1 Title: Rapid evidence assessment of the impacts of sewerage, drainage, and chlorination in urban
2 settings of low-and middle-income countries

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11 Highlights

- 12 ● Most of the included studies focused on sewerage interventions with very few looking at
13 chlorination and none looking at the effects of drainage alone.
- 14 ● Chlorination and sewerage interventions, when implemented alone, were found to be
15 successful in reducing disease burden.
- 16 ● Sources of contamination included general lack of improved water and sanitation, sources in the
17 nearby environment, household hygiene practices, and issues with maintaining infrastructure
18 systems.
- 19 ● Infrastructure maintenance issues such as intermittent water supply, leaky pipes, and ineffective
20 chlorination affected the implementation and maintenance of these interventions.
- 21 ● For these interventions to be effective, the infrastructure should be properly maintained and
22 households need to be supported to engage in proper hygiene practices.

23
24 **Keywords:** Drainage, sewerage, chlorination, WaSH, impact, LMIC
25

Abstract

Aims: Rapidly synthesize the available evidence regarding the expected impacts of piped water chlorination, drainage, and sewerage on individuals living in low- and middle-income urban settings.

Methods: A systematic search was conducted in bibliographic databases and library catalogues. Impact evaluations that included a comparator and one of the three interventions of interest, attempted to control for confounding and selection bias, and took place in urban settings in a low- or middle-income country were considered. Outcomes related to health, well-being, economic growth, and the bacterial content of water were considered.

Results: 1483 articles were identified, with 18 included after final screening. Most studies were case-control and took place in Brazil, the Pacific Islands, or south-western Asia. Fifteen studies considered sewerage, five considered chlorination, and two studies considered drainage with some studies considering multiple interventions. All primary outcomes were related to health. When implemented alone, the sewerage and chlorination interventions were largely successful.

Conclusions: The evidence regarding the effects of chlorination, drainage, and sewerage interventions is limited and generally has a high risk of bias. When properly implemented, sewerage and chlorination are likely to have positive health impacts. However, when implemented poorly, all three interventions can have negative health impacts.

1 Introduction

2 Access to clean water and sanitation is a human right (United Nations, 2019). However, three billion
3 people lack access to basic sanitation (United Nations, 2019). Only 36% of the world's population has
4 access to sewerage (WHO/UNICEF JMP, 2017b). Although 92% of the world's population has access to
5 improved drinking water sources (defined as sources that are protected from outside contamination
6 such as fecal matter), water quality remains low around the world (WHO/UNICEF JMP, 2017a, 2019).
7 About two million people die from diarrheal diseases each year because of poor hygiene and sanitation
8 (United Nations, 2019). These numbers are slightly better in urban settings, where 96% of the
9 population has access to an improved water supply and 79% have access to improved sanitation (United
10 Nations, 2018). However, the health impacts of poor water and sanitation can be accentuated in urban
11 settings where people are in close contact with one another (Mackinnon *et al.*, 2019). Despite this, the
12 evidence regarding the health effects of water, sanitation, and hygiene (WaSH) interventions in urban
13 settings remains poor (Mackinnon *et al.*, 2019). There is even less evidence regarding what works in
14 decreasing the health impacts of poor quality water and sanitation in urban settings (Mackinnon *et al.*,
15 2019).

16 The challenges to providing clean and sustainable water and sanitation to a population are compounded
17 within cities (United Nations, 2018; Sosa-Rodriguez, Silva and Arriaga, 2019). Because of this and other
18 factors, improvements in access to WaSH resources have been slower in urban settings than rural
19 settings (United Nations, 2018). Demographic and health trends continue to make urban settings more
20 crowded, worsening the health impacts of poor water and sanitation in these settings (Mackinnon *et al.*,
21 2019). In 54 of the 120 countries for which data are available, growth in access to sewerage has not kept
22 pace with urban growth (United Nations, 2018). Due to how cities are structured, cities need a separate
23 drainage system and sewerage system that is resilient to floods (Sosa-Rodriguez, Silva and Arriaga,
24 2019). In many urban contexts, less than 8% of the wastewater is treated (Sosa-Rodriguez, Silva and
25 Arriaga, 2019). Consequently, more investment in urban WaSH is needed to support human health and
26 well-being (United Nations, 2018).

27 Here, we present the results from a rapid evidence assessment (REA) in which we systematically
28 reviewed and summarized the available, high-quality impact evaluations of three major urban WaSH
29 infrastructure interventions (piped water chlorination, drainage, and sewerage) in low- and middle-
30 income countries. A REA uses a systematic process to search and screen studies but limits the scope and
31 search strategy of the review to ensure that it is "rapid" (Barends, Rousseau and Briner, 2017). We also
32 comment on the factors affecting the impact of the intervention and additional considerations that
33 should be incorporated into the design of these interventions. We hope this work is used by policy
34 makers and practitioners in informing the design and implementation of their initiatives to improve
35 access to water and sanitation.

36 In the subsequent sections, we review the theory of change for the three interventions included in this
37 study. We then provide the methods used to produce this REA and summarize the results from the
38 included studies. We leverage the literature search that was conducted for this REA in order to
39 comment upon common challenges in the implementation, sustainability, and evaluation of WaSH
40 infrastructure interventions. We conclude by discussing the synthesized results, limitations, and
41 implications.

Interventions and theoretical model

We considered three interventions which are likely to be impactful in urban settings: chlorination of centralized water distribution system, expansion of drainage system, and installation of sewerage system. These interventions were chosen because the Millennium Challenge Corporation, an implementing organization, indicated a lack of sufficient, synthesized information in the available literature. The interventions are theorized to decrease population-level exposure to pathogens by improving drinking water, decreasing the amount of standing water, and decreasing exposure to fecal contamination (Figure 1). By decreasing pathogen exposure, the interventions may decrease morbidity. Such decreases in morbidity can be measured by incidence of diarrheal disease, typhoid, and other communicable diseases caused by inadequate WaSH infrastructure. Decreased disease incidence can ultimately result in better educational outcomes, accelerated economic growth, and a variety of other societal benefits. WaSH infrastructure can also have direct effects on these downstream outcomes by improving human dignity, increasing tourism, and supporting self-efficacy. There is significant evidence supporting the links from improved drinking water, decreased standing water and decreased fecal contamination to decreased morbidity and improvement in GDP growth and other social measures (Water Supply and Sanitation Collaborative Council and World Health Organization, 2005). However, evidence linking the three interventions of interest to the downstream effects is lacking in the literature. Many of the steps along this causal chain are difficult to quantify. As such, only paths that have been examined through rigorous impact evaluations are considered here.

Figure 1. Theory of change diagram co-created with Millennium Challenge Corporation and from Water Supply and Sanitation Collaborative Council and World Health Organization (2005)

Methods

The protocol for the rapid evidence assessment was finalized *a priori* to decrease risk of selection bias (Appendix A). The following section outlines the search process and inclusion criteria for this review.

Search strategy

A systematic search of academic bibliographic databases and library catalogues was completed to identify qualifying studies (Appendix B).¹ Due to the narrow scope of this rapid evidence assessment, sector-specific databases were not included in the search. An example of search strings employed by the strategy is presented in Appendix C.

Screening

The selection of studies for data extraction as part of the review was managed using EPPI-Reviewer 4 software (EPPI) and completed by implementing the standard steps of de-duplication, title and abstract screening, and then full text screening (Appendix D).

Inclusion / exclusion criteria (PICO)

This section presents the criteria used to identify studies included in the review, drawing on the PICO format (Higgins *et al.*, 2019).

Population (types of study participants)

The review includes any study with participants residing in urban settings in low- and middle-income countries (LMICs). Countries were defined to be LMIC using the WHO definition (WHO, 2016). We collected data on differential effects and experiences for sub-populations as far as it is possible and useful to do so using Cochrane PROGRESS-Plus criteria (O'Neill *et al.*, 2014).²

Interventions

The interventions considered here are limited to the chlorination of drinking water in the centralized water distribution system, expansion of storm drainage systems, and installation of a sewerage system. Other WaSH infrastructure, behavior change, or household-level interventions were not considered for inclusion. Although we recognize their importance, they fall outside the scope of this rapid evidence assessment, which was meant to respond to the expressed needs of an implementing organization.

Comparison group and study design

We include impact evaluations that employ an experimental or quasi-experimental design and/or analysis method, which seek to robustly measure the net change in outcomes that are attributed to an intervention or policy as compared to some appropriate counterfactual. We include randomized studies and non-randomized studies that attempted to address issues of confounding and selection bias. Feasibility studies, acceptability studies, and non-systematic literature reviews are not accepted. Process evaluations and qualitative studies are also excluded. Systematic reviews are included so long as some of the included studies would individually qualify for this rapid evidence assessment. However, effect sizes are presented only if the meta-effect sizes are reported in such a way that allows for the isolation of the effect of the interventions of interest.

¹ The search strategy development for this review was supported by John Eysers, an information specialist contracted by 3ie.

² Where Progress stands for place of residence, race/ethnicity, occupation, gender, religion, education, socioeconomic status, and social capital, and 'Plus' refers to personal characteristics associated with discrimination, features of relationships and time dependent relationships.

Outcomes

The review considers outcome(s) that assess a change in some indicator of health, well-being, economic growth, and/or the bacterial content of water (Appendix E).

Date, language, and form of publication

Only studies published in English are included. Studies are included if their publication date is 1900 or after. Only peer-reviewed publications are included.

Data extraction

All articles included after full-text screening underwent the same data extraction process. Two reviewers read the manuscripts and recorded the information in a template similar to Supplemental Table 1. The extracted information from the two reviewers was then combined by a single reviewer with verification by the second reviewer. The results tables were generated by the second reviewer from the combined, extracted data. Narrative summaries of results were written by a single reviewer and reviewed by the other. Due to the heterogeneity in the interventions, outcomes and comparison groups, a meta-analysis was not conducted.

Reporting bias

Although there was no formal assessment of bias, we expect that there is considerable risk of reporting bias. Organizations which conducted interventions that did not have positive impacts may choose not to publish their results. Furthermore, journals may not wish to publish articles on projects that had null impacts. In addition, because there is a strong prior hypothesis that these interventions will improve health, results that do not support this hypothesis may be dismissed as erroneous even if they are accurate. As such, results should be interpreted cautiously. Even interventions with several studies indicating positive effects could be subject to this bias as there could be many more unpublished interventions showing a null or even negative effect.

Inputs regarding implementation, sustainability and evaluation

In an effort to support the adoption of evidence-informed policy, we have provided additional inputs regarding the implementation, sustainability, and evaluation of chlorination, drainage, and sewerage interventions. These comments were developed alongside the REA. During the screening process for this rapid evidence assessment, studies were flagged if they provided relevant information regarding the implementation, maintenance, or evaluation of the relevant interventions but otherwise did not meet the inclusion criteria for this assessment. For the most part, these studies had inappropriate comparators and/or insufficient evaluation design to meet our inclusion criteria. Actionable information for the use of practitioners in implementing, maintaining, and evaluating these interventions was extracted from these studies and is presented after the main results.

Results

Search results

Figure 2. PRISMA flow diagram

Through the search for WaSH infrastructure interventions, we identified 1920 papers, of which 1483 remained after de-duplication (Figure 2). After title and abstract screening, 193 papers were included for full-text screening. Finally, 18 studies were identified for inclusion in this rapid evidence assessment. Common reasons for exclusion were that the studies did not consider the correct participants or intervention. For example, studies were excluded because they took place in high-income countries or in rural areas. Many studies were excluded because they did not have a clear comparator or the intervention was not clearly defined. They may not have stated if the municipal water supply was chlorinated or if the sewage system connected to a wastewater treatment plant.

Five studies occurred in Brazil and three studies reviewed evidence from multiple countries (Table 1, Supplemental Table 1). Three studies were in the Pacific Islands, three were in Asia, and two were in Europe. Most studies were either case-control (8) or open-cohort (4). Three systematic reviews were included and the remaining studies were closed cohort (1), cross-sectional (1), or a combined cross-sectional design with a closed cohort (1). Eight studies focused on the installation of a sewerage system

- 1 alone. Five studies considered sewerage and drainage. Two studies were on chlorination and sewerage.
- 2 Three studies reported on the effects of chlorinating a central water distribution. No studies reported on
- 3 the effects of a drainage system alone. All studies were published after 1987.

1 **Table 1.** Summary of included studies in REA

First author	Year	Title	Country	Study design	Intervention	Outcome
Baltazar	1988	Can the case-control method be used to assess the impact of water supply and sanitation on diarrhoea?	Philippines	Case-control	The exposure was access to improved water as defined by using a chlorinated, municipal water supply and/or appropriate in-home water treatment techniques. The exposure also included access to adequate and clean toilets or latrines.	There is no significant effect of being exposed to poor water and/or sanitation on odds of diarrhea.
Barreto	2007	Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil	Brazil	Open cohort	The Blue Bay project laid 2000km of sewer pipes, built 86 pumping stations and connected more than 300,000 households to the sewerage network.	Intervention effects on odds of diarrhea varied from 0.15 to 3.02 depending on the neighborhood and baseline prevalence of diarrhea Diarrhea prevalence fell by about 22% In areas with high baseline risk, prevalence of diarrhea decreased by 43% after the intervention
Butala	2010	Improved health outcomes in urban slums through infrastructure upgrading	India	Open cohort	This is a large scale intervention that is largely funded by the community and involves the connection of water supply for households, underground sewerage and toilets for individual households, storm water drainage, road paving, solid waste management, and street lighting	The intervention resulted in a decrease in the probability of claiming a waterborne illness by 0.62. This was a decrease of 18%.
Clasen	2010	Interventions to improve disposal of human excreta for preventing diarrhea	Multiple	Systematic review	Sanitation interventions to introduce or expand provision or use of facilities for excreta disposal, including sewerage	Effect sizes varied widely; however, 11 of the 13 studies found that these interventions did reduce diarrhea Only one study investigated the effects of providing toilets connected to a sewer and piped water. This intervention was found to be beneficial, relating to a 0.33 risk ratio in diarrhea The quality of the evidence was low, with considerable risk of bias.

Costa	2005	Household structure and urban services: neglected targets in the control of visceral leishmaniasis	Brazil	Case-control	Considers the potential effects of an adequate sewerage system; however, it is unclear how "inadequate sewerage" is defined	Inadequate sewage was related to a 4.18 increase in odds of visceral leishmaniasis
de Oliveira Serra	2015	Comparison between two decades of prevalence of intestinal parasitic disease and risk factors in a Brazilian urban center	Brazil	Open cohort	Lack of access to the public sewerage system is compared to public sewerage system	In 1992-1996, households without sewerage system had 0.86 times the odds of being infected with a parasite than houses with sewerage system In 2010, households without sewerage system had 1.42 times the odds of being infected with a parasite than houses with sewerage system
Ferrer	2008	A hierarchical model for studying risk factors for childhood diarrhoea: a case-control study in a middle-income country	Brazil	Case-control	Expansion of sewerage network in city Looked at sewage network, drainage, septic tank and soak away compared to other methods of sewage disposal	In univariate analysis, sewage disposal was not associated with diarrhea so it did not make it into the final model Sewage disposal did have an effect on diarrhea in children aged 3-8 years but effect estimate is not provided
Gasem	2001	Poor food hygiene and housing as risk factors for typhoid fever in Semarang, Indonesia	Indonesia	Case-control	Presence of closed sewage system vs open sewage system Water from the chlorinated municipal water supply	Households that had an open or no drainage system had 7.19 times the odds of developing typhoid fever compared to households that had a closed sewage system Households that obtained their water from rivers, ponds, wells, or water vendors had 29.18 times the odds of developing typhoid fever compared to households whose water supply was from the chlorinated municipal water supply
Klasen	2012	Benefits trickling away: the health impact of extending access to piped water and	Yemen	Closed cohort	Compares the use of a chlorinated piped water system to a water truck. However, both piped and truck water are stored in tanks at the household level.	Sewerage may have increased diarrhea by about 10% although estimates are inconsistent

sanitation in urban
Yemen

Sewerage systems were installed for
a subset of houses with piped water

Propensity score matching result: Disease
burden in piped water households
increased by 4% in coastal region and by
4.5% in mountain regions compared to
control
PSM result: Disease burden in piped water
and sanitation households decreased by
3.7% compared to piped water households
alone in the coastal region. In the mountain
regions, households with both sanitation
and piped water interventions had 13.8%
increase in disease burden for children
compared to piped water households alone

Kolahi	2008	The impact of an urban sewerage system on childhood diarrhoea in Tehran, Iran: a concurrent control field trial	Iran	Open cohort	Stepwise implementation of a sewerage system 76% of households in intervention areas were connected.	The total population attributable risk was 9%. Diarrhea decreased by 46% in the intervention group and by 37% in the control group after the intervention had been implemented
Moraes	2003	Impact of drainage and sewerage on diarrhoea in poor urban areas in Salvador, Brazil	Brazil	Closed cohort Cross-sectional	Installed a joint sewerage and drainage system such that some neighborhoods received both, some got drainage only, and some got neither	Relative to those with both sewerage and drainage, children in areas with only drainage had 2.97 odds of diarrhea and those with none had 8.10 odds
Norman	2010	Effects of sewerage on diarrhoea and enteric infections: a systematic review and meta-analysis	Multiple	Systematic review	The intervention was sewerage, but the comparisons were variable	Sewerage reduces the relative risk of diarrhea and related outcomes to 0.70. If the comparator is limited to areas with very poor sanitation at baseline, this can be as low as 0.1
Prasad	2018	Epidemiology and risk factors for typhoid fever in central division, Fiji, 2014-2017: a case-control study	Fiji	Case-control	Undamaged, improved municipal sewerage is compared with other sanitation forms	Having unimproved sewerage or damaged improved sewerage system was associated with increased odds of typhoid fever (OR = 4.30)

Rosas-Aguirre	2015	Plasmodium vivax malaria at households: spatial clustering and risk factors in a low endemicity urban area of the northwestern Peruvian coast	Peru	Case-control	Living within 200 meters of a water drain Bathroom connected to sewerage system	In multivariate analysis, living within 200 meters of the water drain was related to 2.3 odds of malaria Having a bathroom connected to a sewer did not affect odds of malaria in univariate analysis, so multivariate analysis was not connected
Sezen	2015	A large multi-pathogen gastroenteritis outbreak caused by drinking contaminated water from antique neighbourhood fountains, Erzurum city, Turkey, December 2012	Turkey	Case-control	Drinking from antique neighborhood fountains, chlorinated tap water, bottled water, and other water sources	Multivariate analysis: Drinking water from antique fountains had OR of 20 and drinking fountain/other water had OR of 2.1 compared to drinking bottled or tap water only
Stewart-Ibarra	2014	Spatiotemporal clustering, climate periodicity, and social-ecological risk factors for dengue during an outbreak in Machala, Ecuador, in 2010	Ecuador	Cross-sectional	Access to sewerage (not defined)	The inclusion of an indicator for sewerage did not improve model fit in linear regressions to predict odds of dengue
Turley	2013	Slum upgrading strategies involving physical environment and infrastructure interventions and their effects on health and socio-economic outcomes	Multiple	Systematic review	This was a systematic review of slum upgrading, which regularly includes improvements to sewerage and drainage	Authors identified three studies that included a sewerage component and nine studies that included a drainage component. Mixed effects on economic and employment outcomes There is some evidence that water-related interventions are successful in decreasing diarrheal diseases Results have significant heterogeneity and a high risk of bias
Werber	2009	Massive outbreak of viral gastroenteritis	Montenegro	Case-control		Acute gastroenteritis was associated with drinking municipal water (OR = 11.2)

associated with
consumption of
municipal drinking water
in a European capital city

The central water system was
chlorinated; however, water was not
held in a tank before distribution.

People who consumed tap and bottled
water had 0.2 times the odds of developing
acute gastroenteritis compared to those
who only drank municipal water

Effects of WaSH infrastructure interventions on health

Results from impact evaluations

Chlorination has mixed effects on communicable disease outcomes

One of the three studies that looked at the impact of chlorinating the municipal water on health found that chlorination reduces the likelihood of contracting a communicable disease (Table 2, Supplemental Table 1). Sezen *et al.* (2015) found that people who drank contaminated water from antique fountains, sometimes hundreds of years old, with unknown underground sources, in Turkey had 20 times (95% CI: 4.6-84) the odds of developing gastroenteritis relative to those who drank from the chlorinated municipal water or from bottled water. However, Werber *et al.* (2009) found that people who drank only chlorinated municipal water had increased odds of developing acute gastroenteritis relative to those who drank from other sources (OR: 11.2, 95% CI: 1.6, ∞). Baltazar *et al.* (1988) found that odds of having clinical diarrhea was not significantly different between children who received both municipal water chlorination and latrine interventions and children who received no intervention or only one of the interventions (OR: 0.79; 95% CI: 0.56-1.13).

1 **Table 2.** Effect estimates from included studies in REA

Study	Intervention type	Analysis method	Outcome	Effect Estimate Type	Effect Estimate
Baltazar (1988)	Chlorination	Logistic regression controlling for confounders and effect modifiers	Odds of having clinical diarrhea for children who drank chlorinated municipal water compared to other sources of water	Odds ratio (95% confidence interval)	0.79 (0.56-1.13)
Barreto (2007)	Sewerage	Mixed effects Poisson regression with clustered standard errors	Prevalence ratio of diarrhea (before vs after intervention) for total population	Prevalence ratio (95% confidence interval)	0.81 (0.78-0.86)
			Prevalence ratio of diarrhea (before vs after intervention) for area with high baseline risk	Prevalence ratio (95% confidence interval)	0.57 (0.55-0.62)
Butala (2010)	Sewerage Drainage	Nonlinear probit regression with clustered standard errors	Probability of health insurance claim after intervention	Beta coefficient (Standard error)	-0.62 (0.025)
Costa (2005)	Sewerage	Backward step-wise multivariate logistic regression models	Odds of having visceral leishmaniasis comparing inadequate sewage system to adequate	Odds ratio (95% confidence interval)	4.18 (1.47-11.80)
de Oliveira Serra (2015)*	Sewerage	Univariate logistic regression	Unadjusted odds of having a parasitic infection comparing no public sewerage system to having public sewerage system from 1992-2006	Odds ratio (95% confidence interval)	0.86 (0.10-7.58)
			Unadjusted odds of having a parasitic infection comparing no public sewerage system to having public sewerage system from 2010-2011	Odds ratio (95% confidence interval)	1.42 (0.87-2.31)
Ferrer (2008)	Sewerage Drainage	Multivariable non-conditional logistic regression	Odds of having diarrhea comparing other sewage disposal methods to sewage network/drainage/septic tank + soak away	Odds ratio (95% confidence interval)	0.74 (0.57-1.02)
Gasem (2001)	Sewerage	Multivariable backwards logistic regression	Odds of developing typhoid fever comparing open sewers/no sewage system to closed sewerage system	Odds ratio (95% confidence interval)	29.18 (2.12-400.8)

	Chlorination		Odds of developing typhoid fever comparing other water sources to chlorinated municipal water supply	Odds ratio (95% confidence interval)	7.19 (1.33-38.82)
Klasen (2012)	Chlorination	Propensity score matching	Probability of disease burden increasing in coastal areas for those who received piped chlorinated water compared to those who did not	Beta coefficient (t-statistic, p-value)	0.0399 (1.98, <0.05)
	Sewerage		Probability of disease burden increasing in mountain areas for those who received piped chlorinated water compared to those who did not	Beta coefficient (t-statistic, p-value)	0.0455 (2.76, <0.01)
			Probability of disease burden increasing in coastal areas for those who received sanitation intervention compared to those who did not	Beta coefficient (t-statistic, p-value)	-0.0373 (1.79, <0.1)
			Probability of disease burden increasing in mountain areas for those who received sanitation intervention compared to those who did not	Beta coefficient (t-statistic, p-value)	0.0187 (0.99, >0.1)
Kolahi (2008)	Sewerage	Chi-square analyses	Population attributable risk for reduction in diarrhea incidence comparing intervention to control	Percentage	9
Moraes (2003)	Sewerage	Multivariable logistic regression	Odds of developing diarrhea for children who received no intervention compared to receiving both sewerage and drainage	Odds ratio (95% confidence interval)	8.10 (4.99-13.16)
	Drainage		Odds of developing diarrhea for children who received the drainage intervention compared to receiving both sewerage and drainage	Odds ratio (95% confidence interval)	2.97 (2.00-4.41)

Norman (2010)	Sewerage	Inverse variance method	Pooled risk of developing enteric infectious disease for those who didn't receive the intervention compared to those who did receive the intervention	Risk ratio (95% confidence interval)	0.70 (0.61-0.79)
Prasad (2018)	Sewerage	Multivariable conditional logistic regression	Odds of developing typhoid fever for having any unimproved sewerage/damaged improved sewerage system compared to undamaged, improved municipal sewerage	Odds ratio (95% confidence interval)	4.30 (1.14-16.21)
Rosas-Aguirre (2015)	Drainage	Multivariable logistic regression	Odds of developing malaria for those who lived less than 200 meters from the water drain compared to those who lived more than 200 meters from the drain	Odds ratio (95% confidence interval)	2.3 (1.3-4.0)
	Sewerage	Univariable logistic regression	Unadjusted odds of developing malaria for those whose bathroom was not connected to sewage system compared to those whose bathrooms were connected	Odds ratio (95% confidence interval)	1.1 (0.7-1.9)
Sezen (2015)	Chlorination	Multivariable conditional logistic regression	Odds of gastroenteritis for those who drank water from the fountains only compared to those who drank only bottled water or only tap water	Odds ratio (95% confidence interval)	20 (4.6-84)
Stewart-Ibarra (2014)*	Sewerage	Chi-square analyses	Percentage of households with no access to sewerage	Percentage (Standard deviation)	22.4 (27.6)
Werber (2009)	Chlorination	Multivariable conditional logistic regression	Odds of developing acute gastroenteritis for those who only drank municipal tap water compared to those who did not	Odds ratio (95% confidence interval)	11.2 (1.6, ∞)

Sewerage reduces disease

Generally, sewerage reduced disease in the identified studies. In Brazil, Barreto *et al.* (2007) found that the prevalence of diarrhea decreased by 19% after the installation of a sewerage system (Prevalence Ratio: 0.81; 95% CI: 0.78-0.86). In Iran, after the sewerage system was installed, 9% of the reduction in diarrhea in the intervention group was due to the intervention (Kolahi, Rastegarpour and Sohrabi, 2009). Costa *et al.* (2005) found that people living in households with an inadequate sewage system had increased odds of developing visceral leishmaniasis relative to those that had an adequate system (OR: 4.18; 95% CI: 1.47-11.80). Prasad *et al.* (2018) found that access to a sewerage system decreased odds of developing typhoid fever (OR: 4.30, 95% CI: 1.14-16.21). However, in Ecuador, the inclusion of an indicator for access to a sewerage system did not improve model fit (Stewart-Ibarra *et al.*, 2014). This indicates that the sewerage system likely had no impact. In Brazil, the prevalence of sewerage increased from 1.9% in 1996 to 62.2% in 2010 (De Oliveira Serra *et al.*, 2015). In both years, the unadjusted odds of having a parasitic infection for households without access to the public sewer system was not statistically different from those in households that were connected (1996 OR: 0.86, 95% CI: 0.10-7.58; 2010 OR: 1.42, 95% CI: 0.87-2.31).

Combining sewerage with chlorination or drainage interventions does not increase effectiveness

Combined sewerage and chlorination interventions did not consistently reduce disease burden. In Yemen, Klasen *et al.* (2012) found that having chlorinated piped water increased disease burden in both the mountain and coastal regions (Mountain $\beta = 0.0399$, t-value = 1.98, $p < 0.05$; Coastal $\beta = 0.0455$, t-value = 2.76, $p < 0.01$). However, the improved sanitation system increased disease burden in the mountain regions but there was a non-statistically significant decrease in coastal areas (Mountain $\beta = 0.0187$, t-value = 1.79, $p < 0.1$; Coastal $\beta = -0.0373$, t-value = 0.99, $p > 0.1$). Gasem *et al.* (2001) found that households that did receive the chlorination and sewerage interventions had increased odds of typhoid fever compared to the control households (chlorination OR: 7.19, 95% CI: 1.33-38.82; sewerage OR: 29.18, 95% CI: 2.12-400.8).

Similarly, sewerage and drainage interventions did not have consistent effects on disease burden. Butala *et al.* (2010) found that health insurance claims for waterborne illnesses decreased in slums that received the slum upgrading intervention relative to those that did not ($\beta = -0.62$, SE = 0.303). In Brazil, children who lived in households that only received the drainage intervention had 2.97 times (95% CI: 2.0-4.41) the odds of developing diarrhea relative to children in households that received both the sewerage and drainage intervention (Moraes *et al.*, 2003). However, Ferrer *et al.* (2008) did not find a statistically significant difference in odds of developing diarrhea between households who used other sewage disposal methods and households that had a sewerage system, drainage system, or a septic tank plus soakaway (OR: 0.74, 95% CI: 0.57-1.02). In Peru, Rosas-Aguirre *et al.* (2015) found that households who lived less than or equal to 200 meters away from the water drain had increased odds of having malaria than those who lived further from the drain (OR: 2.3, 95% CI: 1.3-4.0).

Results from systematic reviews

All three systematic reviews identified considered the impact of sewerage on health outcomes. However, Clasen *et al.* (2010) and Turley *et al.* (2013) did not disentangle the effects of interventions that fell within the scope of this review from other interventions. Turley *et al.* (2013) considered the effects of drainage as well. All three studies found that sewerage interventions could be successful.

Norman *et al.* (2010) report that the relative risk of diarrhea and related illnesses decreases (RR= 0.7, 95% CI: 0.62-0.79) after sewerage interventions, with a larger effect among areas with poor sanitation at baseline. Clasen *et al.* (2010) only identified one study related to the installation of toilets connected to a sewerage system and piped water. This study found that the risk of diarrhea among intervention households was 0.30 relative to controls. Turley *et al.* (2013) considered a suite of interventions referred to as “slum upgrading.” These included interventions related to sewerage and drainage. They conclude that water related interventions are successful in reducing diarrheal disease incidence.

Heterogeneity in effects

Reports of effects by subgroup were generally limited. Klasen *et al.* (2012) found some differences in the effects of chlorination and sewerage in mountainous vs. coastal regions and adults vs. children. However, these differences were inconsistent, with various effects on missed school/work days, disease incidence, diarrheal incidence, and disease severity. Ferrer *et al.* (2008) report that access to sewerage decreased incidence of diarrhea most in children three to eight years of age, but effect sizes are not presented. Barreto *et al.* (2007) found that the installation of sewerage had the largest effect in decreasing incidence of diarrhea in neighborhoods with high baseline risk. The two systematic reviews which included multiple studies that are eligible for this rapid evidence assessment found significant heterogeneity in effects as well (Norman, Pedley and Takkouche, 2010; Turley *et al.*, 2013). Norman *et al.* (2010) assessed heterogeneity using a parametric bootstrap version of the DerSimonian and Laird Q test and found that the proportion of total variance due to between-study variance across all of their included studies was 0.87. Turley *et al.* (2013) did not quantify the heterogeneity across included effect sizes.

Hypothesized sources of contamination

Since these studies considered the spread of disease, many identified various sources of contamination. Hypothesized sources of contamination fell into four broad categories: general lack of improved water and sanitation, sources in the nearby environment, household hygiene practices, and issues with maintaining infrastructure systems.

Improved water and sanitation

Five studies highlighted lack of improved water and sanitation as sources of contamination. Having an inadequate sewage system may attract flies and therefore increase the risk for communicable disease (Costa *et al.*, 2005). After there were improvements in human excreta disposal systems, contamination from parasites or other pathogens may be reduced (Baltazar *et al.*, 1988; Butala, VanRooyen and Patel, 2010; Clasen *et al.*, 2010; De Oliveira Serra *et al.*, 2015).

Nearby environment and household hygiene

Contaminants in the nearby environment also affected disease burden. Living near open sewers or garbage pits as well as the household’s proximity to open drains increased risk for contracting typhoid, diarrhea or malaria (Gasem *et al.*, 2001; Ferrer *et al.*, 2008; Rosas-Aguirre *et al.*, 2015). This could be due to proximity to standing water or that low-income households tend to live closer to these exposures. Household hygiene practices such as unsafe storage of water, eating unwashed produce, or lack of

handwashing behaviors also increased risk for bacterial contamination (Klasen *et al.*, 2012; Stewart-Ibarra *et al.*, 2014; Prasad *et al.*, 2018).

Maintenance and sustainability

Issues with the maintenance and sustainability of the infrastructure systems may have led to contamination. Multiple studies found that leaky pipes increased exposure to pathogens and contaminated water supply (Klasen *et al.*, 2012; Sezen *et al.*, 2015; Prasad *et al.*, 2018). In sewerage systems, corrosion of the sewer pipes can cause leakage into nearby crops which then contaminated food (Prasad *et al.*, 2018). Structural issues with infrastructure systems such as electrical pump failures and an intermittent water supply create a drop in the water pressure that then allows for contaminated water to be pulled into the water distribution system (Moraes *et al.*, 2003; Werber *et al.*, 2009; Klasen *et al.*, 2012). Werber *et al.* (2009) found that the lack of a holding tank to store water prevented the chlorination from working as the chlorine did not have enough contact time with the water for it to actually disinfect.

Study quality and risk of bias

Although a formal risk of bias assessment was not conducted, many of these studies have a high risk of bias and should be interpreted with caution. Half are case-control studies with significant scope for recall bias. There was a failure in the implementation of the chlorination, drainage, or sewerage system in seven of the studies, which could have significantly affected study findings. Four of the studies pool the effects of the interventions of interest with effects from other interventions. Variation in the comparators of many of the remaining studies makes the comparison of effects across studies challenging and largely inappropriate. Seven of the studies fail to adequately control for confounding, while five studies report unclear or inappropriate statistical approaches. These findings are consistent with what Turley *et al.* (2013) found as they also found a high risk of bias in the literature.

Implementation, sustainability, and evaluation of WaSH infrastructure interventions in urban settings

Considerations for implementation and sustainability

WaSH infrastructure projects, including piped water and chlorination, have a tendency to degrade with age, causing increased risk of communicable disease (Mermin *et al.*, 1999). Large, WaSH infrastructure projects tend to encounter the same set of challenges: an intermittent water supply, leaking pipes, improper spacing between sewer lines and water pipes, and low water pressure. These issues affect the effectiveness of WaSH projects in achieving their desired health and well-being impacts. An intermittent water supply may be caused by leaking pipes and associated with increased *E. coli* in the water (Grimmeisen *et al.*, 2016). Furthermore, an intermittent or irregular water supply is associated with acute diarrhea among under-five children (Ferrer *et al.*, 2008; Adane *et al.*, 2017). The incidence of cholera increased by 155% in the 12 days after a day when the neighborhood tap water was cut in Uvira in the Democratic Republic of Congo (Jeandron *et al.*, 2015). In Zimbabwe, there was a typhoid outbreak when access to the chlorinated municipal water was removed because of non-payments or clogged pipes (Muti *et al.*, 2014). If the water supply is unreliable, households are more likely to store water, people may revert to less safe water sources, or hygiene behaviors may be reduced to conserve water

(Muti *et al.*, 2014; Jeandron *et al.*, 2015; Adane *et al.*, 2017; Lee *et al.*, 2020). All of these behaviors may increase people's exposures to pathogens. Moving from an intermittent to a continuous water supply can have beneficial effects on costs and timesaving, but these effects may disproportionately favor the wealthy (Burt *et al.*, 2018).

Leaky pipes in either the water distribution system or sewer lines increases exposure to pathogens. Leaking pipes may diminish the relative benefits of chlorination (Ries *et al.*, 1992; Bhunia, Ramakrishnan, *et al.*, 2009; Saha *et al.*, 2009; Klasen *et al.*, 2012; Sezen *et al.*, 2015). Leaks in water pipes that are in close proximity to sewage pipes allow suction of sewage water into the pipe during negative pressure moments (Bhunia, Ramakrishnan, *et al.*, 2009). When water must travel long distances through pipes in need of repair with low water pressure, it may be more likely to become contaminated (Mermin *et al.*, 1999). Low water pressure and inadequate chlorination may contribute to contamination of water with fecal coliforms, especially as the water main system ages (Brainard *et al.*, 2018). Fixing leaking pipes may improve water pressure, decrease backflow and contamination, and improve chlorine concentrations (Mermin *et al.*, 1999). Improperly repaired pipes also allow for bacterial contamination and affect chlorine concentrations (Topal *et al.*, 2019). Due to cracks in the sewage pipelines, lack of pressure in the distribution system, and improper distances between the sewage system and the water system pipelines, sewage may enter the municipal water supply (Cárdenas *et al.*, 1993; Saha *et al.*, 2009). Corroded sewer pipes can also leak into nearby crops which can contaminate food sources (Prasad *et al.*, 2018).

Besides pipe maintenance, the entire infrastructure system needs to be properly constructed and maintained. In Hyderabad, Pakistan, the sewage sludge treatment plants were not properly maintained and sewage was allowed to discharge directly into the river, contaminating household water sources (Yousafzai *et al.*, 2019). Electrical pump failures in water distribution can lead to water contamination as water pressure drops (Moraes *et al.*, 2003; Werber *et al.*, 2009; Klasen *et al.*, 2012). In addition, chlorination is only effective if the chlorine has enough time in the water system for it to disinfect. If the water distribution system does not have a holding tank, the water will not be adequately chlorinated for it to actually reduce pathogen exposure (Ries *et al.*, 1992; Werber *et al.*, 2009). For chlorination to be effective, the residual chlorine level needs to be greater than 0.3 mg/L. Lu and Zhang (2005) found that when residual chlorine in water samples increased from <0.1 mg/L to 0.3 mg/L, bacteria cell counts decreased from 10,000 CFU/mL to 1000 CFU/mL. Lu *et al.* (2014) found that residual chlorine levels between 0.5-1.5 mg/L were able to suppress bacterial growth even when there was sufficient organic substrate.

To ensure the success and sustainability of projects that implement these interventions, these challenges should be addressed during the design phase of the project.

Considerations for design of an impact evaluation

The design of a rigorous evaluation of the causal impacts of large-scale infrastructure projects is challenging due to logistical, political, and ethical concerns. It is rarely possible to randomize such projects. Therefore, the analytical approach taken in order to accurately estimate the impact of large-scale infrastructure projects on the health and well-being of their beneficiaries should be established during the study design phase. It is recommended that a pre-analysis plan is written before the

beginning of data collection. Such a plan can be registered at [RIDIE](#) or one of the journals supported by the [Center for Open Science](#). The benefit of such an approach is that it ensures that the necessary data is collected to allow for a successful evaluation after the study is completed.

Given the complexities of the evaluation of large-scale infrastructure projects, four analytical approaches are recommended for impact evaluation: propensity score matching, difference-in-difference analysis, synthetic control analysis, and interrupted time series. The choice of methods should be informed by the expected trends in outcomes over time and the availability of adequate controls. Secular trends have been shown in the prevalence of diarrhea (Lee *et al.*, 2020). Therefore, if possible, it is beneficial to collect baseline data at several time points before project implementation in order to establish secular trends. Furthermore, due to the spatial clustering of risk factors for many WaSH-related communicable diseases, it is important to carefully consider suitable control groups (Bi *et al.*, 2016). Such groups can be identified through spatial mapping, comparisons of trends over time, and/or matching on known risk factors.

The primary outcome of interest must be designated before the beginning of data collection. Expected effect sizes can then be used to inform power calculations. Based on disease prevalence and expected impacts of sanitation interventions, intestinal diseases (such as cholera, gastroenteritis, typhoid) are likely to have the largest decreases in response to the proposed interventions. However, which diseases will be impacted is affected by local context. There is an association between the installation of a sewer system and the rate of diarrhea in children under five (Barreto *et al.*, 2007). Having a nearby open sewage ditch is associated with increased odds of diarrhea and ascariasis as well (Moubarrad and Assobhei, 2005; Ferrer *et al.*, 2008). Living in a house with open sewers is also associated with increased odds of typhoid fever compared to living in a house with a closed drainage/sewage system (Gasem *et al.*, 2001). Individuals in households who use a chlorinated, municipal water source may have lower odds of developing typhoid than those who use alternate water sources (Gasem *et al.*, 2001). Typhoid is also related to the use of public water sources, drinking piped water, and low elevation which may reflect poor drainage (Bhunia, Hutin, *et al.*, 2009; Baker *et al.*, 2011; Jenkins *et al.*, 2019). Muti *et al.* (2014) found that the number of typhoid fever cases dropped after the municipal water supply was chlorinated. Cholera has also been found to be associated with poor drainage systems and sewage overflow (Rebaudet *et al.*, 2013b). Although broader impacts including increased economic output and improved measures of well-being are expected, it may take several years for these to develop. As such, these are likely to be inappropriate primary outcomes for any study under five years.

There is likely to be an additive effect in which access to sewage and chlorinated water may improve health outcomes more than access to each one individually (Baltazar *et al.*, 1988). If there is a desire to quantify the impacts of each intervention separately and additively, a multi-arm trial design is necessary. Failure to implement such a design results in an inability to separate the effects of many different interventions which were implemented simultaneously, and may result in future projects replicating ineffective portions of the larger project (Butala, VanRooyen and Patel, 2010).

Given the seasonality of rainfall in most regions of the world, there is often also a seasonal variation in the incidence of cholera and likely other waterborne diseases (Rebaudet *et al.*, 2013a). As such, it is recommended that studies include matched data collection periods during different seasons over at

least a two-year span. Other climate variations such as unusually heavy flooding may also affect results, but will be harder to account for (Rebaudet *et al.*, 2013a).

The microbial content of the same piped water system varies by location: residential, industrial, sewage hub, and more (Bohra, Modasiya and Bahura, 2012). Therefore, if water quality is of interest, it may be appropriate to collect water samples at several different types of locations.

There is also a need to collect information on the reliability of water and household coping strategies for intermittent water as these may affect the interventions' impact (Lee *et al.*, 2020). If the piped water source is not reliable, households are more likely to rely on stored water and rely on multiple water sources. Household hygienic practices should also be collected. Household hygiene practices such as unsafe storage of water, eating unwashed produce, or lack of handwashing behaviors also increased risk for bacterial contamination (Ries *et al.*, 1992; Moubarrad and Assobhei, 2005; Klasen *et al.*, 2012; Muti *et al.*, 2014; Stewart-Ibarra *et al.*, 2014; Prasad *et al.*, 2018).

Other transmission sources should also be collected so that the effects of the intervention on disease burden can be isolated. These include food from street vendors, other water sources (including bottled water and ice), and proximity to wastewater effluents (Black *et al.*, 1985; Koo *et al.*, 1996; Gasem *et al.*, 2001; Moubarrad and Assobhei, 2005; Bhunia, Hutin, *et al.*, 2009; Lee *et al.*, 2020).

Potential confounders identified in the literature that may be on the pathway between WaSH interventions and health/well-being outcomes can be found in Table 3.

Table 3. Potential confounders in the pathway between WaSH and health outcomes

Individual-level characteristics	Household-level variables	Village-level characteristics	Intervention-specific variables
Sociodemographic (age, gender, ethnicity, education, marital status, socioeconomic status, employment, migration history)	Infrastructure (water source, house type, floor type, toilet type, independent kitchen, drainage access, refuse collection, house construction materials, occurrence of flooding)	Prevalence of access to WaSH infrastructure	Baseline sewage access
Child-specific (low birth weight, nutritional status – LAZ and WLZ, history of being breastfed)	Household characteristics (Number of children less than 5 years, level of health services utilization, crowding in house)	Neighborhood female education	Background incidence of disease/outcome
Hygiene behaviors (handwashing – observed and/or reported, open	Hygiene behavior (food handling practices, boiling water, presence	Geographic and climate related (clustering, elevation	Spatial risk factors (distance from flowing water

defecation, sharing food, ice in beverages or eating ice outside home, health knowledge/awareness)	of soap, water storage practices, presence of feces, presence of animals, toilet cleanliness, presence of wash stand, food sources and hand washing behaviors	level, daily precipitation rates, season)	body/road, distance from drain)
	Surrounding environment (nearby open sewage ditch/garbage dump, paved roads, streets, or sidewalks)		Residual chlorine levels

1

2 Discussion

3 Although there was considerable heterogeneity in results, sewerage and chlorination interventions
4 tended to be successful in improving health, largely measured through reduced incidence of diarrhea
5 and other intestinal diseases, when they were implemented alone. When these interventions were
6 implemented together, we found mixed effects of the combined interventions on disease burden, most
7 likely due to issues with intervention implementation and maintenance. The effects of drainage are also
8 ambiguous, raising the possibility that living near a drain could increase disease, possibly due to
9 exposure to standing water. The most commonly cited sources of illness among included studies were a
10 lack of improved water and sanitation, the nearby environment, household hygiene practices, and issues
11 with maintaining infrastructure systems. Chlorination, drainage, and sewerage will address three of
12 these sources, but households must be supported to engage in proper hygiene practices if these
13 interventions are to have their full effect.

14 Limitations in available studies

15 Although 18 studies represent an adequate research base, these studies are not evenly distributed
16 across the three interventions of interest. While there are many interventions which consider sewerage,
17 far fewer consider the effects of chlorination and none identify the effects of drainage alone. The
18 determination of the unique effects of the individual interventions is challenging because interventions
19 were often implemented alongside one another. In addition, authors often pool the effects of our
20 interventions of interest with those of other WaSH interventions (Baltazar *et al.*, 1988; Ferrer *et al.*,
21 2008; Butala, VanRooyen and Patel, 2010). For example, Ferrer *et al.* (2008) calculate the odds of
22 diarrhea among those with a sewerage network, drainage system, and septic tank plus soakaway
23 relative to those with any other human waste disposal system. Therefore, it is not possible to identify
24 which of the three listed disposal systems is driving the effect estimate or what the effect of sewerage
25 alone is. In other studies, subgroup analyses are mentioned, but not reported in full, making it unclear
26 what effect the intervention actually had (Ferrer *et al.*, 2008).

1 Additionally, many studies use data-driven model selection approaches which tend to result in the
2 reporting of statistically significant results and null results not being reported. Some considered the
3 intervention in their multivariable models but did not report the adjusted estimates, most likely because
4 the effects of the interventions were not statistically significant in the final model (Ferrer *et al.*, 2008;
5 Stewart-Ibarra *et al.*, 2014; De Oliveira Serra *et al.*, 2015). Stewart-Ibarra *et al.* (2014) used Akaike
6 Information Criteria (AIC) values to determine which covariates would remain in the final model. Access
7 to sewerage did not make it into the final model which indicates that it may have had a null effect;
8 however, results are not presented so this conclusion cannot be made. This pattern of using the data to
9 determine model specification and only reporting statistically significant effects induces a form of
10 reporting and publication bias. This may make interventions appear more effective than they are.

11 Finally, most studies considered the incidence of intestinal disease and did not look at the other
12 outcomes that could be impacted by these interventions. This is likely because these interventions are
13 expected to have the largest effect on intestinal disease outcomes. However, many other outcomes
14 would be of interest and could be affected. In particular, these interventions may have significant effects
15 on perceived welfare and human dignity. They could have long term economic outcomes by affecting
16 how people relate to each other and improve opportunities for economic growth.

17 Implications

18 Generally, sewerage and chlorination interventions were found to have positive impacts by reducing
19 disease burden when adequately implemented. The impacts of drainage interventions and combined
20 interventions were mixed. Many of the interventions included in this REA were not implemented
21 successfully, which may have contributed to the mixed results. Household hygiene practices, the
22 surrounding neighborhood/environment, and lack of improved water and sanitation modified the
23 impact of these interventions.

24 Strengths, limitations, and future directions

25 The primary strength of this work is that it is a result of a rigorous and systematic search of the available
26 peer reviewed literature. However, due to the rapid nature of this assessment, the search was limited to
27 only six databases. We did not perform any searches in the grey literature or in specialist websites.
28 There is a possibility that there may be additional evidence related to the three WaSH infrastructure
29 interventions that was not captured in our search. However, we were still able to identify 18 unique
30 studies through our systematic search. We found that the studies included in our REA considered the
31 impacts on intestinal diseases. We did not find any studies looking at other health outcomes, social well-
32 being, or economic growth. Additionally, we did not find any studies looking at the impact of drainage
33 interventions alone on health or societal benefits. This suggests that these are areas where further
34 research is needed. The majority of the studies included were case-control studies where the primary
35 objective was not to evaluate an intervention but to identify potential causes of a disease outbreak.
36 Rigorous studies that are designed *a priori* with the intent to evaluate impact are needed to understand
37 if WaSH infrastructure interventions can improve health and social well-being.

38 Conclusion

39 Generally, chlorination and sewerage were successful in reducing disease burden when they were
40 implemented alone. Implementation issues, such as intermittent water supply, leaky pipes, and
41 ineffective chlorination, affected the impact of the interventions. These challenges had the dual effect of

1 decreasing the impact of interventions and making it impossible to determine what the impact of
2 interventions would have been had they been implemented properly. For these interventions to be
3 successful, the infrastructure must be properly maintained and should be sustainable. We hope that this
4 work will highlight the importance of planning for sustainability in the implementation of infrastructure
5 works. But sustainable infrastructure is not sufficient. Behavior change interventions are needed to
6 ensure that the household engages in proper hygiene practices in order to gain the maximum benefit
7 from infrastructure works. We hope that practitioners use this work when designing their own WaSH
8 infrastructure interventions.

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1 **Supplemental Table 1.** Extended summary of included studies in REA

First author	Year	Title	Topic	Country	Collaborating organization	Intervention	Study design	Statistical approach	Covariates considered
Baltazar	1988	Can the case-control method be used to assess the impact of water supply and sanitation on diarrhoea?	Sewerage	Philippines	University of the Philippines University of North Carolina	The exposure was access to improved water as defined by using a chlorinated, municipal water supply and/or appropriate in-home water treatment techniques	Case-control	Logistic regression	Age, sex, education of head of household and mother, feeding practices, level of health services utilization, number of children <5 years of age, frequency of bathing the child
			Chlorination		World Bank Cebu Institute of Medicine Nutrition Center of the Philippines	The exposure also included access to adequate and clean toilets or latrines.			
Barreto	2007	Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil	Sewerage	Brazil	Inter-American Development Bank Federal University of Bahia London School of Hygiene and Tropical Medicine	The Blue Bay project laid 2000km of sewer pipes, built 86 pumping stations and connected more than 300,000 households to the sewerage network.	Open cohort	Hierarchical effect decomposition	Baseline sewage coverage, mother and child's age, birthweight, breastfeeding, height-for-age, maternal marital status and education, house structure, indoor toilet, open sewage, household

									excreta disposal, water supply, refuse collection, paved road, drainage, hygiene, coverage by the sewage intervention
Butala	2010	Improved health outcomes in urban slums through infrastructure upgrading	Sewerage	India	Yale School of Medicine	This is a large scale intervention that is largely funded by the community and involves the connection of water supply for households, underground sewerage and toilets for individual households, storm water drainage, road paving, solid waste management, and street lighting	Open cohort	Difference-in-difference	Year, neighborhood
			Drainage		Harvard School of Public Health			Nonlinear probit	
					Mahila SEWA Housing Trust				
					Brigham and Women's Hospital				
Clasen	2010	Interventions to improve disposal of human excreta	Sewerage	Multiple	Cochrane Systematic Reviews	Sanitation interventions to introduce or	Systematic review	Mean of log cluster-level data	--

		for preventing diarrhoea				expand provision or use of facilities for excreta disposal, including sewerage			
Costa	2005	Household structure and urban services: neglected targets in the control of visceral leishmaniasis	Sewerage	Brazil	Instituto de Doencas Tóxicas Nathan Portella Universidade Federal do Piauí Universidade Federal do Rio de Janeiro Universidade do Estado do Rio de Janeiro	Consider the potential effects of an adequate sewerage system; however, it is unclear how "inadequate sewerage" is defined	Case-control	Logistic regression	Age, gender, crowding, migration, literacy, percentage of households in the census tract that were in favelas, background incidence of visceral leishmaniasis
de Oliveira Serra	2015	Comparison between two decades of prevalence of intestinal parasitic disease and risk factors in a Brazilian urban center	Sewerage	Brazil	Federal University of Ceará University of International Integration of the Afro-Brazilian Lusophony FUNCAP CNPQ	Lack of access to the public sewerage system is compared to public sewerage system	Open cohort	Logistic regression	Unclear

Ferrer	2008	A hierarchical model for studying risk factors for childhood diarrhoea: a case-control study in a middle-income country	Sewerage	Brazil	Federal University of Bahia	Expansion of sewerage network in city	Case-control	Logistic regression	Maternal age, education, marital status, occupation, and race; cohabitation with biological father; family income; total goods owned; housing; water treatment, food storage; food outside the house; food on the floor; person who prepares the food was present; separate kitchen; child spent time outside the home; child was in contact with someone with diarrhea; people/room; children under 5 in the household; child at day care; feces in the yard; irregular water supply; garbage disposal; water
					Escola Bahiana de Medicina e Saude Publica	Looked at sewage network, drainage, septic tank and soak away compared to other methods of sewage disposal			
					Londong School of Hygiene and Tropical Medicine				

									source; taps working; irregular water supply; water storage; flooding in house
Gasem	2001	Poor food hygiene and housing as risk factors for typhoid fever in Semarang, Indonesia	Sewerage Drainage Chlorination	Indonesia	Diponegoro University University Medical Centre St. Radboud	Presence of closed sewerage system vs open sewerage system Water from the chlorinated municipal water supply	Case-control	Multivariable conditional backward logistic regression	Type of water supply in house; washing hands before eating; current working status; using ice cubes in beverage; eating location; employment; water quality for bath; teeth brushing; and drinking; e. coli in uncooked drinking water; water source; sewage system; floor materials

Klasen	2012	Benefits trickling away: the health impact of extending access to piped water and sanitation in urban Yemen	Sewerage	Yemen	University of Gottingen	Compare the use of a chlorinated piped water system to a water truck. However, both piped and truck water are stored in tanks at the household level.	Closed cohort	Difference-in-difference	Household size, number of children, number of elderly, dependency ratio, age of HH head, years of education of HH head, sex of HH head, % children enrolled in school, per capita income, education, hand washing, soap use, water purification, knowledge about water-related diseases, wealth, perceived health status
					KfW Entwicklungsbank	Sewerage systems were installed for a subset of houses with piped water		Instrumental variable	
								Propensity score matching	
								Trend analysis	

Kolahi	2008	The impact of an urban sewerage system on childhood diarrhoea in Tehran, Iran: a concurrent control field trial	Sewerage	Iran	Shahid Beheshti University World Bank Tehran Sewerage Company	Stepwise implementation of a sewerage system 76% of households in intervention areas were connected.	Open cohort	Calculate population attributable risk	--
Moraes	2003	Impact of drainage and sewerage on diarrhoea in poor urban areas in Salvador, Brazil	Sewerage Drainage	Brazil	Federal University of Bahia PAHO LSHTM Brazilian National Research Council CBPq International Development Research Centre of Canada	Installed a joint sewerage and drainage system such that some neighborhoods received both, some got drainage only, and some got neither	Closed cohort Cross-sectional	Incidence density ratio Logistic regression	Time in residence; mother's origin; religion; schooling of HH, income; house size, house floor and walls; number of bedrooms, water supply; wash stand presence; electricity; animals in house; child's age, gender, and birth order; number children in the house; per capita income; exclusive use of the kitchen

Norman	2010	Effects of sewerage on diarrhoea and enteric infections: a systematic review and meta-analysis	Sewerage	Multiple	University of Surrey University of Santiago de Compostela Centro de Investigacion Biomedica en Red de Epidemiologia y Salud Publica	The intervention was sewerage, but the comparisons were variable	Systematic review	Inverse variance method Random effects pooled estimates	--
Prasad	2018	Epidemiology and risk factors for typhoid fever in central division, Fiji, 2014-2017: a case-control study	Sewerage	Fiji	Dunedin School of Medicine Edith Cowan University University of Sydney Fiji Center for Communicable disease Control Fiji Health Sector Support Program Telethon Kids Institute Murdoch Children's Research Institute Fiji National University Wildlife Conservation Society, Melanesia Region Program University of Melbourne	Undamaged, improved municipal sewerage is compared with other sanitation forms	Case-control	Conditional logistic regression	Drank from alternate water source; water not always available from main source; did not wash produce before eating; high handwashing frequency after defecation; use soap for handwashing; socioeconomic indicators; recent rain and flooding
Rosas-Aguirre	2015	Plasmodium vivax malaria at	Drainage	Peru	Universidad Peruana Cayetano	Living within 200 meters of a	Case-control	Logistic regression	Household size; potable water

		households: spatial clustering and risk factors in a low endemicity urban area of the northwestern Peruvian coast	Sewerage		Heredia Universite catholique de Louvain Sub-region de Salud Luciano Castillo Colonna Caucaseco Scientific Research Center	water drain Bathroom connected to sewage system			availability; presence of domestic or peri-domestic animals; spatial malaria clusters, less than 200 meters from drain; materials in walls and floors; electricity; bathroom connected to sewage; bed net owned; bed net used by household head; outdoor occupation
Sezen	2015	A large multi- pathogen gastroenteritis outbreak caused by drinking contaminated water from antique neighbourhood fountains, Erzurum city, Turkey, December 2012	Chlorination	Turkey	Public Health Institution of Turkey WHO Country Office, Turkey Erzurum Provincial Public Health Directorate	Drinking from antique neighborhood fountains, chlorinated tap water, bottled water, and other water sources	Case- control	Conditional logistic regression	Age, sex
Stewart-	2014	Spatiotemporal	Sewerage	Ecuador	MSP	Access to	Cross-	Stepwise	More than four

Ibarra	clustering, climate periodicity, and social-ecological risk factors for dengue during an outbreak in Machala, Ecuador, in 2010	National Institute of Meteorology and Hydrology National Secretary of Higher Education, Science, Technology, and Innovation of Ecuador Global Emerging Infections Surveillance and Response System Latin American Observatory of Extreme Events Universidad del Zulia Latin American Observatory partnership IRI Earth Institute Columbia University Centro de Modelado Cientifico Escuela Superior Politecnica del Litoral Inational Insitute of Meterology and Hydrology State University of New York	sewerage (not defined)	sectional	model selection	people per bedroom; population density; more than one other household sharing the home; people per household; receiving remittances; people emigrate for work; age, education, employment, and sex of household head; ethnicity; access to municipal garbage collection and sewerage; piped water in the house; paved roads; drinking tap water; renting house; distance to hospital
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University of
Florida
University of
KwaZulu-Natal
Ministry of Health,
Ecuador
Universidad
Tecnica de
Machala
Cornell University
Harvard University
State University of
New York Upstate
Medical University

Turley	2013	Slum upgrading strategies involving physical environment and infrastructure interventions and their effects on health and socio-economic outcomes	Sewerage Drainage	Multiple	Cochrane Systematic Reviews	This was a systematic review of slum upgrading, which was defined to include the following intervention categories: physical environment and infrastructure (including sewerage systems and storm drainage); health education and behavioral interventions; social environment interventions; and health and	Systematic review	--	--
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social services interventions									
Werber	2009	Massive outbreak of viral gastroenteritis associated with consumption of municipal drinking water in a European capital city	Chlorination	Montenegro	Robert Koch Institute Insitute of Public Health, Podgorica, Montenegro Direction des Affaires Sanitaires Sociales de l'Isere Istituto Superiore di Sanita, Rome French Food Safety Agency World Health Organization Health Protection Scotland	The central water system was chlorinated; however, water was not held in a tank before distribution.	Case-control	Logistic regression	Age, sex

1

2 **Supplemental Table 1 (cont'd).** Extended summary of included studies in REA

First author	Year	Outcome	Other results	Hypothesized sources of contamination	Conclusions	Problems with implementation	Problems with study design, limitations, and biases
Baltazar	1988	There is no significant effect of being exposed to poor water and/or sanitation on odds of diarrhea.	While not significant, there does appear to be a possible dose response, with larger odds of diarrhea calculated for more	Poor water and sanitary practices	There may be a relationship between poor water and sanitation and odds of diarrhea	--	Access to chlorinated municipal water and a sewage system are pooled with other sources of water and sanitation

exposures.

Barreto	2007	Intervention effects on odds of diarrhea varied from 0.15 to 3.02 depending on the neighborhood and baseline prevalence of diarrhea Diarrhea prevalence fell by about 22% In areas with high baseline risk, prevalence of diarrhea decreased by 43% after the intervention	High risk areas were more likely to have significant reductions in odds of diarrhea than low risk areas The reduction in diarrhea was not fully explained by sanitation or environmental factors, but could be fully explained by the intervention	--	Implementation of the sanitation program was associated with reduction in longitudinal prevalence of diarrhea Reduction could be fully explained by increase in coverage of sewer system connections	Improvements in sewage access were not uniform across low and high risk areas	Although efforts are made to control for other changes which would have occurred over the study period, it is possible that the reduction was a result of other factors and temporal trends.
Butala	2010	The intervention resulted in a decrease in the probability of claiming a waterborne illness by 0.62. This was a decrease of 18%.	--	Water and sanitation	Slum upgrading in India is associated with improved health outcomes	--	Data was collected from insurance claims. As such, generalizability to the uninsured may be limited. If there was any change in the insurance system or its demographics, results could be effected. This likely also resulted in an underestimation of cases. It is possible that the reduction was a result of other factors and temporal trends.

							Control neighborhoods were those that had not organized to participate and could therefore have different profiles This intervention includes many factors beyond sewage and drainage.
Clasen	2010	Effect sizes varied widely; however, 11 of the 13 studies found that these interventions did reduce diarrhea Only one study investigated the effects of providing toilets connected to a sewer and piped water. This intervention was found to be beneficial, relating to a 0.33 risk ratio in diarrhea The quality of the evidence was low, with considerable risk of bias.	--	Improper disposal of human excreta	Interventions to improve excreta disposal are effective in preventing diarrheal disease Most studies found that the sanitation interventions were protective against diarrhea	--	Did not pool effects
Costa	2005	Inadequate sewage was related to a 4.18 increase in odds of visceral leishmaniasis	--	Flies are attracted to overcrowded houses with inadequate sewage system due to odor and carbon dioxide	Improving household structure and providing basic urban services could help control spread of VL	--	Cases were randomly chosen from a list provided by the electric company 29% of cases were lost to follow-up through death or failure to locate

emissions

Cases and controls were not matched on age or socioeconomic status

de Oliveira Serra	2015	In 1992-1996, households without sewerage system had 0.86 times the odds of being infected with a parasite than houses with sewerage system In 2010, households without sewerage system had 1.42 times the odds of being infected with a parasite than houses with sewerage system	Piped water and drinking water treatment were also associated with increased odds of parasitic infection (0.18 and 0.26 respectively) Toilets had no effect Risk factors varied slightly over time	Improvement in sanitation and water treatment reduced parasite contamination in 2010	Study showed a reduction in intestinal parasitic diseases from 1992-2011 and improvement in sanitary conditions of the population	--	Unclear what variables were included in the multivariate regression Very small sample of households with sewer connections in 1992-1996
Ferrer	2008	In univariate analysis, sewage disposal was not associated with diarrhea so it did not make it into the final model Sewage disposal did have an effect on diarrhea in children aged 3-8 years but effect	--	Socioeconomic factors were large portion of diarrhea burden Presence of garbage dumps in area	Investment in sanitation improvements helped improve the effect of water and sanitation factors on diarrheal disease	--	Used p-values to determine what was included in multivariate model Definition of sewage includes factors not considered as sewage in this review

		estimate is not provided		Expansion of sewerage network probably contributed to why sewage didn't show up in the final model			
Gasem	2001	Households that had an open or no drainage system had 7.19 times the odds of developing typhoid fever compared to households that had a closed sewage system Households that obtained their water from rivers, ponds, wells, or water vendors had 29.18 times the odds of developing typhoid fever compared to households whose water supply was from the chlorinated municipal water supply	--	Living in a house with open sewers Drinking contaminated water Street food	Typhoid fever was associated with poor housing, inadequate personal and food hygiene	--	--

Klasen	2012	<p>Sewage may have increased diarrhea by about 10% although estimates are inconsistent</p> <p>Propensity score matching result: Disease burden in piped water households increased by 4% in coastal region and by 4.5% in mountain regions compared to control</p>	<p>Piped water was often related to increased rates of disease, diarrhea, and missed work/school, especially among children.</p>	<p>Pipe system: coastal region had a main water pipe that tested positive for E. coli indicating possible leaks in that pipe</p> <p>Leaks in the small distribution pipes may also cause additional pollution</p> <p>Irregular water supply in mountainous regions which has led to water rationing and increases risk for contamination</p> <p>Intermittent water supply would also affect clogging of the sewerage system which could also affect contamination</p>	<p>Health impact from the infrastructure investment is mixed as in the mountain town, health deteriorated for intervention households. In coastal town, clear effects weren't found from the water intervention and marginal improvements were found in the sanitation intervention</p> <p>Water networks should only be extended if water supply is reliable and can be assured</p> <p>Providing piped sewers without reliable water access can worsen community health</p> <p>Frequent water quality tests along piped water networks are needed to monitor water quality</p>	<p>Intermittent water supply with inadequate chlorination</p>	<p>Treatment is not random (assigned to entire neighborhoods/streets) so quasi-experimental approaches were used</p> <p>Inferences are largely limited to mountain regions due to data limitations</p>
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Propensity score matching result: Disease burden in piped water and sanitation households decreased by 3.7% compared to piped water households alone in the coastal region. In the mountain regions, households with both sanitation and piped water interventions had 13.8% increase in disease burden for children compared to piped water households alone

Contamination could be due to water rationing which causes the piped water system to work improperly. Contamination in household storage tanks (where the pipes feed into) though contamination probably came from the pipes. Contamination from household behavior and lack of hygiene behaviors

Purification at household level could address water quality issues

Training to improve water handling at household level could improve health outcomes

Water rationing may be causing negative health problems and this may be aggravated when sanitation facilities are water dependent.

Although they do consider the effects of piped, chlorinated water, this system is so poorly implemented that it does not reflect the expected impacts of a well functioning system.

Authors use several different statistical approaches in order to establish causality. However, this is problematic because it implies that these approaches somehow add additional evidence to one another when, if done correctly, each alone should be sufficient and there is the expectation that they would all come to the same conclusion, regardless of true causality.

Kolahi	2008	The total population attributable risk was 9	There was a decrease in risk of diarrhea in control sites as well by 37%	--	Sewerage was found to decrease diarrhea prevalence	Coverage of sewerage connection wasn't complete as 24% of the residential units in the	Control sites were those scheduled for sewerage connection within four years, but it is unclear how site selection was determined
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		Diarrhea decreased by 46% in the intervention group and by 37% in the control group after the intervention had been implemented				intervention areas were not connected to the sewerage system	Improvements in socio-economic conditions, birth rate reduction, improvements in hygiene behaviors may have contributed to improvement in control group as well Children tended to be older in the sample taken after the installation of the sewer in intervention areas
Moraes	2003	Relative to those with both sewerage and drainage, children in areas with only drainage had 2.97 odds of diarrhea and those with none had 8.10 odds	Age group results show that diarrhea episodes were highest in the no intervention group starting at 12 months and then all three groups declined for older age groups	Possibly due to intervention groups having a more reliable water supply service than control	Incidence of diarrhea in the intervention groups was lower than in control group, with the combined intervention arm having the lowest incidence	Installation was meant for the entire area and not achieved due to funding limitations	There were some differences between intervention and control groups on baseline characteristics that are likely to affect results; however, these were controlled for in the logistic regression Children weren't independent and diarrhea episodes in a single child were not independent. Unsure if they took this into account Small number of communities in each arm - only 3 per Two cross-sections
Norman	2010	Sewerage reduces the relative risk of diarrhea and related outcomes	May be a dose response in which each "step" of sanitation	--	Sewerage has a positive effect on enteric infectious disease burden as	--	Two of the studies had low connection rates to the sewerage rates Possible diarrhea recall

[illegible]

Rosas-Aguirre	2015	In multivariate analysis, living within 200 meters of the water drain was related to 2.3 odds of malaria Having a bathroom connected to a sewer did not affect odds of malaria in univariate analysis, so multivariate analysis was not connected	--	Proximity to large drain where water accumulates after rain and therefore creates breeding areas for mosquitoes Irregularity in bed and course of drain as well as waste disposal along the drain creates favorable conditions for breeding grounds	Living close to the water drain was found to be associated with increased risk for malaria Null result for sewage since it wasn't included in final model	--	Used backward selection model that only retained variables that had a p-value less than 0.05
Sezen	2015	Multivariate analysis: Drinking water from antique fountains had OR of 20 and drinking fountain/other water had OR of 2.1 compared to drinking bottled or tap water only	Cases were geographically clustered	Contamination from sewerage pipes into water supply to fountains	Drinking contaminated untreated water from the antique fountains led to the outbreak of gastroenteritis	Sewerage work carried out in area of antique fountains led to contamination of water in fountains	Only control for age and sex
Stewart-Ibarra	2014	The inclusion of an indicator for sewerage did not improve model fit in linear regressions to predict odds of dengue	Living closer to the hospital and having piped water increased odds of dengue 22.4% of households did not have access to sewerage	Piped water may get contaminated when it is placed in uncovered secondary storage containers People living closer to the hospital may be more likely to report	Poor housing conditions, access to piped water inside the home, distance to central hospital and household head age and sex were found to be risk factors of dengue	--	Used AIC values to determine which variables to include in their model, and then did not report all models tested

Turley	2013	Authors identified three studies that included a sewerage component and nine studies that included a drainage component. Mixed effects on economic and employment outcomes There is some evidence that water-related interventions are successful in decreasing diarrheal diseases Results have significant heterogeneity and a high risk of bias	--	--	Sanitation and drainage interventions were found to have impacts on diarrhea with mixed results on parasitic infections	--	Due to the design of most slum upgrading interventions, it generally not possible to disentangle the effects of the various components of slum upgrading
Werber	2009	Acute gastroenteritis was associated with drinking municipal water (OR = 11.2) People who consumed tap and bottled water had 0.2 times the odds of developing	About 40% of the water was lost before reaching consumers. Illness declined after hyper-chlorination occurred	Municipal water supply Lack of holding tank - as there is not enough time for the free residual chlorine to disinfect drinking water Electrical pump	Chlorination is not sufficient to prevent disease if other measures are not properly taken.	No chlorine was actually detectable in the water samples	Matching may not have been sufficient

acute
gastroenteritis
compared to those
who only drank
municipal water

failures which
could then have
caused drop in
water pressure for
fecally
contaminated
water/raw sewage
to leak into water
distribution
system

Appendix A: Rapid evidence assessment on urban WaSH Interventions - Protocol

1 Background

1.1 The interventions

There are three interventions that form the scope of this rapid evidence assessment. They include:

- Chlorination of drinking water in the centralized water distribution system
- Expansion of storm drainage system
- Creation of sewage system

1.2 Expected Theories of Change

Figure A.1. Theory of change diagram co-created with Millennium Challenge Corporation and from Water Supply and Sanitation Collaborative Council and World Health Organization (2005)

1.3 Rationale for the review

This rapid evidence assessment will inform the cost-benefit analysis for the Timor-Leste country economist at the Millennium Challenge Corporation. It will also serve as a public good to provide a rapid synthesis of the available evidence on large-scale urban infrastructure projects in L&MICs.

2 Review objectives

The purpose of this review is to identify the expected health, social, and economic effects of three interventions (water chlorination, expanded drainage, and the installation of sewers) in an urban setting in L&MICs.

3 Method

This objective will be accomplished through a targeted, systematic literature search. Literature will be screened for quality and summarized visually and in a narrative format.

3.1 Criteria for including and excluding studies in the review (PICO)

<i>Criteria</i>	<i>Included</i>	<i>Excluded</i>
Participants	Individuals in urban settings in L&MICs	Individuals in high income settings. Individuals not living in urban settings
Intervention	Chlorination, drainage, sewers	Latrine and septic tank installation Behavior change interventions Surface water (river, lake, pond ocean) Point of use interventions
Comparison	Before-after, intervention-control	If there is no comparison
Outcome	Diarrhea, soil-transmitted helminths, other parasitic infections Environmental enteric enteropathy DALYs and QALYS GDP	Behavioral outcomes Agricultural and veterinary outcomes Chemical pollutants (sulfur dioxide, arsenic, lead, selenium, cadmium, manganese, etc.)

3.1.1 Types of study participants

- Individuals living in urban settings in L&MICs
 - Using the 2016 WHO definition of L&MICs
 - Countries were included if they were L&MICs at the time of implementation

Subpopulations considered:

- Children under 5 in urban settings in L&MICs

3.1.2 Types of interventions

- Chlorination of centralized drinking water distribution system in urban settings
- Expansion of storm drainage system in urban settings
- Installation of sewers in urban settings

3.1.3 Types of outcome measures

- Diarrhea incidence
- Soil-transmitted helminths infections
- Other parasitic infections

- Economic growth (GDP)
- Environmental enteric enteropathy
- Disability-adjusted life years (DALYs) averted
- Quality-adjusted life years (QALYs) gained

3.1.4 Types of study design

- Randomized controlled trial
- Regression discontinuity design
- Controlled before-and-after studies, including
 - Propensity score matching
 - Instrumental variable
 - Difference-in-differences
- Simulation modeling
- Case-control
- Interrupted time series
- *Excluding case studies*

3.1.5 Date, language, and form of publication

- Date: Publications must be published after 1900 and studies must be of settings that are post-1900
- Language: English
- Publication forms:
 - Peer-reviewed

3.2 Search strategy

See Appendix C.

3.2.1 Electronic searches of bibliographic databases and library catalogues

The following databases will be searched: Ebsco Discovery (limited to REPEC and World Bank), CAB Abstracts, CAB Global Health, Medline, Embase, and the Social Sciences Citation Index

3.3 Selection of studies

3.3.1 Screening

Study screening will be conducted in accordance with standard 3ie guidelines. Two reviewers will screen all studies. In the case of discrepancies, the study will be included for the next phase of review.

3.3.2 Data extraction and coding procedures

Data extraction templates will be modified from 3ie's repository coding protocol and the coding protocols typically used for systematic reviews. This includes bibliographic, geographic information and substantive data, as well as standardized methods information. In addition, we will extract data on interventions, outcomes, population, and effect sizes for parameters relevant to the Theory of Change.

3.3.3 Critical appraisal

All included systematic reviews and impact evaluations will be appraised using the 3ie systematic review database protocol and the impact evaluation protocol, respectively. Studies that do not fall into these categories will be appraised using the appropriate protocol.

3.6 Data presentation

We will provide a narrative summary of the papers identified. This will include an overall description of the available literature and a general synthesis of findings. Individual studies will be briefly presented. In addition, studies will be summarized in a table and a theory of change diagram.

Appendix B: Databases and catalogues searched

Electronic searches of bibliographic databases and library catalogues

- EBSCO Discovery: IDEAS RePeC and World Bank e-library
- EBSCO: CAB Abstract;
- Ovid: CAB Global Health; Medline
- Embase
- Social Sciences Citation Index

Appendix C: Example search strings for CAB Abstracts (Ebsco)

S25 S3 AND S22 AND S23 AND S24

788

S24 S6 OR S9 OR S13

239,023

S23 TI (("random* control* trial*" OR "random* trial*" OR RCT OR "cluster random* trial" OR "propensity score matching" OR PSM Or "regression discontinuity design" OR RDD OR "difference in difference*" OR "systematic* review*" OR meta-analy* OR "meta analy*" OR SR OR "control* random* trial*" OR "case control" OR matching OR "interrupted time series" OR "random* allocation*" OR (random* N3 (allocat*)) OR "instrumental variable*" OR "research synthesis" OR "scoping review" OR "rapid evidence assessment" OR "systematic literature review" OR ((quantitative OR "comparison group" OR counterfactual OR "counter factual" OR counter-factual OR experiment*) N3 (design OR study OR analysis)) OR quasi-experimental OR "quasi experimental" OR QED OR (simulation N2 model*))) OR AB (("random* control* trial*" OR "random* trial*" OR RCT OR "cluster random* trial" OR "propensity score matching" OR PSM Or "regression discontinuity design" OR RDD OR "difference in difference*" OR "systematic* review*" OR meta-analy* OR "meta analy*" OR SR OR "control* random* trial*" OR "case control" OR matching OR "interrupted time series" OR "random* allocation*" OR (random* N3 (allocat*)) OR "instrumental variable*" OR "research synthesis" OR "scoping review" OR "rapid evidence assessment" OR "systematic literature review" OR ((quantitative OR "comparison group" OR counterfactual OR "counter factual" OR counter-factual OR experiment*) N3 (design OR study OR analysis)) OR quasi-experimental OR "quasi experimental" OR QED OR (simulation N2 model*))) OR SU (("random* control* trial*" OR "random* trial*" OR RCT OR "cluster random* trial" OR "propensity score matching" OR PSM Or "regression discontinuity design" OR RDD OR "difference in difference*" OR "systematic* review*" OR meta-analy* OR "meta analy*" OR SR OR "control* random* trial*" OR "case control" OR matching OR "interrupted time series" OR "random* allocation*" OR (random* N3 (allocat*)) OR "instrumental variable*" OR "research synthesis" OR "scoping review" OR "rapid evidence assessment" OR "systematic literature review" OR ((quantitative OR "comparison group" OR counterfactual OR "counter factual" OR counter-factual OR experiment*) N3 (design OR study OR analysis)) OR quasi-experimental OR "quasi experimental" OR QED OR (simulation N2 model*)))

398,665

S22 S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21

4,172,192

S21 TI (Africa or Asia or Caribbean or "West Indies" or "South America" or "Latin America" or "Central America") OR AB (Africa or Asia or Caribbean or "West Indies" or "South America" or "Latin America" or "Central America") OR SU (Africa or Asia or Caribbean or "West Indies" or "South America" or "Latin America" or "Central America") OR GE (Africa or Asia or Caribbean or "West Indies" or "South America" or "Latin America" or "Central America")

2,260,837

1 S20 TI (("transitional country" or "transitional countries")) OR AB (("transitional country" or
2 "transitional countries")) OR SU (("transitional country" or "transitional countries"))

3 140

4 S19 TI ((Imic or Imics or "third world" or "lami country" or "lami countries")) OR AB ((Imic or Imics
5 or "third world" or "lami country" or "lami countries")) OR SU ((Imic or Imics or "third world" or "lami
6 country" or "lami countries"))

7 41,578

8 S18 TI (low N3 middle N3 countr*) OR AB (low N3 middle N3 countr*) OR SU (low N3 middle N3
9 countr*)

10 8,135

11 S17 TI (low* N1 (gdp or gnp or "gross domestic" or "gross national")) OR AB (low* N1 (gdp or gnp
12 or "gross domestic" or "gross national")) OR SU (low* N1 (gdp or gnp or "gross domestic" or "gross
13 national"))

14 149

15 S16 TI ((developing or less* N1 developed or "under developed" or underdeveloped or "middle
16 income" or low* N1 income) N1 (economy or economies)) OR AB ((developing or less* N1 developed or
17 "under developed" or underdeveloped or "middle income" or low* N1 income) N1 (economy or
18 economies)) OR SU ((developing or less* N1 developed or "under developed" or underdeveloped or
19 "middle income" or low* N1 income) N1 (economy or economies))

20 2,159

21 S15 TI ((developing or less* N1 developed or "under developed" or underdeveloped or "middle
22 income" or low* N1 income or underserved or "under served" or deprived or poor*) N1 (countr* or
23 nation* or population* or world)) OR AB ((developing or less* N1 developed or "under developed" or
24 underdeveloped or "middle income" or low* N1 income or underserved or "under served" or deprived
25 or poor*) N1 (countr* or nation* or population* or world)) OR SU ((developing or less* N1 developed
26 or "under developed" or underdeveloped or "middle income" or low* N1 income or underserved or
27 "under served" or deprived or poor*) N1 (countr* or nation* or population* or world))

28 3,979,129

29 S14 TI (Afghanistan OR Albania OR Algeria OR Angola OR Antigua OR Barbuda OR Argentina OR
30 Armenia OR Armenian OR Aruba OR Azerbaijan OR Bahrain OR Bangladesh OR Barbados OR Benin OR
31 Belize OR Bhutan OR Bolivia OR Botswana OR Brazil OR Brasil OR "Burkina Faso" OR "Burkina Fasso" OR
32 "Upper Volta" OR Burundi OR Urundi OR Cambodia OR "Khmer Republic" OR Kampuchea OR Cameroon
33 OR Cameroons OR Cameron OR Camerons OR "Cape Verde" OR "Central African Republic" OR Chad OR
34 Chile OR China OR Colombia OR Comoros OR "Comoro Islands" OR Comores OR Mayotte OR Congo OR
35 Zaire OR "Costa Rica" OR "Cote d'Ivoire" OR "Ivory Coast" OR Cuba OR "Djibouti" OR "French
36 Somaliland" OR Dominica OR "Dominican Republic" OR "East Timor" OR "East Timur" OR "Timor Leste"
37 OR Ecuador OR Egypt OR "United Arab Republic" OR "El Salvador" OR Eritrea OR Ethiopia OR Fiji OR
38 Gabon OR "Gabonese Republic" OR Gambia OR Gaza OR "Georgia Republic" OR "Georgian Republic" OR

1 Ghana OR "Gold Coast" OR Grenada OR Guatemala OR Guinea OR Guam OR Guiana OR Guyana OR Haiti
 2 OR Honduras OR India OR Maldives OR Indonesia OR Iran OR Iraq OR Jamaica OR Jordan OR Kazakhstan
 3 OR Kazakh OR Kenya OR Kiribati OR Korea OR Kosovo OR Kyrgyzstan OR Kirghizia OR "Kyrgyz Republic"
 4 OR Kirghiz OR Kirgizstan OR "Lao PDR" OR Laos OR Lebanon OR Lesotho OR Basutoland OR Liberia OR
 5 Libya OR Madagascar OR "Malagasy Republic" OR Malaysia OR Malaya OR Malay OR Sabah OR Sarawak
 6 OR Malawi OR Nyasaland OR Mali OR "Marshall Islands" OR Mauritania OR Mauritius OR "Agalega
 7 Islands" OR Mexico OR Micronesia OR "Middle East" OR Moldova OR Moldovia OR Moldovian OR
 8 Mongolia OR Montenegro OR Morocco OR Ifni OR Mozambique OR Myanmar OR Myanma OR Burma OR
 9 Namibia OR Nepal OR Antilles OR "New Caledonia" OR Nicaragua OR Niger OR Nigeria OR "Mariana
 10 Islands" OR Oman OR Muscat OR Pakistan OR Palau OR Palestine OR Panama OR Paraguay OR Peru OR
 11 Philippines OR Philipines OR Phillipines OR Phillippines OR "Puerto Rico" OR Rwanda OR Ruanda OR
 12 "Saint Kitts" OR "St Kitts" OR Nevis OR "Saint Lucia" OR "St Lucia" OR "Saint Vincent" OR "St Vincent" OR
 13 "Grenadines" OR "Samoa" OR "Samoan Islands" OR "Navigator Island" OR "Navigator Islands" OR "Sao
 14 Tome" OR "Saudi Arabia" OR Senegal OR Seychelles OR "Sierra Leone" OR "Sri Lanka" OR "Solomon
 15 Islands" OR Somalia OR Sudan OR Suriname OR Surinam OR Swaziland OR Syria OR Tajikistan OR
 16 Tadzhikistan OR Tadjikistan OR Tadzhi OR Tanzania OR Thailand OR Togo OR "Togolese Republic" OR
 17 Tonga OR Trinidad OR Tobago OR Tunisia OR Turkey OR Turkmenistan OR Turkmen OR Uganda OR
 18 Ukraine OR Uruguay OR Uzbekistan OR Uzbek OR Vanuatu OR "New Hebrides" OR Venezuela OR
 19 Vietnam OR "Viet Nam" OR "West Bank" OR Yemen OR Zambia OR Zimbabwe OR Jamahiriya OR
 20 Jamahiryria OR Libia OR Mocambique OR Principe OR Syrian OR "Indian Ocean" OR Melanesia OR
 21 "Western Sahara") OR AB (Afghanistan OR Albania OR Algeria OR Angola OR Antigua OR Barbuda OR
 22 Argentina OR Armenia OR Armenian OR Aruba OR Azerbaijan OR Bahrain OR Bangladesh OR Barbados
 23 OR Benin OR Belize OR Bhutan OR Bolivia OR Botswana OR Brazil OR Brasil OR "Burkina Faso" OR
 24 "Burkina Fasso" OR "Upper Volta" OR Burundi OR Urundi OR Cambodia OR "Khmer Republic" OR
 25 Kampuchea OR Cameroon OR Cameroons OR Cameron OR Camerons OR "Cape Verde" OR "Central
 26 African Republic" OR Chad OR Chile OR China OR Colombia OR Comoros OR "Comoro Islands" OR
 27 Comores OR Mayotte OR Congo OR Zaire OR "Costa Rica" OR "Cote d'Ivoire" OR "Ivory Coast" OR Cuba
 28 OR "Djibouti" OR "French Somaliland" OR Dominica OR "Dominican Republic" OR "East Timor" OR "East
 29 Timur" OR "Timor Leste" OR Ecuador OR Egypt OR "United Arab Republic" OR "El Salvador" OR Eritrea
 30 OR Ethiopia OR Fiji OR Gabon OR "Gabonese Republic" OR Gambia OR Gaza OR "Georgia Republic" OR
 31 "Georgian Republic" OR Ghana OR "Gold Coast" OR Grenada OR Guatemala OR Guinea OR Guam OR
 32 Guiana OR Guyana OR Haiti OR Honduras OR India OR Maldives OR Indonesia OR Iran OR Iraq OR
 33 Jamaica OR Jordan OR Kazakhstan OR Kazakh OR Kenya OR Kiribati OR Korea OR Kosovo OR Kyrgyzstan
 34 OR Kirghizia OR "Kyrgyz Republic" OR Kirghiz OR Kirgizstan OR "Lao PDR" OR Laos OR Lebanon OR
 35 Lesotho OR Basutoland OR Liberia OR Libya OR Madagascar OR "Malagasy Republic" OR Malaysia OR
 36 Malaya OR Malay OR Sabah OR Sarawak OR Malawi OR Nyasaland OR Mali OR "Marshall Islands" OR
 37 Mauritania OR Mauritius OR "Agalega Islands" OR Mexico OR Micronesia OR "Middle East" OR Moldova
 38 OR Moldovia OR Moldovian OR Mongolia OR Montenegro OR Morocco OR Ifni OR Mozambique OR
 39 Myanmar OR Myanma OR Burma OR Namibia OR Nepal OR Antilles OR "New Caledonia" OR Nicaragua
 40 OR Niger OR Nigeria OR "Mariana Islands" OR Oman OR Muscat OR Pakistan OR Palau OR Palestine OR
 41 Panama OR Paraguay OR Peru OR Philippines OR Philipines OR Phillipines OR Phillippines OR "Puerto
 42 Rico" OR Rwanda OR Ruanda OR "Saint Kitts" OR "St Kitts" OR Nevis OR "Saint Lucia" OR "St Lucia" OR
 43 "Saint Vincent" OR "St Vincent" OR "Grenadines" OR "Samoa" OR "Samoan Islands" OR "Navigator
 44 Island" OR "Navigator Islands" OR "Sao Tome" OR "Saudi Arabia" OR Senegal OR Seychelles OR "Sierra

1 Leone" OR "Sri Lanka" OR "Solomon Islands" OR Somalia OR Sudan OR Suriname OR Surinam OR
 2 Swaziland OR Syria OR Tajikistan OR Tadzhikistan OR Tadjikistan OR Tadjhik OR Tanzania OR Thailand OR
 3 Togo OR "Togolese Republic" OR Tonga OR Trinidad OR Tobago OR Tunisia OR Turkey OR Turkmenistan
 4 OR Turkmen OR Uganda OR Ukraine OR Uruguay OR Uzbekistan OR Uzbek OR Vanuatu OR "New
 5 Hebrides" OR Venezuela OR Vietnam OR "Viet Nam" OR "West Bank" OR Yemen OR Zambia OR
 6 Zimbabwe OR Jamahiriya OR Jamahiryria OR Libia OR Mocambique OR Principe OR Syrian OR "Indian
 7 Ocean" OR Melanesia OR "Western Sahara") OR SU (Afghanistan OR Albania OR Algeria OR Angola OR
 8 Antigua OR Barbuda OR Argentina OR Armenia OR Armenian OR Aruba OR Azerbaijan OR Bahrain OR
 9 Bangladesh OR Barbados OR Benin OR Belize OR Bhutan OR Bolivia OR Botswana OR Brazil OR Brasil OR
 10 "Burkina Faso" OR "Burkina Fasso" OR "Upper Volta" OR Burundi OR Urundi OR Cambodia OR "Khmer
 11 Republic" OR Kampuchea OR Cameroon OR Cameroons OR Cameron OR Camerons OR "Cape Verde" OR
 12 "Central African Republic" OR Chad OR Chile OR China OR Colombia OR Comoros OR "Comoro Islands"
 13 OR Comores OR Mayotte OR Congo OR Zaire OR "Costa Rica" OR "Cote d'Ivoire" OR "Ivory Coast" OR
 14 Cuba OR "Djibouti" OR "French Somaliland" OR Dominica OR "Dominican Republic" OR "East Timor" OR
 15 "East Timur" OR "Timor Leste" OR Ecuador OR Egypt OR "United Arab Republic" OR "El Salvador" OR
 16 Eritrea OR Ethiopia OR Fiji OR Gabon OR "Gabonese Republic" OR Gambia OR Gaza OR "Georgia
 17 Republic" OR "Georgian Republic" OR Ghana OR "Gold Coast" OR Grenada OR Guatemala OR Guinea OR
 18 Guam OR Guiana OR Guyana OR Haiti OR Honduras OR India OR Maldives OR Indonesia OR Iran OR Iraq
 19 OR Jamaica OR Jordan OR Kazakhstan OR Kazakh OR Kenya OR Kiribati OR Korea OR Kosovo OR
 20 Kyrgyzstan OR Kirghizia OR "Kyrgyz Republic" OR Kirghiz OR Kirgizstan OR "Lao PDR" OR Laos OR
 21 Lebanon OR Lesotho OR Basutoland OR Liberia OR Libya OR Madagascar OR "Malagasy Republic" OR
 22 Malaysia OR Malaya OR Malay OR Sabah OR Sarawak OR Malawi OR Nyasaland OR Mali OR "Marshall
 23 Islands" OR Mauritania OR Mauritius OR "Agalega Islands" OR Mexico OR Micronesia OR "Middle East"
 24 OR Moldova OR Moldovia OR Moldovian OR Mongolia OR Montenegro OR Morocco OR Ifni OR
 25 Mozambique OR Myanmar OR Myanma OR Burma OR Namibia OR Nepal OR Antilles OR "New
 26 Caledonia" OR Nicaragua OR Niger OR Nigeria OR "Mariana Islands" OR Oman OR Muscat OR Pakistan
 27 OR Palau OR Palestine OR Panama OR Paraguay OR Peru OR Philippines OR Philipines OR Phillipines OR
 28 Phillippines OR "Puerto Rico" OR Rwanda OR Ruanda OR "Saint Kitts" OR "St Kitts" OR Nevis OR "Saint
 29 Lucia" OR "St Lucia" OR "Saint Vincent" OR "St Vincent" OR "Grenadines" OR "Samoa" OR "Samoan
 30 Islands" OR "Navigator Island" OR "Navigator Islands" OR "Sao Tome" OR "Saudi Arabia" OR Senegal OR
 31 Seychelles OR "Sierra Leone" OR "Sri Lanka" OR "Solomon Islands" OR Somalia OR Sudan OR Suriname
 32 OR Surinam OR Swaziland OR Syria OR Tajikistan OR Tadzhikistan OR Tadjikistan OR Tadjhik OR Tanzania
 33 OR Thailand OR Togo OR "Togolese Republic" OR Tonga OR Trinidad OR Tobago OR Tunisia OR Turkey
 34 OR Turkmenistan OR Turkmen OR Uganda OR Ukraine OR Uruguay OR Uzbekistan OR Uzbek OR Vanuatu
 35 OR "New Hebrides" OR Venezuela OR Vietnam OR "Viet Nam" OR "West Bank" OR Yemen OR Zambia OR
 36 Zimbabwe OR Jamahiriya OR Jamahiryria OR Libia OR Mocambique OR Principe OR Syrian OR "Indian
 37 Ocean" OR Melanesia OR "Western Sahara")

38 2,161,253

39 S13 S10 OR S11 OR S12

40 177,987

41 S12 DE "sewers" OR DE "sewerage" OR DE "sanitation" OR DE "recirculating sewage systems" OR DE
 42 "sewage effluent disposal" OR DE "sewage" OR DE "sewage effluent" OR DE "sewage treatment"

1 35,358

2 S11 DE "water treatment" OR DE "sludge treatment" OR DE "waste water treatment plants" OR DE
3 "water treatment plants"

4 60,705

5 S10 TI (sewer* or sewage or (water N2 treat*)) OR AB (sewer* or sewage or (water N2 treat*)) OR
6 SU (sewer* or sewage or (water N2 treat*))

7 168,799

8 S9 S7 OR S8

9 54,558

10 S8 ((DE "drainage" OR DE "pipe drainage" OR DE "subsurface drainage" OR DE "surface drainage"
11 OR DE "drainage equipment" OR DE "drainage systems" OR DE "drainage water") OR (DE "flow to
12 drains")) OR (DE "drain laying")

13 23,389

14 S7 TI (drain or drains or drainage) OR AB (drain or drains or drainage) OR SU (drain or drains or
15 drainage)

16 54,558

17 S6 S4 OR S5

18 14,776

19 S5 DE "chlorination"

20 2,675

21 S4 TI ((chlorine N3 water) or chlorinat*) OR AB ((chlorine N3 water) or chlorinat*) OR SU (
22 (chlorine N3 water) or chlorinat*)

23 14,776

24 S3 S1 OR S2

25 297,726

26 S2 DE "urban population" OR DE "urban society" OR DE "urban sites" OR DE "urban planning" OR
27 DE "urban environment" OR DE "neighbourhoods" OR DE "residential areas" OR DE "suburban areas" OR
28 DE "urban areas" OR DE "urban hinterland" OR DE "wildland urban interface" OR DE "urban
29 development" OR DE "urban areas" OR DE "towns"

30 95,456

31 S1 TI (urban* or town* or city or cities or slum or slums or favela* or suburb* or conurbation* or
32 suburbia or ghetto* or "built environment*") OR AB (urban* or town* or city or cities or slum or slums
33 or favela* or suburb* or conurbation* or suburbia or ghetto* or "built environment*") OR SU (urban* or

1 town* or city or cities or slum or slums or favela* or suburb* or conurbation* or suburbia or ghetto* or
2 "built environment*")
3 294,577
4

Appendix D: Steps for study screening

1. **Removal of duplicate studies:** An automated process within EndNote was used to remove known duplicate files.
2. **Import study records:** After de-duplication, all output files of the implemented search strategy were imported into EPPI.
3. **Title and abstract screening:** The title and abstract (T&A) of all imported and de-duplicated studies were screened by two reviewers using the criteria set out in the protocol. Each reviewer indicated whether (s)he believed the study met the inclusion criteria. In practice, this means assigning a 'yes' or 'no' outcome to each T&A screened. Weekly meetings were held by the review team to reconcile any differences in screening outcomes and make refinements to the screening approach adopted. The output of this process was a set of screened studies that were put forward for full text screening.
4. **Full-text screening:** A full text for each study that met all inclusion criteria defined in the T&A screening was retrieved. Two reviewers examined each full text in detail against the protocol again and assigned a 'yes' or 'no' outcome only. The output of this stage was a set of studies deemed suitable to include in the rapid evidence assessment.

1 Appendix E: Illustrative list of outcomes considered

Outcome category	Specific outcomes considered
<i>Health</i>	Diarrheal incidence Typhoid Soil-transmitted helminths infections Parasitic infections (e.g. cryptosporidium, giardia, etc.) Bacterial infections (e.g., cholera, <i>E. coli</i> , etc.) Environmental enteropathy
<i>Welfare</i>	Disability-adjusted life years (DALYs) averted Quality-adjusted life years (QALYs) gained
<i>Social benefits</i>	GDP growth Improved educational outcomes Increase tourism

2 Note: additional outcomes within these categories were included when identified