

RESEARCH ARTICLE

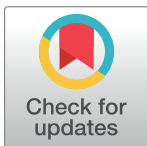
Barriers and facilitators to fecal sludge treatment in humanitarian camps: A systematic review of interventions

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Abstract

Treatment of human excreta in humanitarian camps remains rare, leading to environmental and public health risks. Fecal sludge treatment (FST) can help reduce these risks. Our objective was to summarize barriers (hindering implementation) and facilitators (enabling implementation) to FST in humanitarian camps to inform guidance. We completed a systematic review of eight databases and 39 websites in 2020, with an update in April 2023. Documents were included if they assessed FST implementation, in a humanitarian camp setting, with primary data collection of at least output level indicators. Overall, 53 documents, including 75 FST interventions from 12 countries were included. We identified 424 barriers and 435 facilitators in 11 categories: performance (239), operation (146), technical (109), economic (78), environmental (59), spatial (55), social/cultural (47), temporal (44), safety (34), supply (29), and institutional (19). The most common facilitators of FST implementation were: high reduction efficiencies; rapid implementation with available technologies; low capital and operational costs; ease of operation and maintenance; and, achieving effluent discharge standards, effluent reuse, and safe discharge. The most common barriers included under- or over-designed systems with inappropriate materials, needing strong operational supervision and additional treatment, with effluents not meeting discharge standards. Future guidance should focus on recommendations to enable facilitators and hinder barriers. Limitations included that most of the research was from one country (Bangladesh), and in stable contexts. Strengths of this work include a holistic, broad, example-based summary of actual FST implementations in camps in humanitarian settings. This review can be used to develop guidance and checklists for implementing FST in humanitarian camps, and future research needed.

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Introduction

The Sustainable Development Goals (SDG) aim to achieve a better and more sustainable future by addressing global challenges. SDG target number 6.2 is “by 2030, achieve access to adequate

and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations". However, in 2022, 3.4 billion people still lacked access to safely managed sanitation worldwide [1]. Moreover, it is estimated that in 2019, 1.5 million people died due to diarrheal diseases [2]. Additionally, 1.5 billion people are infected with soil-transmitted helminth infections worldwide, related to improper waste and excreta management [3].

Water, sanitation, and hygiene (WASH) interventions are implemented to prevent and control waterborne and infectious diseases. The main pathways for pathogens to infect humans are fecal-oral, through feces, fluids, fingers, flies, and food. The overall goal of reducing disease transmission is achieved by disrupting transmission routes. Humanitarian contexts are particularly vulnerable to poor WASH access, as political instability, mass displacement, and ongoing crises reduce access and availability of WASH infrastructure [4, 5]. The current common practice for sanitation in humanitarian emergencies is to collect and discharge untreated sludge into the environment, which can cause environmental and public health risks, and tensions with host communities and institutions. This was exemplified in Haiti where the cholera outbreak began in 2010 due to uncontrolled dumping of untreated fecal sludge [6].

Additionally, people living in humanitarian camps usually face several constraints that make implementing sanitation solutions, specifically, more difficult. This includes challenging ground conditions (rocky soils, high groundwater table, low infiltration capacity, and flood prone areas), lack of space, limited technical skills and capacities, densely populated area, material unavailable locally, and limited funding [7].

Faecal sludge management (FSM) is a sanitation intervention increasingly used in humanitarian contexts, including camps, to help prevent the spread of waterborne diseases by controlling potential contamination through infected feces [8]. Faecal sludge is human excreta that comes from onsite sanitation technologies and has not been transported through a sewer. It is raw or partially digested, a slurry or semisolid, and results from the collection, storage or treatment of combinations of excreta and blackwater, with or without greywater. It is highly variable in consistency, quantity, and concentration [9]. FSM is a multi-step process in which faecal sludge is managed from the point of generation to the point of use or ultimate disposal. It is usually broken down into 4–6 steps, including: collection, containment, emptying, transport, treatment (FST), and end-use or disposal. It also encompasses system management, operation, and maintenance [10].

Collecting and synthesizing the knowledge regarding FSM interventions in humanitarian camps has been hindered because: emergency interventions are often not evaluated and, if they are, results are often in grey literature rather than peer-reviewed literature. There is a need to summarize the available evidence on FST in humanitarian camps, identifying barriers and facilitators to implementation, to help inform future research, guidance, and programming of FST in humanitarian camps.

Methods

We conducted a systematic review of scientific publications and grey literature assessing the barriers and facilitators to FST implementation in humanitarian camps, following the PRISMA guidelines and reporting requirements for systematic reviews ([S1 Checklist](#)) [11]. Datasets for this manuscript are included as [S1](#) and [S2](#) Tables.

Search strategy

We searched eight journal databases in October 2020, and 39 international organization websites, between January 2020 and July 2021. The search was completed primarily in English, and

in Spanish for the LILACS database. There was no restriction on publication date. The list of databases and organization's websites searched, with the date of search and the keywords and categories used, are in [S1 Appendix](#). For several databases and websites, including Google Scholar and UNHCR website, the number of titles we could access was restricted to the first 1,000 results. For reference screening, we reviewed the references of documents that met final inclusion criteria.

Screening process and eligibility criteria

For databases, title results were exported into Zotero and screened. For websites where downloading was not possible, title screening was done directly online, and included documents downloaded for abstract screening. Search results after title screening were exported into Zotero, and duplicates removed. References were initially screened by title, then abstract, and finally full text, based on inclusion and exclusion criteria.

Initially, documents were included if they: assessed FST implementations during the steps of containment, emptying, transport, treatment, and reuse/disposal; including at least output-level results; and, were implemented in a humanitarian setting, as defined by "important losses and damage that were inflicted upon communities and individuals, possibly including loss of life and livelihood assets, and that left the affected communities unable to function normally without outside assistance" [7]. Humanitarian settings included disasters triggered by natural or technological hazards, conflicts, fragile states and protracted crises, and communicable disease outbreaks that occurred in a low- or middle-income country.

Initially, documents were excluded if they: 1) were not related to fecal sludge management as described in the eligibility criteria; 2) were related to healthcare sanitation; 3) were not implemented in a humanitarian context as described in the eligibility criteria; 4) did not include output level data from primary data collection on an intervention; 5) were a duplicate; and/or, 6) were not accessible. When criteria could not be deduced from the title or the abstract, the document was included in the next stage of review. The reason for not including a document during the full document review is recorded in [S1 Checklist](#).

As 266 documents were included after full-text review, we then added additional eligibility criteria on intervention and setting. Studies and reports were included into the review if they were about FST implementation in camps in humanitarian settings.

Abstracts, full text, and additional review screenings were completed independently by two authors. At each stage, discrepancies were discussed between the authors and resolved. The list of documents assessed with the additional criteria, and reason for exclusion is recorded in [S2 Table](#).

Review update

In April 2023, we updated the systematic review. We searched Pubmed with date constraints from October 10, 2020 to April 24, 2023 and Google Scholar with dates constraints from 2020–2023. The list of databases searched, with the date and keywords used, is in [S1 Appendix](#). Inclusion and exclusion criteria were the same as previously used. The list of documents assessed is recorded in [S2 Table](#).

Data extraction process

The following parameters were extracted from included documents: title, publication year, country, crisis phase, FST category, study type, type of treatment, barrier or facilitator, barrier or facilitator type, description of barrier or facilitator, and page number. Before data collection, we established options for data extraction categories ([Table 1](#)). An intervention was defined as

Table 1. Options set for four categories for data collection.

Crisis phase	FSM step	Study type	Barrier or facilitator type
First phase emergency (<1 year)	On-site treatment	Intervention only	Environmental ^a
Stabilization—recovery phase (1–3 years)	(Semi-) centralized treatment	Research intervention	Spatial ^a
Protracted (>3 years) Unknown		Research on existing intervention	Economic ^a
			Institutional ^a
			Social and/ or cultural ^a
			Temporal ^a
			Technical ^b
			Operation ^b
			Performance ^b
			Safety ^b
			Supply ^b

^a from six dimensions of complexity [12]

^b added categories during data extraction and analysis

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a unique treatment system implemented in one setting; please note one intervention could have been described in several documents. A facilitator was defined as a characteristic supporting FST implementation, and a barrier hindering FST implementation. The dataset is available in [S1 Table](#).

Data was extracted in Microsoft Excel (Redmond, WA, USA) independently by two authors, and discrepancies discussed and resolved.

Quality appraisal

We used the Bond Evidence checklist [13] to rate and categorize interventions into four quality categories: weak evidence (up to 37%), minimum standard (up to 62%), good standard (up to 81%), and gold standard (up to 100%). Interventions were graded independently by two authors, and discrepancies discussed and resolved.

Data synthesis

After cleaning the data, including remove duplicate interventions, we developed facilitators and barriers categories. We grouped treatments into treatment modules, defined as one treatment technology (e.g. constructed wetlands). A treatment system was defined as one or multiple treatment modules (e.g. lime treatment associated with constructed wetlands and incineration). We analyzed results by country, crisis phase, treatment module, and quality assessment. We synthesized results by category, grouped similar barriers and facilitators, calculated their percentage of occurrence, and provided descriptive examples in the text. We summarized overall results into the top 10 mentioned barriers or facilitators, and recommendations for implementation guidance and future research.

Results

A total of 6,991 documents were initially included through peer-reviewed databases search ([S3 Table](#)), and 11,386 through organizations' websites. There were 3,820 documents remaining after de-duplication and title review. Abstract review reduced the total to 747 documents, and full text review reduced the total to 266 documents. With the additional inclusion criteria, 49 documents remained (47 documents and 2 from reference chaining). In the review update,

307 titles were screened, with 57 included after de-duplication and title review. After abstract review, 23 documents were included, 4 of which remained after full-text review. Thus, there was a final total of 53 documents included in the study (Fig 1, Table 2).

Included documents were published 1976–2022, with most (89%, $n = 47$) published after 2010. Overall, 75 different interventions were identified, implemented in 12 countries, including Bangladesh (69%, $n = 52$, 27 documents), Myanmar (4%, $n = 3$, 4 documents), Ethiopia (4%, $n = 3$, 3 documents), Lebanon (4%, $n = 3$, 3 documents), and Haiti (3%, $n = 2$, 6 documents).

Interventions were a combination of multiple treatment modules, with 22 different individual modules identified, including lime treatment (23%, $n = 17$, 14 documents), filters (e.g. sand, gravel, glass bead, bristle, and trickling filters) (20%, $n = 15$, 13 documents), infiltration (e.g. infiltration basins, trenches, ponds, and soak pits) (20%, $n = 15$, 7 documents), settling tanks (including also settler-thickening tank and hopper-bottom tanks) (16%, $n = 12$, 6 documents), and ponds (e.g. stabilization, maturation, polishing, oxidation, anaerobic ponds, and lagoons) (16%, $n = 12$, 11 documents).

We identified 424 unique barriers and 435 unique facilitators (859 total). Most barriers and facilitators were from interventions implemented in Bangladesh (76%, $n = 655$), and during the stabilization/recovery phase of the humanitarian crisis (61%, $n = 514$). The barriers and facilitators were primarily from weak evidence (51%, $n = 435$), followed by minimum standard (44%, $n = 382$), and good standard (5%, $n = 42$). The ten most mentioned barriers and facilitators overall are outlined in Table 3.

The barriers and facilitators were classified under 11 categories. The number of reports, interventions, countries, barriers and facilitators, and the percentage of total barriers and facilitators are presented in Table 4. All categories were found in at least 14 different interventions, 15 different documents, and four different countries.

Four of the 11 categories have more than half of their barriers and facilitators as minimum standard or higher (Fig 2). Six categories have more than half of their barriers and facilitators as weak evidence.

Below, we summarize the results for barriers and facilitators by category.

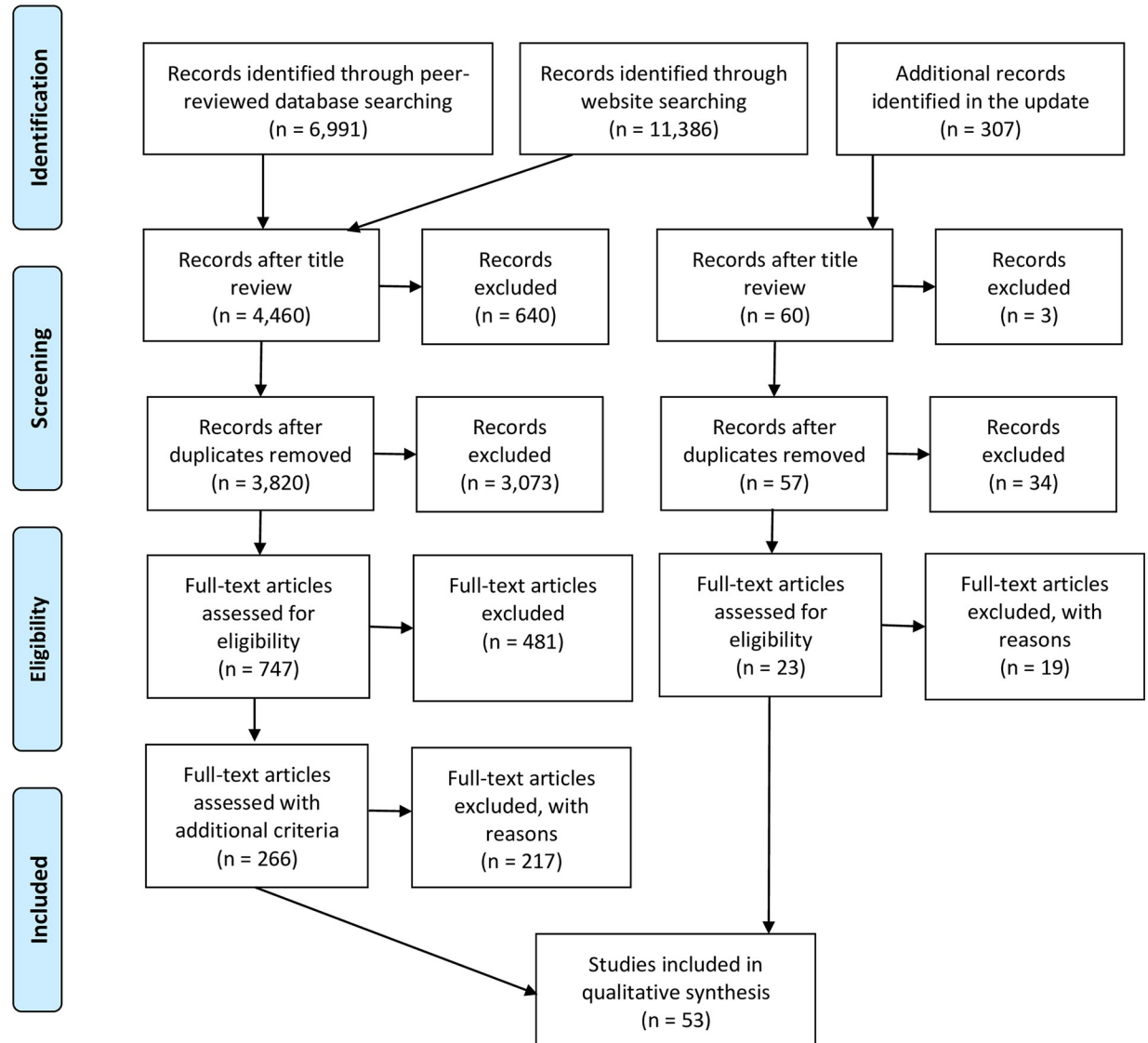
Performance

The most commonly identified performance barrier (61%) was not meeting effluent discharge standards, for some or all parameters. For example, in a treatment system using a settling tank, ABR, and a gravel filter, the final BOD₅ effluent values were still 40 times above the national discharge standards, although the treatment efficiency reached 70% [38]. Another identified barrier was when further treatment was needed for the solid and/or the liquid part of the sludge (31%). For example, in a treatment system including an anaerobic digester and a horizontal filter, treatment of sludge accumulating in the anaerobic chamber and the filter wasn't planned for, so the accumulated sludge was periodically desludged and disposed of on the nearby land [38]. Lastly, systems with low reduction values were also identified as a barrier (10%). For example, a system with hydrated lime treatment, drying beds, ponds, and incineration achieved only 27% BOD₅ reduction [38].

Systems with high reduction efficiencies were the most commonly identified performance facilitator (48%). For example, a system with a dumping station, hopper-bottom tank, ABR, constructed wetlands, maturation pond, infiltration basin, drying beds, infiltration trenches, and incinerator reached a treatment efficiency of 96% for TSS, 85% for COD, and 3 log reduction for *E. coli* [31]. Another facilitator was when systems had effluent values within standards (30%), especially for pathogens. For example, a system including lime stabilization and



PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Fig 1. PRISMA flow diagram.

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Table 2. Studies included in the systematic review.

#	Report	Interventions	Country	Crisis phase	FSM Category	Study Type	Type of treatment	Barrier or Facilitator	Quality category
1	Bastable and Lamb (2012) [14]	1, 70	Haiti	First phase emergency	(Semi-) centralized treatment	Intervention only	Pond, UDDT	1 barrier 2 facilitators	Weak evidence
2	Patrick <i>et al.</i> (2017) [15]	2	Ethiopia	Protracted	On-site treatment	Research on existing intervention	UDDT	1 barrier 10 facilitators	Good standard
3	Eyrard <i>et al.</i> (2015) [16]	3	Bangladesh	Protracted	(Semi-) centralized treatment	Intervention only	Pond, planted drying beds, biogas	16 barriers 10 facilitators	Weak evidence
4	Hettiarachchi (2008) [17]	4	Sri Lanka	Protracted	On-site treatment	Intervention only	Filter	2 barriers 3 facilitators	Weak evidence
5	Daniel and Lloyd (1980) [18]	5	Bangladesh	Protracted	On-site treatment	Research on existing intervention	Anaerobic digester	7 barriers 6 facilitators	Minimum standard
6	Cavalazzi (2016) [19]	6	Thailand	Protracted	(Semi-) centralized treatment	Intervention only	Anaerobic digester, filter, pond	1 barrier 4 facilitators	Weak evidence
7	Karahalios <i>et al.</i> (2018) [20]	7	Kenya	Protracted	(Semi-) centralized treatment	Intervention only	Solar-thermal process	12 facilitators	Weak evidence
8	Kurkowska <i>et al.</i> (2019) [21]	8	Bangladesh	Stabilization-recovery phase	On-site treatment	Intervention only	Biogas	2 barriers 4 facilitators	Weak evidence
9	Ngala <i>et al.</i> (2014) [22]	9	Ethiopia	Protracted	On-site treatment	Intervention only	UDDT	2 barriers 5 facilitators	Weak evidence
10	Sustainable Sanitation and Water Management (2017) [23]	10	Lebanon	Protracted	On-site treatment	Intervention only	Septic tank	3 barriers	Weak evidence
11	Rajbhandari and Dangol (2017) [24]	11	Nepal	Stabilization-recovery phase	(Semi-) centralized treatment	Research on existing intervention	ABR, filter, planted drying beds, biogas, retention tank	2 barriers 5 facilitators	Minimum standard
12	Solidarités International (2010) [25]	12	Bangladesh	Protracted	(Semi-) centralized treatment	Intervention only	Biogas	13 barriers 4 facilitators	Weak evidence
13	Makki (2018) [26]	13	Lebanon	Protracted	On-site treatment	Research on existing intervention	Septic tank	1 barrier 2 facilitators	Minimum standard
14	Rajbhandari <i>et al.</i> (2017) [27]	11	Nepal	Stabilization-recovery phase	(Semi-) centralized treatment	Research on existing intervention	ABR, filter, planted drying beds, biogas, retention tank	2 barriers 2 facilitators	Minimum standard
15	Taylor (1979) [28]	14	India	Stabilization-recovery phase	On-site treatment	Intervention only	Septic tank	5 barriers 2 facilitators	Weak evidence
16	Solidarités International (2018) [29]	15	Bangladesh	First phase emergency	(Semi-) centralized treatment	Intervention only	Lime treatment, geobag, filter	8 barriers 13 facilitators	Weak evidence
17	Jones (2017) [30]	16	Kenya	Protracted	(Semi-) centralized treatment	Intervention only	Solar-thermal process	9 barriers 4 facilitators	Weak evidence
18	Solidarités International (2019) [31]	17	Myanmar	Protracted	(Semi-) centralized treatment	Intervention only	Settling tank, ABR, constructed wetlands, pond, infiltration, unplanted drying bed, incineration	16 barriers 7 facilitators	Weak evidence

(Continued)

Table 2. (Continued)

#	Report	Interventions	Country	Crisis phase	FSM Category	Study Type	Type of treatment	Barrier or Facilitator	Quality category
19	NGO Forum (2019) [32]	18	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Settling tank, ABR, planted drying bed, filter, pond	5 barriers 4 facilitators	Weak evidence
20	Save the Children International (2019) [33]	19	Myanmar	Protracted	(Semi-) centralized treatment	Intervention only	Settling tank, unplanted drying bed, ABR, pond	4 barriers 3 facilitators	Weak evidence
21	Octopus (2019) [34]	20	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Constructed wetland, filter, disinfection	7 barriers 7 facilitators	Weak evidence
22	Furlong <i>et al.</i> (2017) [35]	21, 35	Myanmar, Ethiopia	Protracted, Stabilization–recovery phase	On-site treatment	Research intervention	Vermicomposting	6 barriers 4 facilitators	Weak evidence
23	Elrha (2019) [36]	21	Myanmar	Protracted	On-site treatment	Research intervention	Vermicomposting	4 barriers 2 facilitators	Weak evidence
24	Sanitation Technical Working Group (2018) [37]	36, 37, 38, 39, 40	Bangladesh	First phase emergency	(Semi-) centralized treatment	Intervention only	Lime treatment, biogas	11 barriers 1 facilitator	Weak evidence
25	BRTC and BUET (2020) [38]	23, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Aerobic treatment, biogas, anaerobic digester, constructed wetlands, retention tank, ABR, unplanted drying bed, filter, settling tank, upflow filter, lime treatment, pond, incineration	31 barriers 14 facilitators	Minimum standard
26	icddr,b and UNICEF (2020) [39]	51, 52, 53, 54, 55, 56	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Pond, upflow filter, lime treatment, constructed wetlands, anaerobic digester, infiltration, ABR	6 facilitators	Weak evidence
27	IFRC (2018) [40]	24	Bangladesh	First phase emergency	(Semi-) centralized treatment	Intervention only	Lime treatment, unplanted drying bed, vermicomposting	7 barriers 10 facilitators	Weak evidence
28	Practical Action (2018) [41]	33	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Upflow filter, constructed wetlands, solids burial	4 barriers 9 facilitators	Weak evidence
29	Sanitation Technical Working Group (2018) [42]	57	Bangladesh	First phase emergency	(Semi-) centralized treatment	Intervention only	Lime treatment, geobag	11 barriers 10 facilitators	Weak evidence
30	Sanitation Technical Working Group (2018) [43]	58	Bangladesh	First phase emergency	(Semi-) centralized treatment	Intervention only	Lime treatment	12 barriers 10 facilitators	Weak evidence
31	Solidarités International (2018) [44]	15	Bangladesh	First phase emergency	(Semi-) centralized treatment	Intervention only	Lime treatment, geobag, filter	5 barriers 3 facilitators	Weak evidence
32	WaterAid Bangladesh (2018) [45]	20	Bangladesh	First phase emergency	(Semi-) centralized treatment	Intervention only	Constructed wetlands	4 barriers 1 facilitator	Weak evidence
33	IFRC (2019) [46]	23	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	ABR, aerobic treatment, settling tank, filter, disinfection, anaerobic digester, lime treatment	7 barriers 10 facilitators	Weak evidence

(Continued)

Table 2. (Continued)

#	Report	Interventions	Country	Crisis phase	FSM Category	Study Type	Type of treatment	Barrier or Facilitator	Quality category
34	IFRC (2019) [47]	24	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Lime stabilization, unplanted drying bed	4 barriers 11 facilitators	Weak evidence
35	NGO Forum (2019) [48]	25	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Lime stabilization, unplanted drying bed, filter, infiltration, incineration	8 barriers 1 facilitator	Weak evidence
36	UNICEF Philippines (2015) [49]	26	Philippines	First phase emergency	(Semi-) centralized treatment	Intervention only	Lime treatment	10 barriers 5 facilitators	Weak evidence
37	Kilbride <i>et al.</i> (2013) [50]	27	Haiti	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	UDDT	1 barrier 4 facilitators	Minimum standard
38	Pinera and Reed (2006) [51]	28	India	Stabilization–recovery phase	On-site treatment	Intervention only	Septic tank	1 barrier	Weak evidence
39	Herrera and Sataviriya (1984) [52]	29	Thailand	Protracted	(Semi-) centralized treatment	Intervention only	Pond	1 barrier 7 facilitators	Weak evidence
40	Kinstedt (2012) [53]	27, 30	Haiti, Bolivia	First phase emergency, unknown	(Semi-) centralized treatment, On-site treatment	Intervention only	UDDT	3 barriers	Minimum standard, weak evidence
41	IFRC <i>et al.</i> (2019) [54]	23	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Aerobic treatment	6 barriers 2 facilitators	Weak evidence
42	Howard (1976) [55]	31	Bangladesh	Unknown	(Semi-) centralized treatment	Intervention only	Anaerobic digester, pond, solar-thermal process	6 barriers 6 facilitators	Weak evidence
43	Kramer <i>et al.</i> (2013) [56]	27	Haiti	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	UDDT	10 barriers 11 facilitators	Minimum standard
44	Grieve and Gnilo (2012) [57]	32	Philippines	First phase emergency	(Semi-) centralized treatment	Intervention only	Vermicomposting, lime treatment	3 barriers 3 facilitators	Weak evidence
45	Practical Action (2019) [58]	33	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Upflow filter, constructed wetlands, solids burial	11 barriers 6 facilitators	Weak evidence
46	Preneta <i>et al.</i> (2013) [59]	27	Haiti	Stabilization–recovery phase	(Semi-) centralized treatment	Research on existing intervention	UDDT	4 barriers 4 facilitators	Minimum standard
47	Higgins (2010) [60]	27	Haiti	First phase emergency	(Semi-) centralized treatment	Intervention only	UDDT	2 barriers 4 facilitators	Minimum standard
48	Oxfam and Arup (2019) [8]	23, 34, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Intervention only	Upflow filter, pond, lime treatment, constructed wetlands, ABR, biogas, geobag, aerobic treatment, filter, disinfection, infiltration, settling tank, solids burial, solar-thermal process, unplanted drying bed	119 barriers 146 facilitators	Minimum standard
49	Oxfam (2018) [61]	22	Bangladesh	First phase emergency	On-site treatment	Intervention only	Vermicomposting	5 barriers 3 facilitators	Weak evidence
50	Mishuk <i>et al.</i> (2022) [62]	71	Bangladesh	Protracted	(Semi-) centralized treatment	Research on existing intervention	Upflow filter, solids burial, constructed wetlands, infiltration	3 barriers 12 facilitators	Weak evidence

(Continued)

Table 2. (Continued)

#	Report	Interventions	Country	Crisis phase	FSM Category	Study Type	Type of treatment	Barrier or Facilitator	Quality category
51	Lolkema (2021) [63]	72,73	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Research on existing intervention	Lime stabilization, unplanted drying beds, infiltration, solids drying beds	15 barriers 16 facilitators	Good standard
52	Bill & Melinda Gates Foundation (2021) [64]	74	Lebanon	Protracted	(Semi-) centralized treatment	Intervention only	Anaerobic digester, aerobic trickling filters, infiltration	2 barriers 3 facilitators	Weak evidence
53	Kabir <i>et al.</i> (2020) [65]	75	Bangladesh	Stabilization–recovery phase	(Semi-) centralized treatment	Research on existing intervention	Septic tanks, ABR, planted drying beds	1 barrier 2 facilitators	Minimum standard

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geobags had no *E. coli* recorded in the liquid supernatant [42]. Another facilitator was when effluents could be used as fertilizer in agriculture or energy, with sometimes better quality than commercial products, and having planned discharged routes that were functioning (18%). For example, the briquettes produced through a solar-thermal process burned for longer than normal charcoal and produced less smoke [30].

Operation

A need for strong operational supervision, with frequent labor or specific technical skills was the most commonly identified operation barrier (39%). For example, a biogas system needed strict supervision to add the adequate mixture every day in the reactor to ensure the proper ratio to maximize gas production [16]. Additionally, difficulties in system operation were reported as a barrier (23%), such as the sensitivity of biological treatment to hard-to-control factors [8]. For example, for a solar-thermal system, the briquette recipe had to be refined each day due to variation in sludge quality and quantity [30]. Another barrier was when inputs (e.g. water, fuel, lime) were needed for operation (20%). For example, for a septic tank system, a constant supply of water was necessary to flush the pans and ensure sewage was diluted and bacteriological action could proceed, which was critical in a context with water scarcity [28].

Table 3. Most mentioned barriers and facilitators.

Rank	Barriers	Facilitators	Number of occurrences	Percentage of occurrence
1		Systems with high reduction efficiencies	69	8%
2	Systems not meeting effluent discharge standards		57	7%
3		Effluent within discharge standards	43	5%
4		Systems easy to operate and maintain, requiring basic technical skills from locally-available labor	42	5%
5	Systems over or under-designed, or an inappropriate type of material used		36	4%
6		Low capital and operational costs	34	4%
7	Strong operational supervision, with frequent labor or specific technical skills		32	4%
8	Further treatment needed for the solid and/or the liquid sludge		29	3%
9		Effluents used as fertilizer or energy, and functioning discharged routes	26	3%
10		Rapid implementation	25	3%

<https://doi.org/10.1371/journal.pwat.0000289.t003>

Table 4. Documents, interventions, countries, and barriers and facilitators by category.

Categories	Number of documents	Number of interventions	Number of countries	Percentage of total barriers and facilitators	Number of barriers	Number of facilitators
Performance	42	62	9	28%	94	145
Operation	33	38	9	17%	82	64
Technical	33	40	8	13%	69	40
Economic	26	33	10	9%	37	41
Environmental	26	35	9	7%	22	37
Spatial	20	30	4	6%	31	24
Social/cultural	20	18	7	5%	20	27
Temporal	15	26	6	5%	11	33
Safety	16	20	4	4%	25	9
Supply	19	18	6	3%	16	13
Institutional	15	14	8	2%	17	2
Total	53	75	12	100%	424	435

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Lastly, monitoring was a barrier (12%) because of the additional tasks it required, high staff turnover, decentralized units to reach, and lack of access to adequate testing facilities. For example, significant human resources were necessary to monitor a lime stabilization system through pH checks in every barrel treated [42].

The most common operation facilitator was when systems were easy to operate and maintain (66%), requiring basic technical skills from locally-available labor that could be easily trained on with limited interventions from staff. For example, a system with settling tanks, an upflow filter, constructed wetlands, soak pits, and solids burial pits run by gravity needed limited intervention from the operator [8]. A system with ABR, aerobic treatment, settling tank, glass bead filter, disinfection, anaerobic digestion, and lime treatment required basic mechanical and electric skills for daily operation and maintenance [46]. Additionally, not being dependent on energy source was a facilitator (9%). For example, the infrastructure for a system using thermophilic composting was not dependent on an energy source, which was critical in a context where power supplies were unreliable [56]. It was also a facilitator when processes were flexible (8%), for example when there were multiple geobags to allow time for solids to dry out completely before burial [8].

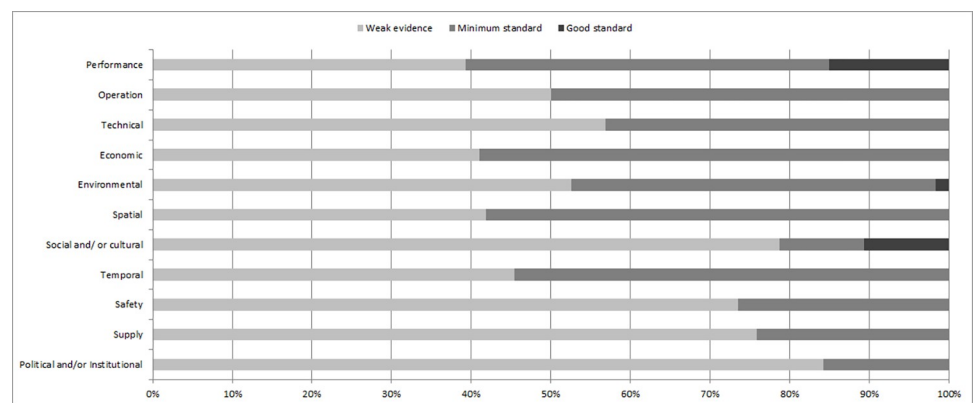


Fig 2. Evidence evaluation per category of barriers and facilitators.

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Technical

The most commonly identified technical barrier was when systems were over or under-designed, or an inappropriate type of material was used (52%). This led to issues such as plants not surviving because of the high sludge concentration [16], or necessary retention time not maintained because of frequent emptying due to high volumes of sludge [32]. For example, the filter material from a system with upflow filtration, constructed wetlands, and solids burial pits clogged because of excessive solid sludge levels at the inlet [58], and in a system with unplanted drying beds, the local rice bags used were too compact to allow large-scale rapid infiltration [40]. Additionally, the need for technical expertise or supervision for design or construction was a barrier (17%). For example, a biogas system needed highly skilled masons for construction [16]. Another barrier was construction quality (10%), with brick layer collapsing [25], or pipes leaking [48]. For example, in a system with a dumping station, a hopper-bottom tank, an ABR, constructed wetland, a maturation pond, an infiltration basin, drying beds, infiltration trenches, and an incinerator, the pipes got clogged with solid sludge, and the brick walls cracked due to poor brick and mortar quality [31]. Lastly, it was a barrier when scaling-up the system was difficult (7%), especially when constructed with concrete. For example, in a system with lime treatment, settling tanks, solids burial pits, and infiltration trenches, structures were made of concrete and were less simple to expand than excavated lagoons [8].

The most common technical facilitator was when systems were easy to scale-up (50%), by adding modules in parallel when there was sufficient space. For example, in a system with lime treatment, geobags, and gravel and sand filters, the number of barrels, geobags, and infiltration beds could be increased to raise the system capacity [29]. Proper design and using appropriate materials were also facilitators (18%). For example, a solar-thermal system had two chambers to allow adequate time for proper maturation of fecal sludge [22]. Lastly, a facilitator was when systems were easy to design and/or construct (18%), with low technical expertise needed. For example, lime treatment was identified as a simple, straightforward, robust technology that could be designed and constructed in the local context, as construction did not require prior knowledge and experience [47].

Economic

High capital and/or operational costs were the most common economic barrier (62%), such as building infrastructure [8] or sourcing lime [37]. For example, the worms cost US\$210/kg in 2015 in a system using vermicomposting [35], and a system with lagoon lime treatment and dewatering beds had a whole life cost of more than US\$200,000 [8]. Additionally, an identified barrier was when local authorities could not cover the costs and external funding was necessary (22%). For example, in a system with lime stabilization, the government agreed to manage the site even though they lacked funds to support it financially; when external funding ended, the government was no longer able to maintain and operate the site [49]. In another system with thermophilic composting, compost sales could only cover ~70% of labor inputs, excluding infrastructure investments, general site maintenance, or transport and collection of the wastes, so external funding was necessary [56].

Low capital and operational costs, due to low salaries, inexpensive locally-available materials, and/or low power consumption were the most commonly identified economic facilitator (81%). For example, a system with an ABR, aerobic treatment, a settling tank, a glass bead filter, disinfection, anaerobic digestion, and lime treatment had an operational cost of US\$5/m³ treated, that could be reduced using renewable energy [46]. A system with a settling tank, ABR, unplanted and planted gravel filters, and a polishing pond had a capital cost of less than US\$500/m³ treated [8]. Another facilitator was when outputs helped cover

operational costs, with reduced desludging [22], or generating revenues by selling compost or briquettes [50] (14%). For example, in a system with a feeding tank and a biogas, biogas use saved US\$95 in cylinder gas costs [27]. In a system with feeding tank, ABR, anaerobic filter, and planted drying beds, around US\$200/year was saved due to using treated wastewater for farmland [27].

Environmental

Heavy rains were the most common environmental barrier (45%), because they could halt construction work [25], induce landslides [32], or increase sludge drying time [16]. For example, the time to dry sludge in drying beds increased from three to five weeks during the rainy season [31]. Another barrier was floods or earthquakes damaging the systems (27%). For example, a system with the effluent at a low level and an ABR below the ground level was not able to discharge when the surrounding area flooded [8]. Lastly, an identified barrier was a high water table (18%) because it could overflow the systems [26] or decrease the soil infiltration capacity [28]. For example, because of the additional flow going through the treatment system during the rainy season, infiltration basins were not able to infiltrate the wastewater which overflowed to the neighboring field [31].

The most commonly identified environmental facilitator was when systems were working well in certain climates, like the ponds in dry seasons [16], or were resistant to environmental issues, like the constructed wetlands for earthquakes [8] (54%). For example, a UDDT system was set up in a warm and arid climate, which resulted in a warm, very dry and moderately alkaline environment in the UDDT vaults, inhospitable for many microorganisms [15]. Adaptations were also facilitators when done to resist environmental issues (35%), like roofs to cover drying beds from the rain [44], or constructing the system above the ground to prevent flooding [8]. For example, locally made polytunnels (bamboo and see through plastic) were covering unplanted drying beds during the rain and removed during a sunny day or before a cyclone [40]. Lastly, systems with additional positive environmental impacts were identified as facilitators (11%), like biogas production reducing firewood use [21]. For example, briquettes produced through solar-thermal process created lower smoke and soot than charcoal [20].

Spatial

The most commonly identified spatial barrier was lack of space to construct the system or additional modules for scale up, and systems with high land occupation like constructed wetlands (58%). Available space constrained the systems that could be implemented [37]. For example, the amount of suitable land required for thermophilic composting operation (0.6 hectares for 10,000 people) was a limitation [56]. Another barrier was hilly terrains (39%), which led to access issues [8], and increasing costs and time for construction and operation [29]. For example, multiple systems in Cox's Bazar, Bangladesh were accessible only by foot, not to motorized and non-motorized transport [47].

Systems with low land occupation like lime treatment was the most common spatial facilitator (75%). For example, a system with upflow filters, constructed wetlands and solids burial pits required a 700 ft² area for a maximum influent of 5 m³/day [41]. Another identified facilitator was systems that could be implemented in multiple topographies and laid out to reduce occupied space, like geobags or rectangular shaped tanks [8] (17%). For example, small biogas plants (2 to 4 m³ for two to four latrine blocks) were flexible and preventing destroying existing shelters or WASH facilities for their implementation [16].

Social/cultural

The most commonly identified social and cultural barrier was when the population had difficulty accepting the treatment solution (45%), sometimes leading to stopping the system [57]. Communication and education were identified as important to overcome this issue [56]. For example, questions on using biogas for cooking were raised by users regarding its compatibility with the Muslim faith [16]. Another barrier was when how people used the latrines influenced how the system functioned (35%), like using flushing water in UDDT [22] or chemicals with vermicomposting [61]. For example, people threw waste material (plastic, piece of bricks, etc.) into the organic waste chamber and the slurry pit of a biogas system [25]. Lastly, systems with bad odors were a barrier (20%). For example, ponds resulted in olfactory nuisance for the surrounding population [16].

The most common social and cultural facilitator was user acceptance and ownership (37%), when users had benefits from the treatment outputs, like using the biogas or briquettes [20], or if the treatment system was far from the settlements [33]. For example, households benefiting from biogas for cooking had strong ownership of the system and were willing to be involved in the maintenance [16]. Another facilitator was when systems were already in line with people's habits, or were improving their life (26%). For example, briquettes produced through solar-thermal process could be used with current cooking infrastructures and required minimum behavioral change [20]. User acceptance was more investigated and discussed in the included documents for on-site systems, like for the UDDT or the biogas [35].

Temporal

The most commonly identified temporal barrier was when systems had long start up time (64%), due to long construction or commissioning time. For example, in a system with constructed wetland, sand filter, chlorination and an infiltration pit, six months were necessary for the system to reach targeted reductions for BOD, pathogens and nutrients [8].

Rapid implementation, due to short set up or commissioning time, was the most common temporal facilitator (76%), thanks to prefabricated tanks or simple techniques like lime treatment and geobags [8]. For example, simple excavated lined lagoons for lime treatment were quick to construct and decommission [8].

Safety

Systems putting people in contact with dangerous substances were the most commonly identified safety barrier, like lime from lime treatment [42] (44%) or smoke from an incinerator affecting the workers [31]. Contact with pathogens from the sludge, through flies or through the plant's operation [8], was another barrier (32%). For example, many flies bred on maturation ponds [31]. Lastly, open pits and possible theft of materials were also an identified barrier (24%). For example, to avoid accidents, ponds were fenced and families were instructed to keep their children away [16].

Systems preventing sludge contact by having it enclosed up to the discharge routes, were the most commonly identified safety facilitator (67%). For example, an upflow filter was contained in closed plastic tanks which limited physical contamination and vectors proliferation [8]. Another facilitator was adaptations limiting sludge contact and vectors spreading (22%). For example, a mosquito net covered the containers of a lime treatment system [60].

Supply

The most common supply barrier was material or spare parts difficult to source locally (63%), imported from abroad, or with long shipping time. For example, the fuse from a locally-bought

control module for solar-thermal process was not locally or in-country available, and had to be shipped from Europe [30]. The components poor quality and durability was another identified barrier (19%). For example, the tank panels from an aerobic system needed regular replacement because of the repetitive stress of the mixing action [54].

Locally available materials for construction and operation were the most commonly identified supply facilitator (92%). For example, hydrated lime, gravel and sand were identified as common building materials that can be purchased locally and are readily available [47].

Institutional

Local authorities not involved in the management of the system due to a lack of funds or required skills was the most common institutional barrier (41%). For example, a local government had little interest in managing a lime stabilization system, because they could not foresee a sizable benefit from it [49]. Another barrier was administrative requirements hindering the systems implementation, such as complex authorization processes [19] (35%). For example, for a system with lime treatment, geobags, and gravel and sand filters, the government did not allow permanent infrastructure, so the infrastructure needed to be able to be decommissioned and the use of bricks or cement was not accepted [29].

The only identified institutional facilitator was local stakeholders supporting the system implementation, by paying salaries or identifying the land (100%). For example, for a system with a feeding tank, biogas, a stabilization tank, ABR, an anaerobic filter, and planted drying beds, local stakeholders identified the land to establish the plant, and the municipality provided the operator's salary [24].

Discussion

We completed a systematic review assessing the barriers and facilitators to FST implementation in humanitarian camps. We searched published and grey literature, and included 53 documents summarizing 75 interventions from 12 countries. We found most barriers and facilitators identified were from FST implementations in Bangladesh (76%), and during the stabilization phase of the humanitarian crisis (61%); and, lime treatment was the most implemented treatment module (23%). Below, we discuss: 1) the most mentioned barriers and facilitators; 2) that barriers and facilitators were related to one another; and, 3) that treatment system categories had the most mentioned barriers and facilitators. How these barriers and facilitators can inform guidance are described throughout, followed by limitations and further research needed.

The most mentioned facilitators of FST implementation in humanitarian camps that emerged from the review were systems that: had high reduction efficiencies; were rapidly implemented with available technologies; had low capital and operational costs; were easy to operate and maintain; and, had effluents reaching discharge standards, being reused for agriculture or energy, and were effectively and safely discharged. The most mentioned barriers that emerged were: under- or over-designed systems with inappropriate materials, needing strong operational supervision and additional treatment, and effluents not meeting discharge standards. Future guidance should focus on recommendations to enable facilitators and hinder barriers.

Overall, the main barriers and facilitators were related, meaning the facilitators identified are mitigation measures for the barriers identified (Table 5). For example, if the population has difficulty in accepting a treatment solution (social and cultural category), choosing a solution where users have benefits from the treatment outputs can help increase their acceptance

Table 5. Main barriers and facilitators by category.

Categories	Main barriers	Main facilitators
Performance	Unmet effluent discharge standards	High reduction efficiencies
Operation	Strong supervision, frequent labor, specific technical skills	Easy to operate and maintain, basic technical skills and low labor
Technical	Over or under-designed, inappropriate material used	Easy to scale up
Economic	High capital and/ or operational costs	Low capital and/or operational costs
Environmental	Heavy rains	Systems adapted for certain climates, or resistant to environmental issues
Spatial	Lack of space and systems with high land occupation	Systems with low land occupation
Social/cultural	Population difficulty to accept the treatment solution	User acceptance and ownership
Temporal	Systems with a long start up time	Rapid implementation, due to short set up or commissioning time
Safety	Systems put people in contact with dangerous substances	Systems prevent contact with sludge
Supply	Material or spare parts difficult to source locally	Locally and easily available materials and spare parts
Institutional	Local authorities not involved in the systems management	Local stakeholders supported the implementation

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and ownership. Additionally, in contexts with heavy rains (environmental category), adapting drying beds systems with a roof can reduce sludge drying time.

The performance, operation, and technical categories had the most barriers and facilitators mentioned. Thus, focusing on minimizing barriers and achieving facilitators from these categories when implementing FST in humanitarian camps will yield greater implementation success overall. Interestingly, these categories are linked to the system itself, and less to contextual factors. This may be because humanitarian practitioners did not relate contextual issues to FST specifically when reporting interventions. Barriers related to the treatment system are easier to control as they can be acted upon before FST implementation. For example, the appropriate treatment systems can be chosen based on the treatment performance needed, or the local operational capacity. However, this also means that barriers and facilitators may be difficult to act upon once the system is chosen and operating. Thus, making the right decision before implementation is key, and guidance should focus on helping practitioners make the appropriate decisions on performance, operational, and technical aspects of the treatment systems before and during FST establishment. In addition, some categories identified herein are similar to decision factors in the Compendium of Sanitation Technologies in Emergencies [7] for the treatment technologies: social considerations (social/cultural category), costs (economic category), health and safety (safety category), and material (supply category). These categories should be incorporated into guidance as factors to help decision-making when selecting a treatment system for a particular context.

There were limitations to this research. First, barriers and facilitators were not always clearly defined in included documents, so reviewers had to identify and define them. Additionally, the evidence is overall weak, with only a few categories having more than 50% of barriers and facilitators of minimum standard and few with good standard. Lastly, most of the documents were from Cox's Bazar, Bangladesh and from stable settings, limiting validity of these results outside these contexts.

Based on this review, future research and guidance is needed. Additional implementation and reporting of FST in humanitarian camps is necessary, using a harmonized template across systems and contexts that can be integrated into guidance. This template should, at minimum, identify the beneficiaries clearly, describe the data collection and analysis methodologies, and discuss the changes throughout the FST intervention [13]. Future guidance should help practitioners' decision-making by using the barriers and facilitators identified, with a focus on the performance, operational, and technical aspects of the treatment systems. Future research

should focus on identifying specific knowledge gaps by treatment system and humanitarian context, expanding beyond only camp settings.

Conclusions

In our review we identified 75 FST interventions from 12 countries with 424 barriers and 435 facilitators. We identified the most common barriers and facilitators of FST implementations in humanitarian camps, and recommend future guidance focus on enabling facilitators and hindering barriers. The most common facilitators of FST implementation were: high reduction efficiencies; rapid implementation with available technologies; low capital and operational costs; ease of operation and maintenance; and, achieving effluent discharge standards, effluent reuse, and safe discharge. Limitations of this work include that the majority of barriers and facilitators came from Bangladesh, and stable contexts. Strengths of this work include a holistic, broad, example-based summary of actual FST implementations in camps in humanitarian settings. This review can be used to develop guidance and future research needed.

Supporting information

S1 Checklist. PRISMA 2009 checklist.

(DOC)

S1 Table. Dataset.

(XLSX)

S2 Table. Documents assessed and reason for exclusion.

(XLSX)

S3 Table. Documents included through peer-reviewed databases search.

(XLSX)

S1 Appendix. Databases and websites searched.

(DOCX)

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