor or average performance with respect to environment and costs. It is, therefore, important to consider their common strengths. A careful look at Figure 3 shows that 'reliability', 'user interface' and 'technical acceptability', and 'health performance' (in that order) are their strengths. For Ecosan technologies to favourably compete against the VIP and flush technologies, it is necessary to remodel their designs, in order to perform comparably with the VIP and flush technologies on 'reliability', 'user interface' and 'technical acceptability', and 'health performance'. The sub-items on the scorecards under these three items provide the specifics of where to improve. For example, with respect to health, reducing the frequency of emptying the waste containers, while ensuring no bad odour occurs, can improve user-acceptability for Ecosan, due to perceived improved health.

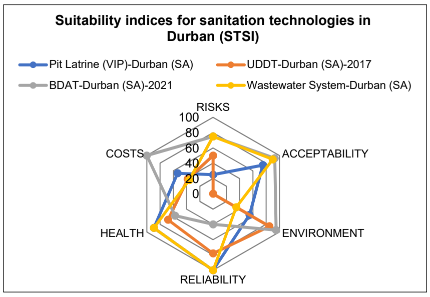

Figure 3: Comparison of different sanitation technologies across Durban in South Africa

5.3 Comparisons between South Africa and Malawi

Figure 4 shows that, had subsidies for sanitation services not been in force for lower (and sometimes middle) households in South Africa, the provision of sanitation services in Malawi would be considerably cheaper than in South Africa. Secondly, the pattern of low acceptability of Ecosan technologies in areas where it has been implemented in South Africa is not replicated in Malawi.

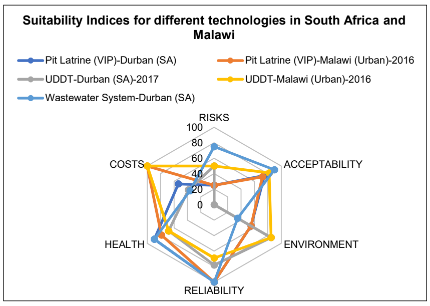

Figure 4: Comparison across countries

In Malawi, there was high acceptability among the recipients in rural areas, as shown in Table 10, based on the study by Harada and Fujii (2020). The acceptability in urban areas as indicated in Figure 4 is high for UDDTs in Malawi. However, there is stiff competition against the VIPs, as stated earlier, based on Chunga *et al.* (2016). From the field trials, the user experience of BDAT (South Africa) and BDT (Uganda) is fairly similar. However, its success in Uganda was based on its uptake as a business model for "pay-per-use". Otherwise, the costs item score would be low for private use by low-income groups, lowering the overall user-acceptability.

Increasing user-acceptability through business model ventures has worked in some community projects in Kenya (Simiyu, 2015: 256).

6. DISCUSSION

The user-acceptability (acceptance) of sanitation technologies depends on factors that are themselves part of the sanitation indices. These include risks to physical harm, health, reliability, costs, effects on the environment, and both the user interface and technical acceptability (WRC, 2018: 60). Whenever sanitation for the relatively poor is subsidised (as in South Africa), the predominant strengths of the common sanitation technologies such as the waste-water flush and VIP toilet systems are their reliability, user interface and technical acceptance, and their health-safety benefits. Ecosan sanitation technologies in South Africa should be altered in design and functionality at least to be on par with the three predominant strengths of the common sanitation technologies. In urban areas of Malawi, where there is no sanitation subsidisation, costs were the predominant factor, in addition to the three factors mentioned above in the South African scenario.

The frequency of handling the excreta and use of hands to handle excreta related to ecological sanitation technologies are the most significant factors that increase the health risk (WRC, 2018: 63-64; Matsebe, 2011: 23-24, 88). Unfortunately, the frequency of handling excreta can only be reduced by increasing the sizes of the storage receptacles, which may have limitations. However, improvements in design can probably be made to enhance the method of handling the excreta, in order to reduce the risk of contact. It appears that the problems of bad odours are related, especially, to the UDDT technology. However, reduction in frequency of handling, due to a larger storage receptacle for excreta, means longer period of presence of excreta in the receptacle and higher probability of bad odours ensuing if the guidelines for the treatment of urine and faeces are not followed. Hashemi and Han (2017: 507) propose the use of acetic acid and sodium bicarbonate for the case of urine. Enlarging the storage receptacles seems to work against the need to stop bad odours, because the waste remains for longer periods of time. However, some innovations could probably solve these problems, such as efforts to improve the method of treatment of faeces in the BDAT using hydrothermal oxidation, thus converting them to carbon dioxide, water, and precipitated inorganic solids (Sutherland *et al.*, 2020: 5; Tobias *et al.*, 2016: 11921). Increased technology costs often accompany this kind of improvements.

The BDT (a predecessor of the BDAT) was tested in a pilot project in Uganda, using a cost-recovery business model of renting it out by the owner. Similar research on pay-per-use models for community sanitation facilities done in Kenya by Simiyu (2015) indicated that the business model was successful financially. Questions remain concerning the affordability for the initial capital cost of newer sophisticated sanitation technologies such as the BDAT by the average poor households that need sanitation for private use.

Conversely, it is arguable that investing in education and training, awareness campaigns, and on-going post-installation support could have a positive impact on the beliefs and norms to improve user-acceptance of the already installed Ecosan technologies (Ssemugabo *et al.*, 2020; Poortvliet *et al.*, 2018). The cost model for Ecosan technologies in South Africa, unlike in Malawi, does not include the benefits, which the users accrue due to conversion of waste to fertilizer or biogas for energy. As a result, Ecosan technologies in South Africa scored fairly poorly under the ‘cost’ item, compared to similar Ecosan toilets in Malawi. Encouraging subsistence agriculture, while communicating UDDT and Earth Auger agricultural benefits may improve user-acceptance of these technologies.

7. CONCLUSIONS

During the planning and implementation of sanitation technologies, the most important factors that affect user-acceptance may differ from country to country, depending on the economic and sociocultural aspects, and the national policy on sanitation financing. The study identified several important points. First, the Ecosan technologies already in use in South Africa hold promising potential if the quality of construction is improved, and both the pre- and post-installation support are continuously provided. Secondly, the comparison of user-acceptance in urban and rural Malawi shows that user-acceptance of ecological sanitation within the same country can differ depending on whether the sanitation technology is being rolled out in urban or rural areas, due to location-based variations in values, beliefs, and norms. Education and awareness campaigns may, however, change the values, beliefs and norms. Thirdly, comparing South Africa and Malawi shows that the predominant factors influencing user-acceptance of sanitation technologies across countries can differ, due to the differences in country-specific sanitation policies, including subsidy policies. Lastly, the study in Uganda showed that, in the absence of subsidies, capital cost recovery for the ecological sanitation technologies, which are usually high, can easily be achieved by means of a business model of renting out the technology for the purposes of ‘paying per use’.

REFERENCES

AJZEN, I. 1991. The theory of planned behavior. Organizational behavior and human decision. *Processes,* 50(2), pp.179-211. https://doi.org/10.1016/0749-5978(91)90020-T

BANERJEE, S.G. & MORELLA, E. 2011. Africa’s water and sanitation infrastructure: Access, affordability, and alternatives. Washington, D.C.: World Bank Publications. https://doi.org/10.1596/978-0-8213-8457-2

BURR, P. & FONSECA, C. 2011. Applying the life-cycle costs approach to sanitation: Costs and service levels in Andhra Pradesh (India), Burkina Faso, Ghana and Mozambique. [Online] Available at: <https://www.ircwash.org/sites/default/files/briefing_note_3_-_applying_life-cycle_costs_approach_sanitation.pdf> [Accessed: 20 March 2021].

CAPODAGLIO, A.G. & OLSSON, G. 2019. Energy issues in sustainable urban wastewater management: Use, demand reduction and recovery in the urban water cycle. *Sustainability* 12(1), pp. 266-911. https://doi.org/10.3390/su12010266

CHUNGA, R.M., ENSINK, J.H.J., JENKINS, M.W. & BROWN, J. 2016. Adopt or adapt: Sanitation technology choices in urbanizing Malawi. *PlosOne,* 11(8), article number e0161262. https://doi.org/10.1371/journal.pone.0161262

DAUDEY, L. 2018. The cost of urban sanitation solutions: A literature review. *Journal of Water, Sanitation and Hygiene for Development,* 8(2), pp.176-195*.* https://doi.org/10.2166/washdev.2017.058

EARTHAUGER. 2021. A hybrid sanitation solution. [Online]. Available at: <http://www.earthauger.org/projects.html> [Accessed: 10 March 2021].

HARADA, H. & FUJII, S. 2020. Challenges and potentials of ecological sanitation: Experiences from the cases in Vietnam and Malawi. *Sanitation Value Chain,* 4(1), pp. 3-16. DOI: 10.34416/svc.00015

HASHEMI, S. 2020. Sanitation sustainability index: A pilot approach to develop a community-based indicator for evaluating sustainability of sanitation systems. *Sustainability,* 12(17), article number 6937. https://doi.org/10.3390/su12176937

HASHEMI, S. & HAN, M. 2017. Methods for controlling stored urine odor in resource-oriented sanitation. *Journal of Water, Sanitation and Hygiene for Development*, 7(3), pp. 507-514. https://doi.org/10.2166/washdev.2017.098

HIGGINS, J.P & GREEN, S. 2008. Cochrane handbook for systematic reviews of interventions: Cochrane book series. Version 5. DOI: 10.1002/9780470712184

HUTTON, G. & VARUGHESE, M. 2016. The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene. [Online]. Available at: <https://www.wsp.org/sites/wsp/files/publications/K8543.pdf> [Accessed: 29 March 2021].

KENNEDY-WALKER, R., EVANS, B., AMEZAGA, J. & PATTERSON, C. 2014. Challenges for the future of urban sanitation planning: Critical analysis of John Kalbermatten's influence. *Journal of Water, Sanitation and Hygiene for Development,* 4(1), pp.1-14. DOI: 10.2166/washdev.2013.164

KUMWENDA, S., MSEFULA, C., KADEWA, W., NGWIRA, B. & MORSE, T. 2017. Estimating the health risk associated with the use of ecological sanitation toilets in Malawi. *Journal of Environmental and Public Health*, November, online article number: 3931802. DOI: 10.1155/2017/3931802

LAGARDIEN, A., MUANDA, C. & BENJAMIN, A. 2012. User-acceptance and functioning of mobile communal sanitation facilities in informal settlements of South Africa: Report to the Water Research Commission. [Online]. Available at: <http://www.wrc.org.za/wp-content/uploads/mdocs/2017-1-12.pdf> [Accessed: 26 March 2021].

LUNGU, K., MORSE, T. & GRIMASON, A. 2008. Ecological sanitation – Implementation, opportunities, and challenges in Chikwawa. *Environment & Health International,* 10(2), pp. 1-7.

MANGA, M., BARTRAM, J. & EVANS, B.E. 2020. Economic cost analysis of low-cost sanitation technology options in informal settlement areas (case study: Soweto, Johannesburg). *International Journal of Hygiene and Environmental Health,* 223, pp. 289-298. https://doi.org/10.1016/j.ijheh.2019.06.012

MATSEBE, G.N. 2011. Perceptions of the users of urine diversion dry (UDD) toilets in medium-density mixed housing in Hull Street, Kimberley. [Online]. Available at: <http://wiredspace.wits.ac.za/bitstream/handle/10539/11789/> [Accessed: 6 March 2021].

MKHIZE, N. 2017. Promoting sanitation and nutrient recovery through urine separation: The role of health and hygiene education in the acceptance, utilisation, and maintenance of urine diversion toilets (UDDT) in rural communities of KwaZulu-Natal (KZN). Master's thesis, University of KwaZulu-Natal. [Online]. Available at: <https://researchspace.ukzn.ac.za/xmlui/handle/10413/15950> [Accessed: 12 April 2021].

MKHIZE, N., TAYLOR, M., UDERT, K.M., GOUNDEN, T.G. & BUCKLEY, C.A. 2017. Urine diversion dry toilets in eThekwini municipality, South Africa: Acceptance, use and maintenance through users' eyes. *Journal of Water, Sanitation and Hygiene for Development*, 7(1), pp. 111-120. https://doi.org/10.2166/washdev.2017.079

MLAMLA, S. & MBANGA, S. 2020. User-acceptance of the Earth Auger sanitation technology in Ida Community, Eastern Cape Province, South Africa. *JOPA,* 56(2), pp. 370-385. [Online]. Available at: <https://hdl.handle.net/10520/ejc-jpad-v56-n2-a15> [Accessed: 15 August 2021].

MUDOMBI, S. 2018. Forward-looking approach to next generation sanitation and industrial development in South Africa. [Online]. Available at: <https://www.tips.org.za/policy-briefs/item/3518-forward-looking-approach-to-next-generation-sanitation-and-industrial-development-in-south-africa-a-briefing> [Accessed: 11 March 2021].

MUNIZ, E. 2013. A proposed sustainable sanitation system for the Zwelitsha section of Langrug informal settlement in Stellenbosch Municipality, South Africa. Unpublished Ph.D. dissertation, Worcester Polytechnic Institute, South Africa.

NAKAGIRI, A., NIWAGABA, C.B., NYENJE, P.M., KULABAKO, R.N., TUMUHAIRWE, J.B. & KANSIIME, F. 2015. Are pit latrines in urban areas of sub-Saharan Africa performing? A review of usage, filling, insects, and odour nuisances. *BMC Public Health*, 16(1), pp.1-16. https://doi.org/10.1186/s12889-016-2772-z

NT (NATIONAL TREASURY). 2017. Vote 36: Water and Sanitation. Budget 2017: Estimates of National Expenditure. National Treasury, Republic of South Africa. [Online] Available at: <http://www.treasury.gov.za/documents/national%20budget/2017/enebooklets/Vote%2036%20Water%20and%20Sanitation.pdf> [Accessed July 22 2021]

POORTVLIET, M., SANDERS, L., WEIJMA, J. & De VREIS, J. 2018. Acceptance of new sanitation: The role of end-users' pro-environmental personal norms and risk and benefit perceptions. *Water Research,* 131, pp. 90-99. DOI: 10.1016/j.watres.2017.12.032

REED, B. 2014. G027: *Ventilated improved pit (VIP) latrines*. Loughborough: WEDC, Loughborough University.

ROMA, E., BUCKLEY, C., JEFFERSON, B. & JEFFREY, P. 2010. Assessing users' experience of shared sanitation facilities: A case study of community ablution blocks in Durban, South Africa. *Water SA [online],* 36(5), pp. 589-594. DOI: 10.4314/wsa.v36i5.61992

ROMA, E., PHILIP, K., BUCKLEY, C., SCOTT, D. & XULU, S. 2013. User perceptions of urine diversion dehydration toilets: Experiences from a cross-sectional study in eThekwini Municipality. *Water SA [online],* 39(2), pp. 302-312. DOI: 10.4314/wsa.v39i2.15

SEYMOUR, Z. 2013. Understanding what sanitation users value – Examining preferences and behaviours for sanitation systems. Unpublished Ph.D. thesis. Georgia Institute of Technology. North Avenue, Atlanta, USA.

SIMIYU, S. 2015. Determinants of usage of communal sanitation facilities in informal settlements of Kisumu, Kenya. *Environment & Urbanization,* 28(1), pp. 241-258. DOI: 10.1177/0956247815616732

SSA (STATISTICS SOUTH AFRICA). 2016. GHS Series Volume VIII Water and Sanitation: In-depth analysis of the GHS 2002-2015 and CS 2016 data. Statistics South Africa. Pretoria. [Online]. Available at: <http://www.statssa.gov.za/publications/03-18-07/03-18-072015.pdf> [Accessed: 15 March 2021].

SSA (STATISTICS SOUTH AFRICA). 2020. General Household Survey 2019. [Online]. Available at: <http://www.statssa.gov.za/publications/P0318/P03182019.pdf > [Accessed: 18 April 2021].

SSA (STATISTICS SOUTH AFRICA). 2021. GDP: Quantifying South African Economic Performance. [Online]. Available at: <http://www.statssa.gov.za/?p=14074> [Accessed: 15 March 2021].

SSEMUGABO, C., HALAGE, A.A., NAMATA, C., MUSOKE, D. & SSEMPEBWA, J.C. 2020. A socio-ecological perspective of the facilitators and barriers to uptake of water, sanitation and hygiene interventions in a slum setting in Kampala, Uganda: A qualitative study. *Journal of Water, Sanitation and Hygiene for Development,* 10(2), pp. 227-237. DOI: 10.2166/washdev.2020.124

STILL, D. & LOUTON, B. 2012. Piloting and testing the pour flush latrine technology for its applicability in South Africa. Water Research Commission. WRC Report No. 1887/1/12 ISBN 978-1-4312-0289-8, Pretoria, South Africa.

SUTHERLAND, C., REYNAERT, E., DHLAMINI, S., MAGWAZA, F., LIENERT, J., RIECHMANNB, M.E., BUTHELEZI, S., KHUMALO, D., MORGENROTH, E., UDERT, K.M. & SINDALL, R.C. 2020. Socio-technical analysis of a sanitation innovation in a peri-urban household in Durban, South Africa. *Science of the Total Environment,* 755(2), online article number: 143284. https://doi.org/10.1016/j.scitotenv.2020.143284

TILLEY, E., ULRICH, L., LUTHI, C., REYMOND, Ph. & ZURBRUGG, C. 2014. Compendium of sanitation systems and technologies. 2nd revised edition. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag).

TOBIAS, H., MARKUS, R. & FREDERIK, V. 2016. Hydrothermal oxidation of fecal sludge: Experimental investigations and kinetic modeling. *Industrial & Engineering Chemical Research*, 55, pp. 11910-11922. https://doi.org/10.1021/acs.iecr.6b03084

TOBIAS, R., O'KEEFE, M., KUNZLE, R., GEBAUER, H., GRUNDL, H., MORGENROTH, E., PRONK, W. & LARSEN, T.A. 2017. Early testing of new sanitation technology for urban slums: The case of the Blue diversion toilet. *Science of the Total Environment,* 576, pp. 264-272. DOI: 10.1016/j.scitotenv.2016.10.057

UNICEF, 2019. Progress on household drinking water, sanitation, and hygiene|2000-2017: Special focus on inequalities. [pdf]. Available at: https://www.unicef.org/media/55276/file/Progress%20on%20drinking%20water,%20sanitation%20and%20hygiene%202019%20.pdf [Accessed: 18 December 2021].

VAN VUUREN, L. 2014. No flash in the pan: How pour flush toilets are driving away SA's sanitation backlog: Sanitation. *Water Wheel*, 13(4), pp. 16-20. https://journals.co.za/doi/10.10520/EJC155565

WHO (WORLD HEALTH ORGANIZATION). 2018. E. Coli: Key facts. [Online]. Available at: <https://www.who.int/news-room/fact-sheets/detail/e-coli> [Accessed: 13 March 2022].

WOHLIN, C. 2014. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering (EASE 2014), 13-14 May, London, England. New York: Association for Computing Machinery, pp. 1-10. DOI: 10.1145/2601248.2601268

WORLD BANK. 2016. The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene: Summary report. [Online]. Available at: <https://documents1.worldbank.org/curated/en/847191468000296045/pdf/> [Accessed: 5 April 2021].

WRC (WATER RESEARCH COMMISSION). 2018. Household sanitation technology assessment and evaluation: Report to the Water Research Commission. [Online]. Available at: <http://www.wrc.org.za/wp-content/uploads/mdocs/2414-1-18.pdf.> [Accessed: 15 March 2021].

WRC (WATER RESEARCH COMMISSION). 2019. The sanitation economy opportunity for South Africa: Sustainable solutions for water security and sanitation. A business perspective. [Online]. Available at: <https://www.globalwaters.org/sites/default/files/tbc-sanitation-economy-opportunity-south-africa.pdf> [Accessed: 22 March 2021].

WSP (WATER AND SANITATION PROGRAM). 2009. Study for financial and economic analysis of ecological sanitation in sub-Saharan Africa. [Online]. Available at: <https://www.wsp.org/sites/wsp.org/files/publications/Ecosan_Report.pdf> [Accessed: 5 March 2021].

WSP (WATER AND SANITATION PROGRAM). 2012. Economic impacts of poor sanitation in Africa: Malawi. [Online]. Available at: <https://www.wsp.org/sites/wsp/files/publications/WSP-ESI-Malawi.pdf> [Accessed: 5 March 2021].

WSUP (WATER AND SANITATION FOR THE URBAN POOR). 2018. Comparing the costs of different urban sanitation solutions in developing cities in Africa and Asia. [Online]. Available at: <PBrief_Comparing-the-costs-of-different-sanitation-solutions_global.pdf> (wsup.com) [Accessed: 6 March 2021].

ZELEZA-MANDA, M.A. 2009. Water and sanitation in urban Malawi: Can the millennium development goals be met? A study of informal settlements in three cities, vol. 7. IIED. [Online]. Available at: <https://pubs.iied.org/sites/default/files/pdfs/migrate/10569IIED.pdf> [Accessed: 12 May 2021].