



Article title: Synergies and Trade-offs between Sanitation and the Sustainable Development Goals

Authors: priti parikh[1], loan diep[2], pascale hofmann[3], Julia Tomei[4], Luiza Campos[5], Tse-Hui Teh[6], Yacob Mulugetta[7], Ben Milligan[8], Monica Lakhanpaul [9]

Affiliations: UCL EFID, CPM[1], UCL, DPU[2], UCL, ISR[3], UCL, CEGE[4], UCL, Bartlett[5], UCL, STEaPP[6], UCL, UNSW[7], Population, Policy and Practice, UCL Great Ormond Street Institute of Child Health[8]

Orcid ids: 0000-0002-1086-4190[1]

Contact e-mail: priti.parikh@ucl.ac.uk

License information: This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY) 4.0 <https://creativecommons.org/licenses/by/4.0/>, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

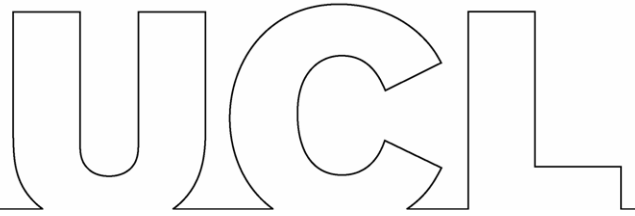
Preprint statement: This article is a preprint and has not been peer-reviewed, under consideration and submitted to UCL Open: Environment Preprint for open peer review.

Funder: Vitol Foundation

DOI: 10.14324/111.444/000054.v2

Preprint first posted online: 05 January 2021

Keywords: SDG, Sanitation, Interdisciplinary, Cross-sectoral partnerships, Synergies, Trade-offs, Sustainable development, Water, The Environment



04 January, 2021

Dear Editors

Please find attached the revised version of our our publication titled **“Synergies and Trade-offs between Sanitation and the Sustainable Development Goals”**. This research was co-developed by an interdisciplinary team at UCL (CEGE, STEaPP, ISR, BSCPM, BSP, Laws, DPU) where the team identified synergies and trade-offs between sanitation and the 169 SDG Targets using published evidence. The team identified 83 (43%) targets requiring action to be taken concerning sanitation systems. Evidence of synergies and trade-offs were identified for 130 (77%) and 28 (17%) targets respectively. The publication provides recommendations for a wide range of stakeholders on how to foster action in sanitation to improve environment, health and well-being. It fits directly with the mission of grand challenges and the work of UCL’s SDG Advisory group.

We are grateful to the reviewers who have provided us with valuable comments and feedback. We look forward to your response and let us know if you need further information from us.

Sincerely,

Priti H. Parikh

Dr. Priti Parikh on behalf of the team, Loan Diep, Dr. Pascale Hofmann, Dr. Julia Tomei, Dr. Luiza Campos, Dr. Tse-Hui The, Professor Yacob Mulugetta, Dr. Ben Milligan and Professor Monica Lakhanpaul

Associate Professor
BBOXX/Royal Academy of Engineering Senior Research Fellow
Engineering for International Development Centre
FICE, CEng, FRSA

Bartlett School of Construction and Project Management
The Bartlett, UCL Faculty of the Built Environment
2nd Floor 1-19 Torrington Place London, WC1E 7HB
Email: priti.parikh@ucl.ac.uk

Synergies and Trade-offs between Sanitation and the Sustainable Development Goals

*Dr. Priti Parikh

Associate Professor and BBOXX/Royal Academy of Engineering Fellow
Director, Engineering for International Development Centre,
Bartlett School of Construction Project Management
University College London
1-19 Torrington Place, London WC1E 7HB
Email: priti.parikh@ucl.ac.uk

Loan Diep

Research Assistant and PhD Candidate
Engineering for International Development Centre,
Bartlett School of Construction Project Management,
University College London
1-19 Torrington Place, London WC1E 7HB
E-mail: loan.diep.10@ucl.ac.uk

Dr. Pascale Hofmann

Associate Professor in Environmental and Sustainable Development
The Bartlett Development Planning Unit
University College London
34 Tavistock Square
WC1H 9EZ
E-mail: p.hofmann@ucl.ac.uk

Dr. Julia Tomei

Assistant Professor in Energy, Resources and Development
UCL Institute for Sustainable Resources
14 Upper Woburn Place
London, WC1H 0NN
Email: j.tomei@ucl.ac.uk

Dr. Luiza C. Campos

Associate Professor in Environmental Engineering
Centre for Urban Sustainability and Resilience
Civil, Environmental and Geomatic Engineering,
University College London
Chadwick Building, London, WC1E6BT
E-mail: l.campos@ucl.ac.uk

Dr. Tse-Hui Teh

Assistant Professor,
The Bartlett School of Planning
Central House
14 Upper Woburn Place
London, WC1H 0NN
E-mail: t.teh@ucl.ac.uk

Professor Yacob Mulugetta

Professor of Energy and Development Policy
UCL Department of Science, Technology, Engineering & Public Policy (STeAPP)

Shropshire House (4th Fl), 11-20 Caper Street
London WC1E 6JA
Email: yacob.mulugetta@ucl.ac.uk

Dr. Ben Milligan
Scientia Fellow, Sustainable Development Law and Policy
University of New South Wales
Sydney NSW 2052 Australia
Email: b.milligan@unsw.edu.au

Professor Monica Lakhanpaul
Professor of Integrated Community Child Health
Population, Policy & Practice Department,
UCL Great Ormond Street Institute of Child Health,
University College London, 30 Guilford Street, London, WC1N 1EH, UK.
Whittington NHS Trust, London
E-mail: m.lakhanpaul@ucl.ac.uk

*Corresponding author

Abstract

To better leverage opportunities arising out of sustainable and inclusive management of sanitation services there is a need for robust and comprehensive evidence of the wide ranging benefits that sanitation can deliver. The Sustainable Development Goals (SDGs) provide a comprehensive framework for sustainable development broken down into 169 interconnected Targets which are articulated under 17 Goals. Based on a methodology developed at University College London (UCL), this study identifies linkages between sanitation and the 169 Targets corroborated by published evidence. We show that there are synergies between sanitation and all 17 Goals and 130 (77%) of the Targets, and trade-offs for 28 (17%) of the Targets. We identified 83 Targets (49%) that call for action in the sanitation sector. The results demonstrate the far-reaching benefits that can be unlocked from investment in sanitation, which extend beyond health and spread across sectors. The evidence base for the 17 goals establishes links that can inform cross-sectoral action, collaborations and investment across governance levels for integrated sanitation solutions. The research provides different stakeholders with a framework that can be applied to context specific cases and projects. We propose a range of recommendations to policy-makers, practitioners, and researchers who seek to take this study further to help achieve the SDGs.

Introduction

In September 2015, the United Nations adopted the 2030 Agenda for Sustainable Development. Comprised of 17 Sustainable Development Goals (SDGs) and 169 Targets, the Agenda proposes a comprehensive global plan of action for 'people, planet and prosperity'. SDG6 aims to "ensure availability and sustainable management of water and sanitation for all" by 2030 (United Nations, 2015, p. 18). It builds on the largely unmet water and sanitation target of the Millennium Development Goals (MDGs) on environmental sustainability as the way MDG targets failed to support a systemic approach towards sanitation that considered the sanitation chain in its entirety. In 2017, 55% of the world's population still lacked access to safely managed sanitation, including an estimated 2 billion who did not have basic access (UNICEF and WHO, 2019). The severe implications of poor sanitation on morbidity rates, health care costs and productivity losses and inadequate sanitation is estimated to cost the global economy USD 260 billion per year (WHO, 2012). Our research calls for particular attention to the sanitation dimension of SDG6 and demonstrates that major gains are possible for all goals if universal access to adequate and equitable sanitation is achieved.

We argue that the SDGs provide a framework to identify priority areas of investment to maximise impact. An increasing number of studies have adopted such an approach and identified priorities for integrated policies from the analysis of relationships between all SDGs (see for example Nilsson et al., 2016; Pradhan et al., 2017; Dawes, 2020). At sectoral level, assessments have been carried out for links between the SDGs and marine ecology and management (Singh et al., 2018), energy systems (Castor et al., 2020; Fuso Nerini et al., 2018; McCollum et al., 2018), climate action (Fuso Nerini et al., 2019) and ecosystems (Maes et al., 2019). In addition, recent studies have explored linkages between the SDGs and infrastructure systems (Thacker et al., 2019), the SDGs and water (Bernhardt, 2015; Mara and Evans, 2018; UN Water, 2016), as well as the water-food-energy nexus among the SDGs (Fader et al., 2018). Yet, linkages between sanitation and the SDGs and their potential contributions to public health, the economy and the environment remain under-studied and require evidence-building for practical action.

The Sustainable Sanitation Alliance (SuSanA), an informal network of 11,000 individual members and 353 partner organisations working towards sustainable sanitation solutions, explored linkages

between sanitation and SDGs to maximise opportunities to improve access to sanitation (SuSanA, 2017). The network highlighted the relevance of sustainable sanitation to meeting the 2030 Agenda by presenting links between sustainable sanitation and all the SDGs and seeks to encourage sanitation sector professionals to take action and strive for intersectoral cooperation (SuSanA, 2017). Building on the work of SuSanA, this study adds value by presenting a novel and replicable evidence-based methodology that enables a systematic exploration of linkages, disaggregated by actions, synergies and trade-offs, between sanitation systems and the 169 Targets. Revealing these linkages not only highlights the importance of sanitation to other SDGs but can further provide valuable insights into the potential and scope for synergistic efforts towards the 2030 Agenda. **The expandable evidence base provided offers a starting point to enhance existing knowledge and demonstrates the value of incorporating sanitation into innovative and integrated approaches and investments.**

The aims of this study are twofold: a) to provide a replicable methodology that establishes linkages with the comprehensive 2030 Agenda and can be applied in specific contexts to demonstrate the wide-ranging benefits of sanitation that extend across sectors and beyond health; b) to establish an evidence base of published material to be further expanded as part of efforts to strategically meet the SDGs. Overall, this paper argues that sanitation plays a crucial role in the achievement of the 2030 Agenda and will be key to developing policies and programmes that support sustainable development.

Methods

A research team from diverse disciplines spanning engineering, urban design and planning, health, social science, political economy, policy and law, worked together from the outset to develop an interdisciplinary approach for knowledge co-production. This approach enables the analysis of complex, interconnected global challenges, providing evidence to support the development of integrated interventions that transcend disciplinary boundaries to develop appropriate approaches and solutions.

The research presented in this paper is based on a definition of safe, inclusive and sustainable sanitation presented in Box 1 which builds upon two concepts. First, SDG Target 6.2, which by 2030 aims to *“achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situation”*. Second, the **sanitation** service delivery ladder established by the Joint Monitoring Programme (JMP), which emphasises 'safely-managed' sanitation and considers the entire sanitation chain (i.e. capture, containment, emptying, transport, treatment and reuse/ disposal) (see also Sachs et al., 2019; SuSanA, 2008; World Health Organization, 2018) to ensure zero detriment to the environment.

Based on a review of existing definitions and discussions, the team noted the need to pay particular attention to the diverse needs of sanitation users, including disadvantaged and vulnerable groups (e.g. persons with disabilities), and the importance of menstrual hygiene and baby wash in the provision of sanitation services, which tend to receive less attention (Gibson et al., 2019; MacRae et al., 2019; Ngunjiri et al., 2014). In resource challenged settings, capacity building of local communities is essential in the provision of sustainable and inclusive sanitation solutions requiring an understanding of contextual socio-cultural factors (McGranahan and Mitlin, 2016). This study is based on the assumption that only safely managed sustainable sanitation systems are implemented in order to capture the far-reaching benefits that sanitation can deliver and set standards for future infrastructure projects and associated policies.

Achieve access to adequate, equitable and dignified sanitation and hygiene for all, paying attention to:

- Safely managed facilities and services for handling and disposal of human urine and faeces along the sanitation chain
- Social diversity and inclusivity (including gender, age, disability, religion)
- Capacity-building of local communities
- Menstrual hygiene and baby wash
- Ending open defecation

Box 1: Working definition used for sanitation to 'achieve adequate and equitable sanitation and hygiene for all'

In this study, the team adapted the in-house methodology developed at University College London (UCL) (Fuso Nerini et al., 2018) for the sanitation sector. Using this structured process, the authors reviewed published evidence to identify linkages between sanitation, as defined above (Box 1), and all the Targets of the 2030 Agenda. The methodology followed a three step-process for each Target, which involved the following questions (see Figure 1 and Box 2):

- A. Does the Target call for action in relation to sanitation i.e. is an action required in the sanitation sector?
- B. Is there published evidence of synergies between the pursuit of the Target and achieving access to adequate, equitable and dignified sanitation and hygiene for all?
- C. Is there published evidence of trade-offs between the pursuit of the Target and achieving access to adequate, equitable and dignified sanitation and hygiene for all?

Using a structured process, the identification of linkages, i.e. call for action, synergies and trade-offs, was initially carried out through a blended approach whereby interdisciplinary pairs used their expertise and knowledge complemented by targeted literature searches to create an interdisciplinary evidence base. Following the method of Fuso Nerini et al. (2018), the authors considered at least one piece of published evidence per Target as verification of a synergy or a trade-off. The aim was to test the structured process and the application and replicability of the methodology to demonstrate the importance of sanitation in achieving the 2030 Agenda. In Step A, the authors explored and identified a linkage between sanitation and a Target to assess how improvements in sanitation would affect the Target in question. For Steps B and C, the team looked at reciprocal synergies and trade-offs between sanitation and all SDG targets. In all three steps, the published evidence considered was limited to academic studies and grey literature (e.g. UN reports) published in English. Sources used spanned urban planning, engineering, environment, health, social sciences and policy. The mapping identified existing evidence to indicate the types of synergies and trade-offs that have occurred in different contexts. Box 2 provides an illustrative example of how the methodology was applied for SDG 11.1.

In total, the team scanned over 500 publications. The results are presented in Appendix 1, which references 233 publications to support the identified calls for action, synergies and trade-offs for all 169 Targets. Each Target provides a short explanation of the identified linkages for questions A, B and C. The preliminary results were compiled in the tabulated worksheet (Appendix 1) and scrutinised and validated by all authors, cross-checked in the same pairs, and presented in a workshop with participation from development practitioners engaged in policy, academia and the delivery of sanitation globally¹. The tabulated worksheet was then finalised jointly by the authors based on feedback during the workshop. The team was unable to identify published evidence for one Target

¹ Workshop organised at Vitol Foundation in September 2019.

(15.8 alien species) with potential links with sanitation and were therefore not shown as having a synergistic relationship with sanitation (Appendix 1).

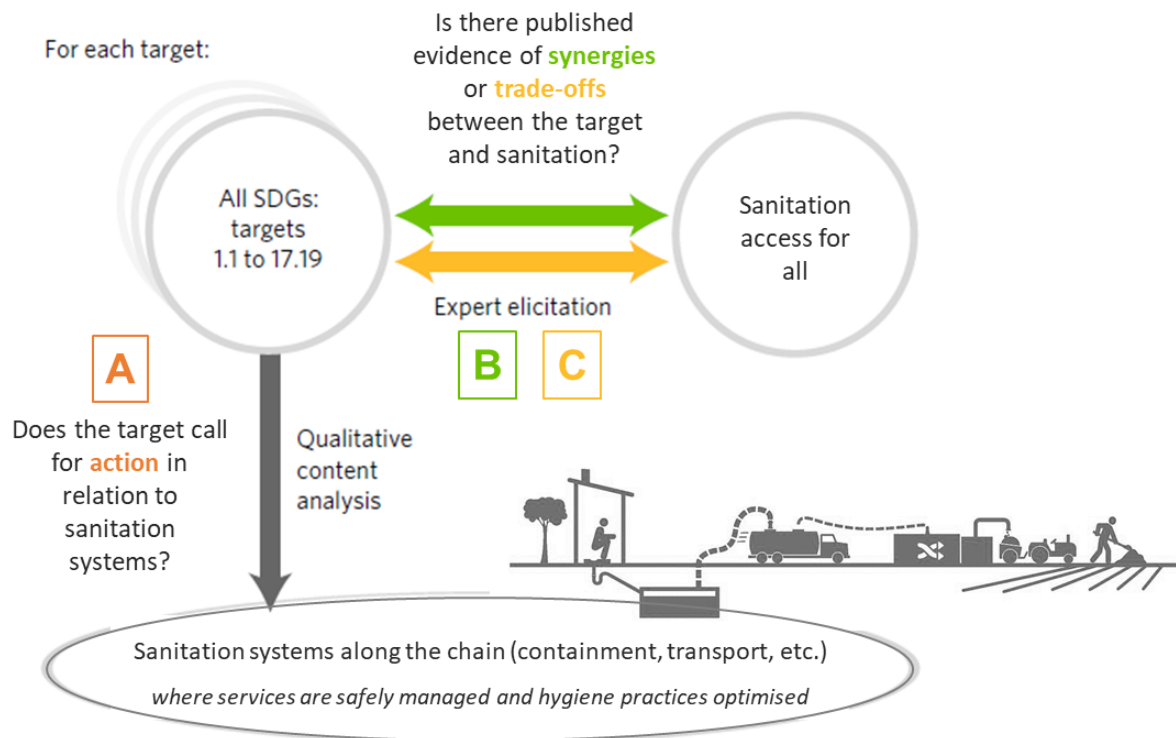


Figure 1: Methodology to assess the interlinkages between sanitation systems and the UN 2030 Agenda (adapted from Fuso Nerini et al., 2018)

Target 11.1 – Make cities and human settlements inclusive, safe, resilient and sustainable

Target 11.6: By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

Two co-authors discussed the call for action, potential synergy and trade-off and used expert knowledge to identify references included below and in Supplementary Table 1.

A) **Call for action:** Yes, there is a call for action in sanitation defined as a basic service, in order to provide services of containment, transport, treatment and safe disposal or re-use of excreta, and particularly in low-income areas which remain under-served or un-served (see for example Dodman et al., 2017).

B) **Synergies:** Yes, access to safe sanitation supports slum upgrading and delivers further benefits from knock-on impacts on housing stock (see for example Parikh et al., 2012).

C) **Trade-offs:** Yes, if upgrading solutions do not lead to adequate, equitable and dignified sanitation for communities and if there is a mismatch between sanitation interventions and individual aspirations (see for example Bartram et al., 2012).

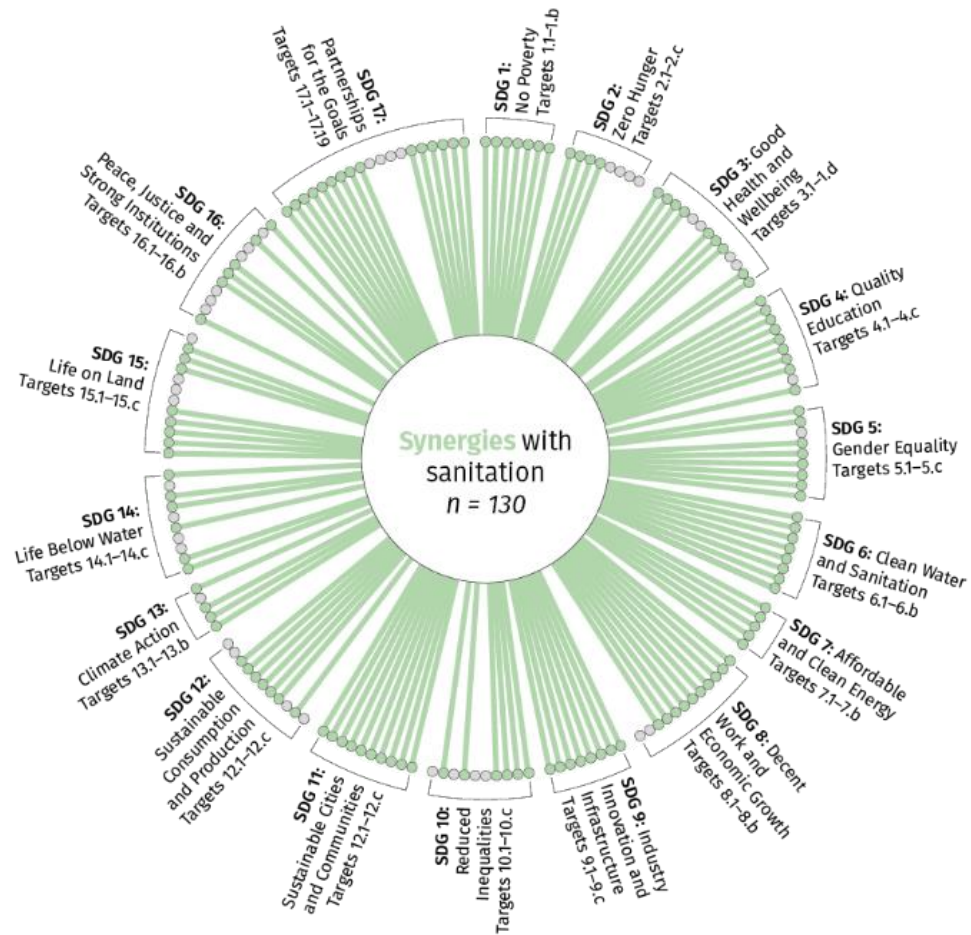
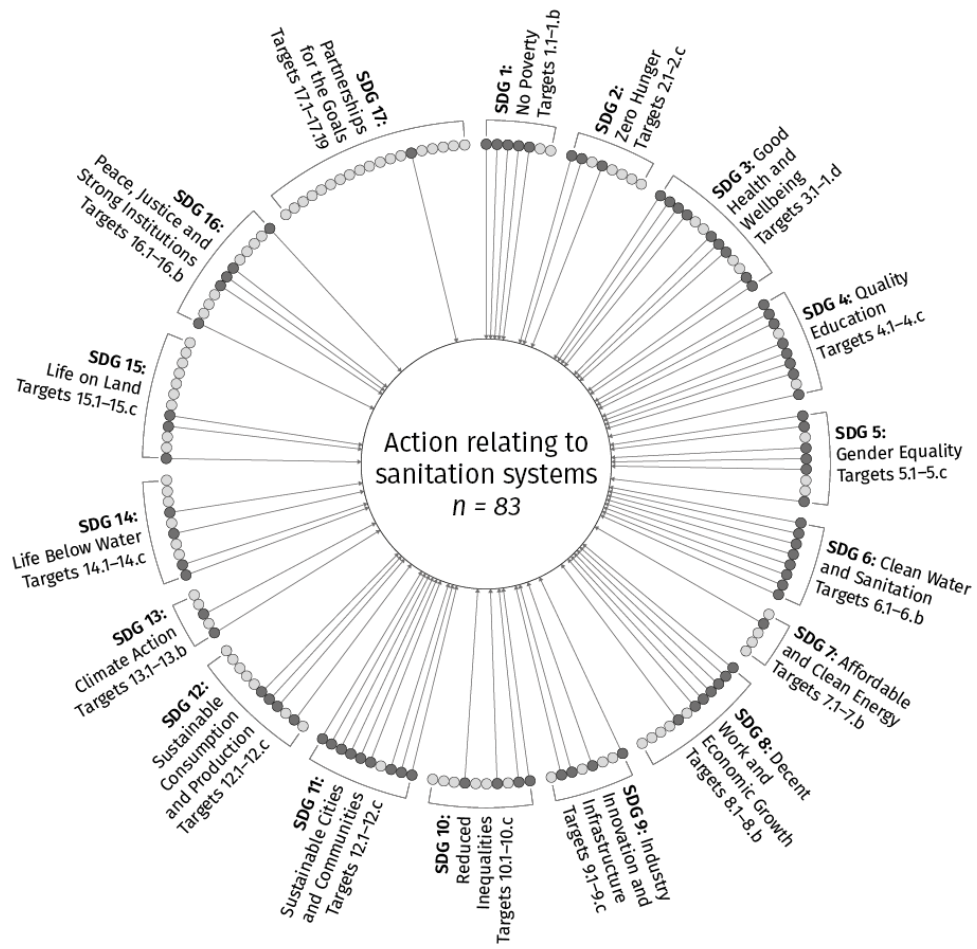
Box 2: Example of identified links (call for action in sanitation, synergies, trade-offs) between sanitation and an SDG target

To present the results of our study, all linkages identified have been clustered into four groups referred to as 'domains', which were drawn from the frameworks set by Fuso Nerini et al. (2018) and Waage

et al. (2015). The first group relates to Goals that seek outcomes of “individual and collective aspirations of greater welfare and wellbeing” (SDG1, SDG3, SDG4, SDG5, SDG10, SDG16). The second group “infrastructure services and innovation” concerns the development of systems of production, distribution and delivery of goods and services (SDG2, SDG6, SDG7, SDG8, SDG9, SDG11, SDG12). The third group refers to “the environment and natural resources” (SDG13, SDG14, SDG15). As in Waage et al. (2015), we categorise SDG17 on governance and partnerships separately and thereby frame it as a **distinct** domain that provides institutional mechanisms which are prerequisite for the delivery of the targets in groups 1, 2 and 3. As in Fuso Nerini et al. (2018), the identification of linkages at target level (in contrast to Waage et al., 2015 who established them at goal level) showed that similar linkages could exist between sanitation and more than one Target across different Goals.

Results

Our study identified linkages between sanitation and all 17 SDGs highlighting that action on sanitation supports delivery of the 2030 Agenda. Implementation of sustainable sanitation systems would contribute significantly to the achievement of all 17 goals at multiple levels - individual, household, community, society and environment. As shown in Figure 2, the assessment found 83 (49%) Targets requiring action to be taken concerning sanitation systems. Evidence of synergies and trade-offs were identified for 130 (77%) and 28 (17%) Targets respectively. The higher number of synergies as compared to trade-offs highlights the wide-ranging benefits of sanitation **can further be explained through** our working definition of sustainable and inclusive sanitation **which assumes** dignity for all, safe management along the service chain and zero harm to the environment. These are discussed below with reference to a few selected sources of published evidence with the complete results of the assessment reported in Appendix 1 and summarised in Figure 2. The linkages identified are presented below according to the four domains.



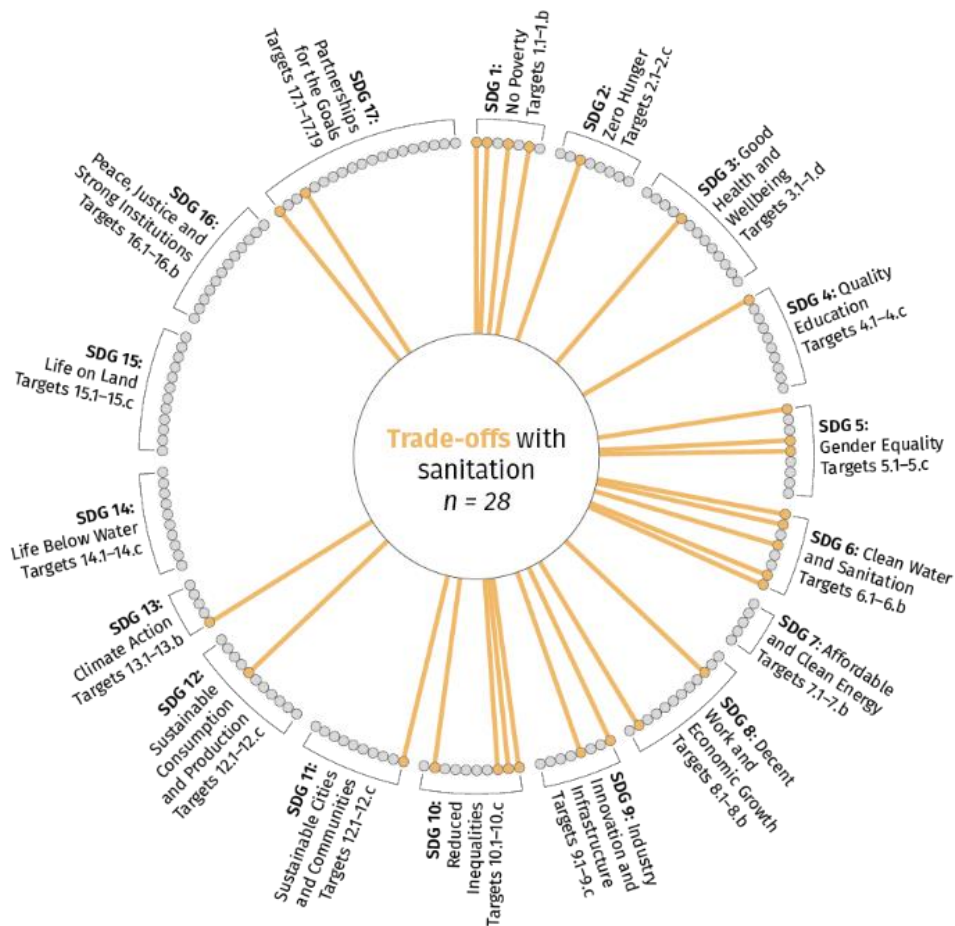


Figure 2: Wheel diagram showing SDGs “calling for action (Question A)”, synergies (Question B) and “trade-off (Question C)”. Diagram adapted from Fuso Nerini et al. (2018). The line represents an evidence call for action, synergy or trade-off and the dot represents each Target

1) Individual and collective aspirations of greater welfare and wellbeing

Nine of the 13 Targets of SDG3 (‘Good health and wellbeing’) call for action on sanitation systems. Among all linkages identified, we highlight that sanitation interventions are required to help reduce pathogen transmissions to eliminate maternal and neonatal mortality (Targets 3.1-2); mitigate stress for pregnant women vulnerable to premature deliveries (Target 3.4); and improve hygiene in healthcare services to promote inclusive access to services (Targets 3.8-9). Several studies confirm that reducing the number of deaths and illnesses caused by air, water and soil pollution depends on the safe disposal of human waste to prevent contamination (Target 3.9) (see for example, Cairncross and Valdmanis, 2006; Giusti, 2009; Montgomery and Elimelech, 2007). There is evidence that lack of access to sanitation is one of the factors leading to diarrhoea and can further reduce the ability to absorb/retain body nutrients leading to malnutrition, which also links to SDG2 (‘Zero Hunger’) (Freeman et al., 2017; Victora et al., 1986). It is important to note that the synergistic effects between action on sanitation and faecal-oral disease reduction are well-researched, but causal links are yet to be fully corroborated (Aiello and Larson, 2002; Norman, 2019). While evidence shows that action in sanitation alone cannot eliminate health issues, this study demonstrates multiple linkages between sanitation and individual and collective wellbeing which go well beyond health.

As sanitation initiatives often fail to target the most marginalised communities, the high cost burden of inadequate sanitation and poor hygiene **these groups subsequently** experience make a direct case for investment in sanitation to support SDG1 (‘No Poverty’) and SDG10 (‘Reduced Inequalities’). Safe sanitation can help safeguard health, thereby reduce medical costs, and can deliver additional benefits including time-savings, increased productivity, and contribute to income generation (Targets 1.1-2)

(Mara et al., 2010; Mehrotra et al., 2000). The combination of time saved as a result of safe sanitation access and associated cost savings can have multiplier effects for households where investment **enhances** sanitation **provision** at home (Parikh et al., 2012). Sanitation improvements are further central to promote social, economic and political inclusion, including that of migrants (Targets 10.2, 10.7) (DeVries and Rizo, 2015; Jobbins et al., 2018). However, trade-offs were also identified for three Targets (Targets 1.1-2, 1.A) highlighting how micro-financing structures need to be not only accessible but affordable in order to minimise the financial burden that sanitation investments can represent for households (Augsburg et al., 2015; Hofmann, 2018; Sinharoy et al., 2019).

While our study revealed multiple linkages between sanitation and SDG5 ('Gender Equality'), in practice, gender-inclusive sanitation has yet to be achieved at scale. Action in sanitation is **particularly urgent** where women and girls bear the brunt of poor infrastructure and services **with** inadequate access **having** a knock-on effect on their health, education, disposable income and time-savings (5.1, 5.4) (Parikh et al., 2015). Sanitation can support SDG5 as well as SDG16 ('Peace, Justice and Strong Institutions') regarding the need for safety, for example from the development of female-friendly toilets, especially where women and girls are exposed to harassment (Targets 5.2, 16.1) (Abrahams et al., 2006; Belur et al., 2017). There is evidence of the relationship between sanitation and taboos around sexual and reproductive health, and the way lack of access to menstrual hygiene management facilities can affect girls' school attendance, although further research is needed on this (Targets 5.1-2, 5.6) (Adukia, 2017; Sommer, 2010). This link re-emerges in SDG4 ('Quality Education'), which also presents linkages with sanitation through Water, Sanitation and Hygiene (WASH) and education (at school and elsewhere) (Target 4.3, 4.5) where action on both sides can positively reinforce each other. Several trade-offs were identified in relation to the forms of sanitation and hygiene education delivery, as stigmas (e.g. around menstruation) sometimes perpetuate where action overlooks the need for structural change both with teachers and students (SDG 4.1) (Johnston-Roblefo and Chrisler, 2013).

2) *Infrastructure services and innovation*

All Targets in SDG6 (water and sanitation) call for action in relation to the delivery of 'adequate and appropriate' sanitation and hygiene infrastructure and supporting service systems. There are also possible synergies with all SDG6 Targets, for example in the way treatment and safe disposal of human faeces and urine safeguards water systems (Targets 6.1, 6.3) (Grant et al., 2012; Haq and Cambridge, 2012). Integrated Water Resource Management (IWRM) can benefit sanitation through reclamation of water/use of wastewater (Target 6.4, 6.5) (Narain, 2002), surface water and aquifer conservation (Target 6.6) (Foster and Ait-Kadi, 2012). However, possible trade-offs within SDG6 occur with the promotion of particular sanitation systems (e.g. flush toilets) that are water-intensive and could impede water security, increase household expenses, and impact on water resources (Targets 6.1-2, 6.4) (Grant et al., 2012; Narain, 2002). This emphasises the need to challenge prevalent discourses where improved sanitation is associated with more water-intensive systems.

Sanitation development objectives are closely aligned with the food and energy sectors – SDG2 ('Zero Hunger') and SDG7 ('Affordable and Clean Energy') – due to the benefits of dealing with human waste as a resource for agricultural production (e.g. Targets 2.1-4 on treated wastewater used for irrigation, sewage sludge for farm productivity) and energy production (e.g. Targets 7.1-2 on human faeces valorisation for biogas production), but such practices are uncommon and typically small-scale and informal and require further evidence-building (Kramer et al., 2013; Lisansky, 1986). Synergies between sanitation and all Targets of SDG7 (Energy) **for which** no trade-offs were identified highlights that investment in sanitation would also benefit other forms of infrastructure that are critical for wellbeing (Kalt et al., 2019; Ortiz et al., 2017). The waste and energy nexus, for example, presents an opportunity to leverage investment across sectors and create multiple social and economic co-benefits (Klinghoffer et al., 2013). Our definition of sanitation assumes implementation of safe

systems covering the entire sanitation value chain, but there will be instances where unsafe disposal or reuse practices may lead to contamination of food and the environment. If such reuse and treatment options are not adequately implemented, this could lead to further contamination of water and soil and present a threat to human health (Grant et al., 2012; Hofmann, 2013). SDG9 ('Industry, Innovation and Infrastructure') also recognises the value of resource-efficient systems and emphasises the need for developing and upgrading sanitation infrastructure that enables the valorisation of excreta in closed-loop systems (Targets 9.1, 9.4, 9.a) (Andersson et al., 2016; Fangzhou et al., 2011).

SDG9 demands investment into innovation which in the sanitation sector could centre around innovative approaches to existing large-scale sanitation systems to include decentralised schemes. This can include green technologies but also ecological sanitation techniques, such as the development of green infrastructure for wastewater treatment (Targets 9.5, 9.b) (GSMA, 2017; Zhou et al., 2018). Also, on wastewater management, there are four targets under SDG12 ('Consumption and Production') calling for change in sanitation infrastructure to re-use waste and thereby reduce pressure on natural resources (Target 12.2, 12.4-6). We identified evidence for different types of synergies to safeguard ecosystems, for example where irrigation techniques or water-efficient toilets reduce the use of freshwater resources, and where the production of gas and electricity from faecal waste reduces pressure on fossil fuel reserves (Targets 7.2, 12.2, 12.5, 12.8) (Cordell et al., 2011; Euler and Aibeo, 2004; Fangzhou et al., 2011). Links between sanitation and SDG13 ('Climate Action') include infrastructural change. In parallel to actions seeking to safeguard pressure on water resources, we identify, for example, that integrated sanitation interventions require to block transmission paths and reduce infection risks in flood-prone areas (Target 13.1) (Howard et al., 2016; Kohlitz et al., 2017).

Our study confirms the fundamental role that sanitation has to play in supporting progress towards SDG11 ('Sustainable Cities and Communities') and SDG8 ('Decent Work and Economic Growth') as a basic service underpinning societal development. Sanitation has a vital role to play in protecting public health in cities as they expand rapidly (Targets 11.1, 11.3) (Bartram et al., 2012; Dodman et al., 2017; Parikh et al., 2012). Sanitation supports economic productivity (Targets 8.1-2) and eco-economic decoupling (Target 8.4) (Cole and Neumayer, 2006; Lüthi et al., 2010; Ramôa et al., 2016; Van Minh and Hung, 2011). Sanitation and SDG8 also link through entrepreneurship, creativity and innovation (SDG 9.3) as small and medium enterprises and research and development institutions play pivotal roles in the sanitation sector. However they face various institutional barriers such as access to affordable financing mechanisms and adequate infrastructure (Scott, Forte and Mazeau, 2017). Sanitation action is required to achieve universal 'decent work' (Targets 8.5-8), including for sanitation workers – and particularly informal workers involved in faecal sludge management – who are not protected by health and safety measures while they operate in marginalised environments. While efforts are growing to address this challenge they remain ad-hoc and fragmented (Cacouris, 2012; Chandler, 1994; World Bank et al., 2019).

3) Environment and natural resources

Sanitation has a crucial role to play in protecting environmental resources and relates to SDG14 ('Life Below Water') and SDG15 ('Life On Land') in two important ways: in reducing pollution to conserve ecosystems; and in enhancing ecosystem services through safe re-use of excreta. The latter is important, because the nutrient content of excreta benefits soils and aquatic systems. On reduced pollution, safer or no waste disposal into the environment requires considering the entire sanitation chain rather than adopting a narrow focus on toilets, which is not sufficient to address environmental contamination. We therefore identify the range of actions required where untreated sewage pollutes coastal and marine areas (Targets 14.1-2, 14.5) (Aronson et al., 2011; Shuval, 2003), as well as terrestrial and inland freshwater ecosystems (15.1-5) (UN-Water, 2016). On the re-use of excreta, published evidence has explored opportunities to restore degraded land and soils (15.2-5) (Bramryd,

2002; Simha and Ganesapillai, 2017; Zasoski et al., 1984), as well as to enrich water resources with nutrients (14.2, 14.7) (Bunting, 2004; Edwards, 1992). Studies on nature-based solutions have proposed a range of techniques supporting the achievement of objectives in both environmental conservation and sanitation service provision, for example through wetland conservation or the construction of artificial wetlands (15.1) (Koottatep et al., 2005; Metcalfe et al., 2018;).

Synergies were identified for several Targets in relation to ecosystem services and the livelihood opportunities they represent; for example, in aquaculture (Target 14.7) (Bunting, 2004; Hofmann, 2013; Mukherjee, 2020; Nhan et al., 2008), and in sustainable tourism (SDG 15.4) to limit the impact of the industry on ecosystems. Furthermore, the water, agricultural and energy sectors are concerned with pollution and waste management (Targets 2.1, 6.1, 6.3, 6.5-6, 7.a) (Narain, 2002; Newell et al., 2010; Niemczynowicz, 1999; Qadir et al., 2010), which is also an important issue tackled by SDG9 ('Industry, Innovation and Infrastructure') through Target 9.4 as mentioned in domain 2, and by SDG12 ('Responsible Consumption and Production') through Targets 12.2, 12.4-6 as mentioned in domain 3 (Andersson et al., 2016; Asano and Levine, 1996; Gensch, 2008). A potential trade-off was identified with Target 15.8 on invasive species as non-native species may be introduced with certain types of sanitation systems (e.g. introduction of alien species through faeces containing seeds), where human waste is applied on soils as a source of nutrients, although no published research was identified to support this.

There is evidence of synergies with integrated climate action reducing environmental contamination from spillage during natural disasters, including that of resilient sanitation infrastructure mentioned in domain 2 (13.1). Building awareness on risks and impacts of climate change on sanitation on-site systems will help the implementation of measures such as the timely emptying of pit latrines and septic tanks in emergency settings to limit environmental impacts (13.3) (Fewster, 2012; Howard et al., 2016). Recent research has explored the potential of off-site composting of human waste on the reduction of greenhouse gas emissions in the context of container-based sanitation systems in slums, thereby articulating the links between sanitation, climate change, the environment and basic services (13.b, 15.1, 11.1) (McNicol et al., 2020).

4) Governance and partnerships for the goals

There are multiple ways through which sanitation relates to the strengthening of institutional mechanisms (SDG17 'Partnerships for the Goals') that can support the achievement of the rest of the SDG Targets. On finance mobilisation and allocation (Targets 17.1-17.5), there is recognition that the poorest countries receive proportionately less Official Development Assistance (ODA) and that water and sanitation-related ODA is poorly targeted (Target 17.2) (Cotton and Bartram, 2008). Yet, ODA can sustainably support sanitation interventions on the ground as well as inform policy-making and regulations (Targets 17.2-5) (Cacouris, 2012; Cha et al., 2017; Goksu et al., 2017; Gopalan and Rajan, 2016; Newborne et al., 2012; World Water Council, 2018). Evidence of positive links between sanitation and SDG17 have also been identified in national policies and strategies which capitalise on their international relationships for exchange of sanitation-related information, knowledge, technology and finance (Targets 17.6-9) (Murphy et al., 2009).

Trade-offs may also exist where practices advocated by the international development community set the path for certain practices that do not match local level aspirations or overlook existing local activities (Khan, 2018). These trade-offs were also identified in other Goals since community needs and/or aspirations are not always reflected in national policy-contexts (for example for Targets 6.a, 12.7). Another trade-off relates to the potential of government taxes increasing the financial burden of households and preventing them from investing in sanitation (17.1). Besides, increasing taxes and revenues is not a guarantee that these are used to fund and sustain the expansion of sanitation

infrastructures across countries (UNICEF, 2016). Some of these challenges are related to the lack of additional finance to pay for sanitation systems that may be costlier than existing ones. Potentially stronger community participation through public-private-civil society partnerships could be a game-changer in the implementation of sanitation systems for which users are willing/able to pay (17.17, 5.5, 6.b, 11.3, 16.7) (Annamraju et al., 2001; Bisaga et al., 2015; Lamichhane and Babcock, 2013). For example, adapting existing sanitation systems to build climate resilience will require a combination of additional finance and will need deeper participation of the users (Oates et al. 2014).

At national-level, policy coherence remains an important challenge that requires stronger collaboration between **governmental** institutions (Target 17.14) (Georgeson and Maslin, 2018). **Beyond governments**, the formation of strategic multi-stakeholder partnerships will be crucial to achieve the successful planning and implementation of sanitation interventions, **including potential beneficiaries** (Targets 17.16-17) (Allen et al., 2017; ODI and FDC, 2003). **This is particularly relevant in the context of climate resilience (SDG13) in relation to sanitation services which need to be part of national policies and planning (Target 13.2), and within which community participation is critical (Target 13b). Yet, there is significant uncertainty around climate change impacts, and this means that today's investments may not result in climate resilient sanitation systems. Thus, important trade-offs may emerge during the development and adoption of adaptation strategies (Target 13.1). Establishing partnerships will require exploring a range of business models that bring together multiple actors, and building capacity to plan and implement projects collaboratively across levels (Targets 17.4-17.9).** High-quality, timely and reliable data management, including appropriate monitoring and evaluation systems will support the planning, implementation and measurement of progress for sanitation interventions (Targets 17.18-19) (Cotton and Bartram, 2008; Mason, Matoso and Smith, 2015).

Discussion and recommendations

Our structured review process demonstrates that sanitation action is required to achieve all 17 SDGs. We have identified evidence of synergies between sanitation and 130 Targets out of a total of 169 across the Goals. Synergies **exist** between sanitation and all Targets that consider inclusivity, social diversity and human wellbeing. **Hence**, cross-sectoral thinking will result in using resources more effectively, thereby encouraging collaboration and reducing conflict over resources. For example, inclusive sanitation services which embed menstrual hygiene and baby wash management have a direct link with targets in SDG3 and SDG5 that explicitly recognise the diverse needs of girls and women, new-borns and children and vulnerable populations such as the disabled. The rights and dignity of the workforce engaged in sanitation service provision is highlighted through links with SDG9 and SDG10. However, many of the identified trade-offs emphasise possible barriers to inclusive interventions due to conflicting objectives at various scales of action, especially where individual aspirations are overlooked by city, national or global-level strategic agendas. This is as much to do with policy design not taking into account contextual concerns, as it is with difficulties encountered with policy implementation. **While this study emphasises the need to strengthen governance systems for integrated and cross-sectoral action, this requires further efforts around contextual guidance and documentation which is a gap also identified by Scott et al. (2019).**

Due to the evidence-based methodology and structured process, our study was able to identify a higher number of linkages between sanitation and the SDG Targets compared to the 2017 SuSanA study referenced in the introduction (SuSanA, 2017), including less established ones. This concerns, for instance, evidence links between sanitation improvements and SDG10 on reduced inequalities (six Targets), and SDG4 on health such as the reduction of maternal mortality, the decrease in mortality from non-communicable diseases and the promotion of mental health and wellbeing (Hirve et al., 2015; Mishra et al., 2017; Padhi et al., 2015).

Wide-ranging and innovative solutions in the sanitation sector are required to achieve resource efficiency, reduction in environmental contamination and improved working conditions in low and middle-income countries, especially for those informally engaged in sanitation service delivery (Rush and Marshall, 2015). Meeting the principle of zero harm to the environment would require shifting the focus away from just the provision of toilets to inclusion of the entire sanitation value chain to include safe sanitation systems. In addition to reducing environmental risk such solutions would also negate associated health risks (diarrhoeal diseases etc). Much more than other forms of infrastructure, adaptation and scaling up of sanitation services are highly contingent on and heavily influenced by socio-cultural practices (Dittmer, 2009). **Hence, adopting participatory approaches and the integration of local population's knowledge to support decision-making would go some way to develop sanitation solutions which are socio-culturally acceptable.**

The synergies and trade-offs documented here are based on a high-level assessment of evidence globally which cuts across geographies, cultures and political contexts. **While the** global scope of our analysis highlights general implications for sustainable development of action in the sanitation sector it does not offer guidance regarding the degree to which these manifest in specific contexts. Context-specific reviews will be required for different types of sanitation systems to ensure proposed interventions are appropriate and locally relevant. Applying the methodology to concrete case studies **will help expand the evidence base established here.** Case studies can further help assess the suitability of various technical options for safe sanitation systems to local conditions, acceptance of safe sanitation solutions **along** the entire value chain **to** reduce environmental risk, **identify complex trade-offs in context,** and understand socio-cultural barriers to scale-up appropriate solutions. Evidence of the far-reaching impact of sanitation within countries will further provide opportunities to harmonise and leverage in-country investment for sanitation. This would support the development of guidelines and practical tools to enable diverse stakeholders to deliver safe and inclusive sanitation solutions appropriate for local contexts. **Context specific case studies could also include a cross-sectoral evaluation as policy makers often have to compare demands across before allocating limited resources.**

The following two sections **provide recommendations** specifically to decision-makers and practitioners involved in sanitation and related sectors regarding how to take the results of this study further. The third section offers suggestions for researchers to replicate this methodology and/or **expand the evidence base** on linkages between sanitation and the SDGs. **The recommendations combine our findings from the study as well as the above-mentioned workshop with development practitioners.**

To governmental institutions and policymakers: addressing the current institutional and financial fragmentation in sanitation provision will require holistic and integrated policies, underpinned by collaborative and participatory approaches. In most countries, sanitation services are included within public health or water resources ministries where there are multiple and conflicting demands on limited human and financial resources. Depending on the context, addressing the financing gap in sanitation requires either convergence of efforts across ministries or the creation of dedicated cross-sectoral nodal agencies to deliver meaningful sanitation outcomes. Current sanitation investments have been directed to the provision of physical infrastructure in the formal city and less focused on the delivery of services for low-income households and informal settlements (Hutchings et al., 2018). Universalisation of sanitation will require a shift towards **co-produced sanitation solutions** and inclusive decision-making policies and processes that include the voices of potential users, including marginalised groups (Burra et al., 2003; Hasan, 2006; McGranahan and Mitlin, 2016). **A range of actors are developing closed-loop systems which provide an opportunity for governmental institutions and policymakers to form inclusive and innovative partnerships.**

To practitioners (including funding institutions, private enterprises, INGOs/NGOs and community-based organisations): there is a need to expand evidence on cross-sectoral and multi-level governance collaboration. Practitioners can play an important role in supporting evidence-driven approaches by documenting and disseminating the impact of integrated sanitation interventions. This can be done with support from researchers and used to leverage further funding, in particular for regions and communities currently bypassed by investment. Financing institutions play a fundamental role in supporting the development and scaling-up of innovative solutions for the delivery of adequate, equitable and dignified sanitation interventions through harmonising funding streams to achieve the wide-ranging benefits of sanitation investments evidenced in this study. The private sector, NGOs and community-based organisations will be instrumental in adapting our framework as a participatory monitoring and evaluation tool which can be used to holistically consider impacts of sanitation interventions, socio-cultural factors, and acceptance of solutions.

To researchers: significant research is needed to analyse collaborative investment and intervention models to meet the SDGs. This is key to support practitioners whose resources are often limited to conduct such studies to develop documentation and expand the evidence base. It is crucial to apply the methodology set out in this study in a variety of contexts to build a compendium of case studies with research that reflects realities on the ground and that considers evidence in different languages and goes beyond what has already been published (e.g. verbal testimonies and unpublished data). Similar to Evans and Howard (2019), we argue this would support an enriched evidence base and help to substantiate the wide-ranging synergies between sanitation and the SDGs for a variety of socio-political settings. This requires research that embraces the principles of transdisciplinarity and knowledge co-production with active participation from multiple actors including policy actors and end-users to incorporate and embed knowledge in concrete political, geographical and socio-economic settings (Lang et al., 2012).

Conclusion

Sanitation as a sector suffers from under-investment of resources. For governments with limited resources, the ability to harmonise efforts across ministries would leverage funding from multiple programmes and initiatives and open the possibility to pitch for funding from sources beyond the traditional sectoral funders. Through the established linkages between sanitation and the 2030 Agenda, this research demonstrates the wide-ranging benefits of sanitation, which extend beyond health across multiple sectors. The identification of synergies locates areas where cross-sectoral thinking will result in using resources more effectively, thereby encouraging collaboration and reducing conflict over resources.

Current sanitation policies and investments bypass marginalised communities and groups, particularly poor women and children and those with disabilities, which in practice has meant that their access to services are deficient at best. A lack of targeted and inclusive policies and actions for those groups impedes progress towards achieving SDG6 and hence all SDGs. In addition, specifically in marginalised areas (informal settlements) knowledge gaps on socially and culturally acceptable technical solutions appropriate for various complex settings result in knowledge and policy gaps.

This study builds on the need to adopt holistic sanitation systems which consider the entire value chain from safe containment to transport, treatment, disposal and reuse of waste to broker wide reaching benefits and mitigate negative social and environmental impacts. Priority areas in sanitation research for the coming years include understanding and developing reuse and recovery technologies and practices to better integrate a sanitation chain that responds to the water-food-energy nexus.

Acceptance of solutions, such as reuse and recovery of human waste, will require acknowledgement of socio-cultural and environmental factors to achieve the direct and tangible impacts that sanitation can have on people and their communities. Shifting the focus away from toilet-centric approaches to a holistic system approach will not only minimise environment risk but would also lead to better health outcomes in terms of reduced morbidity and mortality.

The synergies identified in our study recognise issues where cross-sector thinking would result in more effective use of financial resources, enhanced collaboration, and reduced conflict in currently underserved settings. Notably, sanitation has a synergistic link with all or nearly all of the Targets of the Goals for poverty, education, gender, water, energy, industry/infrastructure, and cities; this highlights potential synergistic funding opportunities. Given the complexity of the SDGs and the need to integrate multifaceted issues, including climate change, urbanisation, population growth and pressure on environmental resources, experts from different disciplines will need to work together with diverse societal actors to break down traditional silos whilst considering both centralised and decentralised sanitation systems. **The methodology presented provides a mechanism that can expand our knowledge base to support the development of more holistic solutions bringing together research, practice and policy actors to create evidence-based policies and practices for integrated resource mobilisation and implementation. It paves the way for transdisciplinary research and practice that can foster inclusive and safe sanitation solutions for all through deeper explorations of context specific case studies.**

This research provides different stakeholders, including policymakers, funders, practitioners and researchers, with a **replicable** framework. This can advance knowledge and facilitate informed decision-making to enhance funding, planning and implementation of sanitation within transdisciplinary research and practice to achieve the 2030 Agenda. The evidence-base initiated here, **while limited in scope and requiring further expansion, can be used as a starting point to** leverage and harness investment in sanitation and other sectors to make a difference to the state of sanitation access and address the SDGs more effectively. Most importantly, this is a call for urgent action for everyone to change the status quo to ensure adequate, equitable and inclusive sanitation for all by 2030.

Funding

This research has been supported by the Vitol Foundation with in-kind contribution from University College London and led by UCL's Engineering for International Development Centre.

Conflict

No conflict of interest to declare.

Author Contributions:

PP led the study team, contributed to the development of the initial and adapted methodology and paper search exercise and data analysis and led the writing of the manuscript, LD led the evidence base paper search exercise and contributed to the development of the adapted methodology, data analysis, data capture and writing, PH and LCC contributed to the development of the adapted methodology, paper search exercise, data analysis, writing, JT and YM contributed to the development of initial and adapted methodology, paper search exercise, data analysis and writing, BM contributed to the development of the initial methodology, paper search exercise, data analysis and writing, TT and ML contributed to the development of the adapted methodology, paper search exercise, data analysis and writing. All authors helped to critique the output for intellectual content.

Acknowledgements

The team would like to acknowledge the support of Vitol Foundation without whom this study would have not been possible. We are grateful to all the participants of our multi-stakeholder workshop organised in September 2019 who provided valuable feedback on the study. Dr Priti Parikh who heads the Engineering for International Development Research Centre at UCL is supported through a BBOXX/Royal Academy of Engineering Senior Research Fellowship (Ref: RCSR1819\8\38). Loan Diep is supported by the UCL Urban Sustainability and Resilience Centre. Professor Lakhanpaul is supported by the National Institute for Health Research (NIHR) Biomedical Research Centre based at UCL Great Ormond Street Institute of Child Health/Great Ormond Street Hospital NHS Foundation Trust and the National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care (CLAHRC) North Thames at Bart's Health NHS Trust. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health and Social Care.'

References:

- Abrahams, N., Mathews, S., Ramela, P., 2006. Intersections of “sanitation, sexual coercion and girls” safety in schools’. *Trop. Med. Int. Heal.* 11, 751–756. <https://doi.org/10.1111/j.1365-3156.2006.01600.x>
- Adukia, A., 2017. Sanitation and education. *Am. Econ. J. Appl. Econ.* 9, 23–59. <https://doi.org/10.1257/app.20150083>
- Aiello, A.E., Larson, E.L., 2002. What is the evidence for a causal link between hygiene and infections? *Lancet Infect. Dis.* 2, 103–110. [https://doi.org/10.1016/S1473-3099\(02\)00184-6](https://doi.org/10.1016/S1473-3099(02)00184-6)
- Allen, A., Hofmann, P., Mukherjee, J., Walnycki, A., 2017. Water trajectories through non-networked infrastructure: insights from peri-urban Dar es Salaam, Cochabamba and Kolkata. *Urban Res. Pract.* 10, 22–42. <https://doi.org/10.1080/17535069.2016.1197306>
- Andersson, K., Dickin, S., Rosemarin, A., 2016. Towards “sustainable” sanitation: Challenges and opportunities in urban areas. *Sustain.* 8. <https://doi.org/10.3390/su8121289>
- Annamraju, S., Calaguas, B., Gutierrez, E., 2001. Financing water and sanitation: key issues in increasing resources to the sector, Water Aid briefing paper. London.
- Aronson, R.B., Thatje, S., McClintock, J.B., Hughes, K.A., 2011. Anthropogenic impacts on marine ecosystems in Antarctica. *Ann. N. Y. Acad. Sci.* 1223, 82–107. <https://doi.org/10.1111/j.1749-6632.2010.05926.x>
- Asano, T., Levine, A.D., 1996. Wastewater reclamation, recycling and reuse: Past, present, and future. *Water Sci. Technol.* 33, 1–14. [https://doi.org/10.1016/0273-1223\(96\)00401-5](https://doi.org/10.1016/0273-1223(96)00401-5)
- Augsburg, B., Caeyers, B., Oteiza, F., 2015. The costs and benefits of investing in a toilet: Views from Indian and Nigerian households and their policy implications, The Institute for Fiscal Studies.
- Bartram, J., Charles, K., Evans, B., O’hanlon, L., Pedley, S., 2012. Commentary on community-led total sanitation and human rights: Should the right to community-wide health be won at the cost of individual rights? *J. Water Health* 10, 499–503. <https://doi.org/10.2166/wh.2012.205>
- Belur, J., Parikh, P., Daruwalla, N., Joshi, R., Fernandes, R., 2017. Perceptions of gender-based violence around public toilets in Mumbai slums. *Int. J. Comp. Appl. Crim. Justice* 41, 63–78. <https://doi.org/10.1080/01924036.2016.1240094>
- Bernhardt, L.M., 2015. Water and sanitation in the 2030 Agenda for Sustainable Development: A linked agenda, in: *Water and Sanitation in the 2030 Agenda for Sustainable Development: A Linked Agenda*.
- Bisaga, I., Norman, G., Drabble, S., 2015. How can we influence municipal governments to allocate more money to sanitation? London.
- Bramryd, T., 2002. Impact of Sewage Sludge Application on the Long-Term Nutrient Balance in Acid Soils of Scots Pine (*Pinus Sylvestris*, L.) Forests. *Water. Air. Soil Pollut.* 140, 381–399. <https://doi.org/10.1023/1020142311652>
- Bunting, S.W., 2004. Wastewater aquaculture: perpetuating vulnerability or opportunity to enhance poor livelihoods? *Worlds. Poult. Sci. J.* 1, 51–75. <https://doi.org/10.1079/arc2004001>

- Burra, S., Patel, S., Kerr, T., 2003. Community-designed, built and managed toilet blocks in Indian cities. *Environ. Urban.* 15, 11–32. <https://doi.org/10.1177/095624780301500202>
- Cacouris, J., 2012. *Recognising and dealing with informal influences in water and sanitation services delivery.* London.
- Cairncross, S., Valdmanis, V., 2006. Water supply, sanitation and hygiene promotion, in: *Disease Control in Developing Countries.* The World Bank, Washington DC, pp. 771–792.
- Castor, J., Bacha, K., Fuso Nerini, F., 2020. SDGs in action: A novel framework for assessing energy projects against the sustainable development goals. *Energy Res. Soc. Sci.* 68, 101556. <https://doi.org/10.1016/j.erss.2020.101556>
- Cha, S., Mankadi, P.M., Elhag, M.S., Lee, Y., Jin, Y., 2017. Trends of improved water and sanitation coverage around the globe between 1990 and 2010: Inequality among countries and performance of official development assistance. *Glob. Health Action* 10. <https://doi.org/10.1080/16549716.2017.1327170>
- Chandler, T.D., 1994. Sanitation privatization and sanitation employees' wages. *J. Labor Res.* 15, 137–153. <https://doi.org/10.1007/BF02685726>
- Cole, M.A., Neumayer, E., 2006. The impact of poor health on total factor productivity. *J. Dev. Stud.* 42, 918–938. <https://doi.org/10.1080/00220380600774681>
- Cordell, D., Rosemarin, A., Schröder, J.J., Smit, A.L., 2011. Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. *Chemosphere* 84, 747–758. <https://doi.org/10.1016/j.chemosphere.2011.02.032>
- Cotton, A., Bartram, J., 2008. Sanitation: On- or off-track? Issues of monitoring sanitation and the role of the joint monitoring programme. *Waterlines* 27, 12–29. <https://doi.org/10.3362/1756-3488.2008.003>
- Dawes, J.H.P., 2020. Are the Sustainable Development Goals self-consistent and mutually achievable? *Sustain. Dev.* 28, 101–117. <https://doi.org/10.1002/sd.1975>
- DeVries, K., Rizo, A., 2015. Empowerment in action: savings groups improving community water, sanitation, and hygiene services. *Enterp. Dev. Microfinance* 26, 34–44. <https://doi.org/10.3362/1755-1986.2015.005>
- Dittmer, A., 2009. *Towards total sanitation: socio-cultural barriers and triggers to total sanitation in West Africa.*
- Dodman, D., Leck, H., Rusca, M., Colenbrander, S., 2017. African Urbanisation and Urbanism: Implications for risk accumulation and reduction. *Int. J. Disaster Risk Reduct.* 26, 7–15. <https://doi.org/10.1016/j.ijdrr.2017.06.029>
- Edwards, P.E.T., 1992. *Reuse of human wastes in aquaculture: a technical review.* Washington, D.C.
- Euler, H., Aibeo, P., 2004. Application of ecosan principles through public private partnership projects -prospects and limitations, in: Wener et al., C. (Ed.), *2nd International Symposium. IWA and GTZ, Eschborn.* <https://doi.org/10.1177/014572178401000201>
- Fader, M., Cranmer, C., Lawford, R., Engel-Cox, J., 2018. Toward an understanding of synergies and trade-offs between water, energy, and food SDG targets. *Front. Environ. Sci.* 6.

<https://doi.org/10.3389/fenvs.2018.00112>

Fangzhou, D., Zhenglong, L., Shaoqiang, Y., Beizhen, X., Hong, L., 2011. Electricity generation directly using human feces wastewater for life support system. *Acta Astronaut.* 68, 1537–1547. <https://doi.org/10.1016/j.actaastro.2009.12.013>

Fewster, E., 2012. Resilient WASH systems in flood-prone areas; Techniques to improve the resilience of community WASH systems in flood-prone areas.

Foster, S., Ait-Kadi, M., 2012. Integrated Water Resources Management (IWRM): How does groundwater fit in? *Hydrogeol. J.* 20, 415–418. <https://doi.org/10.1007/s10040-012-0831-9>

Freeman, M.C., Garn, J. V., Sclar, G.D., Boisson, S., Medlicott, K., Alexander, K.T., Penakalapati, G., Anderson, D., Mahtani, A.G., Grimes, J.E.T., Rehfuess, E.A., Clasen, T.F., 2017. The impact of sanitation on infectious disease and nutritional status: A systematic review and meta-analysis. *Int. J. Hyg. Environ. Health* 220, 928–949. <https://doi.org/10.1016/j.ijheh.2017.05.007>

Fuso Nerini, F., Sovacool, B., Hughes, N., Cozzi, L., Cosgrave, E., Howells, M., Tavoni, M., Tomei, J., Zerriffi, H., Milligan, B., 2019. Connecting climate action with other Sustainable Development Goals. *Nat. Sustain.* 2, 674–680. <https://doi.org/10.1038/s41893-019-0334-y>

Fuso Nerini, F., Tomei, J., To, L.S., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Castán Broto, V., Anandarajah, G., Milligan, B., Mulugetta, Y., 2018. Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nat. Energy* 3, 10–15. <https://doi.org/10.1038/s41560-017-0036-5>

Gensch, R., 2008. Agriculture and sanitation. *Urban Agric.* 20, 38–40.

Georgeson, L., Maslin, M., 2018. Putting the United Nations Sustainable Development Goals into practice: A review of implementation, monitoring, and finance. *Geo Geogr. Environ.* 5, 1–25. <https://doi.org/10.1002/geo2.49>

Gibson, L., Yamakoshi, B., Burgers, L., Alleman, P., 2019. *Menstrual Health and Hygiene* 93.

Giusti, L., 2009. A review of waste management practices and their impact on human health. *Waste Manag.* 29, 2227–2239. <https://doi.org/10.1016/j.wasman.2009.03.028>

Goksu, A., Trémolet, S., Kolker, J., Kingdom, B., 2017. *Easing the Transition to Commercial Finance for Sustainable Water and Sanitation.* Washington DC.

Gopalan, S., Rajan, R.S., 2016. Has Foreign Aid Been Effective in the Water Supply and Sanitation Sector? Evidence from Panel Data. <https://doi.org/10.1016/j.worlddev.2016.04.010>

Grant, S.B., Saphores, J.-D., Feldman, D.L., Hamilton, A.J., Fletcher, T.D., Cook, P.L.M., Stewardson, M., Sanders, B.F., Levin, L.A., Ambrose, R.F., Deletic, A., Brown, R., Jiang, S.C., Rosso, D., Cooper, W.J., Marusic, I., 2012. Taking the “Waste” Out of “Wastewater” for Human Water Security and Ecosystem Sustainability. *Science* (80-.). 337, 681–686. <https://doi.org/10.1126/science.1216852>

GSMA, 2017. *Loowatt: Digitising the container-based sanitation value chain in Madagascar.*

Haq, G., Cambridge, H., 2012. Exploiting the co-benefits of ecological sanitation. *Curr. Opin. Environ. Sustain.* 4, 431–435. <https://doi.org/10.1016/j.cosust.2012.09.002>

- Hasan, A., 2006. Orangi Pilot Project: the expansion of work beyond Orangi and the mapping of informal settlements and infrastructure. *Environ. Urban.* 18, 451–480. <https://doi.org/10.1177/0956247806069626>
- Hirve, S., Lele, P., Sundaram, N., Chavan, U., Weiss, M., Steinmann, P., Juvekar, S., 2015. Psychosocial stress associated with sanitation practices: Experiences of women in a rural community in India. *J. Water Sanit. Hyg. Dev.* 5, 115–126. <https://doi.org/10.2166/washdev.2014.110>
- Hofmann, P., 2018. The dialectics of urban water poverty trajectories: policy- driven and everyday practices in Dar es Salaam. University College London.
- Hofmann, P., 2013. Wasted waste —Disappearing reuse at the peri-urban interface. *Environ. Sci. Policy* 31, 13–22. <https://doi.org/10.1016/j.envsci.2013.03.011>
- Howard, G., Calow, R., Macdonald, A., Bartram, J., 2016. Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. *Annu. Rev. Environ. Resour.* 41, 253–276. <https://doi.org/10.1146/annurev-environ-110615-085856>
- Hutchings, P., Johns, M., Jornet, D., Scott, C., Van den Bossche, Z., 2018. A systematic assessment of the pro-poor reach of development bank investments in urban sanitation. *J. Water Sanit. Hyg. Dev.* 8, 402–414. <https://doi.org/10.2166/washdev.2018.147>
- Jobbins, G., Langdown, I., Bernard, G., 2018. Water and sanitation, migration and the 2030 Agenda for Sustainable Development. London.
- Johnston-Robledo, I., Chrisler, J.C., 2013. The Menstrual Mark: Menstruation as Social Stigma. *Sex Roles* 68, 9–18. <https://doi.org/10.1007/s11199-011-0052-z>
- Kalt, G., Wiedenhofer, D., Görg, C., Haberl, H., 2019. Conceptualizing energy services: A review of energy and well-being along the Energy Service Cascade. *Energy Res. Soc. Sci.* 53, 47–58. <https://doi.org/10.1016/j.erss.2019.02.026>
- Khan, S., 2018. Swachh Bharat Mission (Urban): Needs vs Planning. New Delhi. <https://doi.org/10.13140/RG.2.2.10084.27527>
- Klinghoffer, N.B., Themelis, N.J., Castaldi, M.J., 2013. Waste to energy (WTE): an introduction, in: *Waste to Energy Conversion Technology*. Elsevier, pp. 3–14. <https://doi.org/10.1533/9780857096364.1.3>
- Kohlitz, J.P., Chong, J., Willetts, J., 2017. Climate change vulnerability and resilience of water, sanitation, and hygiene services: A theoretical perspective. *J. Water Sanit. Hyg. Dev.* 7, 181–195. <https://doi.org/10.2166/washdev.2017.134>
- Koottatep, T., Surinkul, N., Polprasert, C., Kamal, A.S.M., Koné, D., Montangero, A., Heinss, U., Strauss, M., 2005. Treatment of septage in constructed wetlands in tropical climate: lessons learnt from seven years of operation. *Water Sci. Technol.* 51, 119–126. <https://doi.org/10.2166/wst.2005.0301>
- Kramer, S., Preneta, N., Kilbride, A., 2013. Thermophilic composting of human wastes in uncertain urban environments: A case study from Haiti, in: *36th WEDC International Conference: Delivering Water, Sanitation and Hygiene Services in an Uncertain Environment*. WEDC, Nakuru, pp. 1–6.
- Lamichhane, K.M., Babcock, R.W., 2013. Survey of attitudes and perceptions of urine-diverting

- toilets and human waste recycling in Hawaii. *Sci. Total Environ.* 443, 749–756.
<https://doi.org/10.1016/j.scitotenv.2012.11.039>
- Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustain. Sci.* 7, 25–43. <https://doi.org/10.1007/s11625-011-0149-x>
- Lisansky, J., 1986. Farming in an Urbanizing Environment: Agricultural Land Use Conflicts and Right to Farm. *Hum. Organ.* 45, 363–371. <https://doi.org/10.17730/humo.45.4.671438400n604680>
- Lüthi, C., McConville, J., Norström, A., Panesar, A., Ingle, R., Saywell, D., Schütze, T., 2010. Rethinking Sustainable Sanitation for the Urban Domain, Proceedings of the Water Environment Federation. <https://doi.org/10.2175/193864710798285363>
- MacRae, E.R., Clasen, T., Dasmohapatra, M., Caruso, B.A., 2019. “It’s like a burden on the head”: Redefining adequate menstrual hygiene management throughout women’s varied life stages in Odisha, India. *PLoS One* 14, e0220114. <https://doi.org/10.1371/journal.pone.0220114>
- Maes, M.J.A., Jones, K.E., Toledano, M.B., Milligan, B., 2019. Mapping synergies and trade-offs between urban ecosystems and the sustainable development goals. *Environ. Sci. Policy* 93, 181–188. <https://doi.org/10.1016/j.envsci.2018.12.010>
- Mara, D., Evans, B., 2018. The sanitation and hygiene targets of the sustainable development goals: Scope and challenges. *J. Water Sanit. Hyg. Dev.* 8, 1–16.
<https://doi.org/10.2166/washdev.2017.048>
- Mara, D., Lane, J., Scott, B., Trouba, D., 2010. Sanitation and health. *PLoS Med.* 7.
<https://doi.org/10.1371/journal.pmed.1000363>
- Mason, N., Matoso, M., Smith, W., 2015. Private sector and water supply, sanitation and hygiene.
- McCullum, D.L., Echeverri, L.G., Busch, S., Pachauri, S., Parkinson, S., Rogelj, J., Krey, V., Minx, J.C., Nilsson, M., Stevance, A.S., Riahi, K., 2018. Connecting the sustainable development goals by their energy inter-linkages. *Environ. Res. Lett.* 13. <https://doi.org/10.1088/1748-9326/aaafe3>
- McGranahan, G., Mitlin, D., 2016. Learning from Sustained Success: How Community-Driven Initiatives to Improve Urban Sanitation Can Meet the Challenges. *World Dev.* 87, 307–317.
<https://doi.org/10.1016/j.worlddev.2016.06.019>
- McNicol, G., Jeliazovski, J., François, J.J., Kramer, S., Ryals, R., 2020. Climate change mitigation potential in sanitation via off-site composting of human waste. *Nat. Clim. Chang.* 10, 545–549.
<https://doi.org/10.1038/s41558-020-0782-4>
- Mehrotra, S., Vandermoortele, J., Delamonica, E., 2000. Basic Services for All? Public Spending and the Social Dimensions of Poverty, United Nations Children’s Fund Innocenti Research Centre. Florence.
- Metcalfe, C.D., Nagabhatla, N., Fitzgerald, S.K., 2018. Multifunctional wetlands: pollution abatement by natural and constructed wetlands, in: *Multifunctional Wetlands*. Springer, Cham.
- Mishra, S.R., Dhimal, M., Bhandari, P.M., Adhikari, B., 2017. Sanitation for all: the global opportunity to increase transgenerational health gains and better understand the link between NCDs and NTDs, a scoping review. *Trop. Dis. Travel Med. Vaccines* 3, 1–7.
<https://doi.org/10.1186/s40794-017-0051-3>

- Montgomery, M.A., Elimelech, M., 2007. Water and Sanitation in Developing Countries: Including health in the Equation. *Environ. Sci. Technol.* 41, 17–24. <https://doi.org/10.1021/es072435t>
- Mukherjee, J., 2020. *Blue Infrastructures*. Springer, Singapore. https://doi.org/10.1007/978-981-15-3951-0_4
- Murphy, H.M., McBean, E.A., Farahbakhsh, K., 2009. Appropriate technology – A comprehensive approach for water and sanitation in the developing world. *Technol. Soc.* 31, 158–167. <https://doi.org/10.1016/j.techsoc.2009.03.010>
- Narain, S., 2002. The flush toilet is ecologically mindless: Think about it. *Down to Earth* 10, 1–14.
- Newborne, P., Tucker, J., Bayliss, K., 2012. Strengthening pro-poor targeting of investments by African utilities in urban water and sanitation - the role of the International Development Association of the World Bank, Water Aid. London.
- Newell, D.G., Koopmans, M., Verhoef, L., Duizer, E., Aidara-Kane, A., Sprong, H., Opsteegh, M., Langelaar, M., Threfall, J., Scheutz, F., der Giessen, J. van, Kruse, H., 2010. Food-borne diseases - The challenges of 20 years ago still persist while new ones continue to emerge. *Int. J. Food Microbiol.* 139, S3–S15. <https://doi.org/10.1016/j.ijfoodmicro.2010.01.021>
- Ngure, F.M., Reid, B.M., Humphrey, J.H., Mbuya, M.N., Pelto, G., Stoltzfus, R.J., 2014. Water, sanitation, and hygiene (WASH), environmental enteropathy, nutrition, and early child development: Making the links. *Ann. N. Y. Acad. Sci.* 1308, 118–128. <https://doi.org/10.1111/nyas.12330>
- Nhan, D.K., Verdegem, M.C.J., Binh, N.T., Duong, L.T., Milstein, A., Verreth, J.A.J., 2008. Economic and nutrient discharge tradeoffs of excreta-fed aquaculture in the Mekong Delta, Vietnam. *Agric. Ecosyst. Environ.* 124, 259–269. <https://doi.org/10.1016/j.agee.2007.10.005>
- Niemczynowicz, J., 1999. Urban hydrology and water management – present and future challenges. *Urban Water* 1, 1–14. [https://doi.org/10.1016/S1462-0758\(99\)00009-6](https://doi.org/10.1016/S1462-0758(99)00009-6)
- Nilsson, M., Griggs, D., Visbeck, M., 2016. Map the interactions between Sustainable Development Goals. *Nature* 534, 320–322. <https://doi.org/10.1038/534320a>
- Norman, G., 2019. Does improved sanitation mean healthier kids? [WWW Document]. *Water Sanit. Urban Poor*. URL <https://www.wsup.com/blog/does-improved-sanitation-mean-healthier-kids/> (accessed 10.22.19).
- ODI, FDC, 2003. *Multi-Stakeholder Partnerships Issue Paper Pulling together to uplift and empower the world*. Kuala Lumpur.
- Ortiz, M.A., Kurvers, S.R., Bluysen, P.M., 2017. A review of comfort, health, and energy use: Understanding daily energy use and wellbeing for the development of a new approach to study comfort. *Energy Build.* 152, 323–335. <https://doi.org/10.1016/j.enbuild.2017.07.060>
- Padhi, B.K., Baker, K.K., Dutta, A., Cumming, O., Freeman, M.C., Satpathy, R., Das, B.S., Panigrahi, P., 2015. Risk of adverse pregnancy outcomes among women practicing poor sanitation in rural India: A population-based prospective cohort study. *PLoS Med.* 12, 1–18. <https://doi.org/10.1371/journal.pmed.1001851>
- Parikh, P., Fu, K., Parikh, H., McRobie, A., George, G., 2015. Infrastructure Provision, Gender, and Poverty in Indian Slums. *World Dev.* 66, 468–486.

<https://doi.org/10.1016/j.worlddev.2014.09.014>

- Parikh, P., Parikh, H., Mrobie, A., 2012. The role of infrastructure in improving human settlements. *Proc. Inst. Civ. Eng. Urban Des. Plan.* 166, 101–118. <https://doi.org/10.1680/udap.10.00038>
- Pradhan, P., Costa, L., Rybski, D., Lucht, W., Kropp, J.P., 2017. A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Futur.* 5, 1169–1179. <https://doi.org/10.1002/2017EF000632>
- Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P.G., Drechsel, P., Bahri, A., Minhas, P.S., 2010. The challenges of wastewater irrigation in developing countries. *Agric. Water Manag.* 97, 561–568. <https://doi.org/10.1016/j.agwat.2008.11.004>
- Ramôa, A., Lüthi, C., McConville, J., Matos, J., 2016. Urban sanitation technology decision-making in developing countries: a critical analysis of process guides. *Int. J. Urban Sustain. Dev.* 8, 191–209. <https://doi.org/10.1080/19463138.2016.1186674>
- Rush, H., Marshall, N., 2015. Case Study: Innovation in Water, Sanitation and Hygiene. 1–62.
- Sachs, J., Schmidt-Traub, G., Kroll, C., Lafortune, G., Fuller, G., 2019. Sustainable Development Report 2019. New York.
- Scott, P., Forte, J., Mazeau, A., 2017. Barriers and opportunities for sanitation SMEs: A study of the wider market system in Ghana. London.
- Scott, R., Scott, P., Hawkins, P., Blackett, I., Cotton, A., Lerebours, A., 2019. Integrating basic urban services for better sanitation outcomes. *Sustainability* 11, 1–17. <https://doi.org/10.3390/su11236706>
- Shuval, H., 2003. Estimating the global burden of thalassogenic diseases: Human infectious diseases caused by wastewater pollution of the marine environment. *J. Water Health* 1, 53–64. <https://doi.org/10.2166/wh.2003.0007>
- Simha, P., Ganesapillai, M., 2017. Ecological Sanitation and nutrient recovery from human urine: How far have we come? A review. *Sustain. Environ. Res.* 27, 107–116. <https://doi.org/10.1016/j.serj.2016.12.001>
- Singh, G.G., Cisneros-Montemayor, A.M., Swartz, W., Cheung, W., Guy, J.A., Kenny, T.A., McOwen, C.J., Asch, R., Geffert, J.L., Wabnitz, C.C.C., Sumaila, R., Hanich, Q., Ota, Y., 2018. A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals. *Mar. Policy* 93, 223–231. <https://doi.org/10.1016/j.marpol.2017.05.030>
- Sinharoy, S.S., Pittluck, R., Clasen, T., 2019. Review of drivers and barriers of water and sanitation policies for urban informal settlements in low-income and middle-income countries. *Util. Policy* 60, 100957. <https://doi.org/10.1016/j.jup.2019.100957>
- Sommer, M., 2010. Putting menstrual hygiene management on to the school water and sanitation agenda. *Waterlines* 29, 268–278. <https://doi.org/10.3362/1756-3488.2010.030>
- SuSanA, 2017. Sustainable sanitation and the SDGs: interlinkages and opportunities, Sustainable Sanitation Alliance Knowledge Hub.
- SuSanA, 2008. Towards more sustainable sanitation solutions - SuSanA Vision Document.

- Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., O'Regan, N., Rozenberg, J., Watkins, G., Hall, J.W., 2019. Infrastructure for sustainable development. *Nat. Sustain.* 2, 324–331. <https://doi.org/10.1038/s41893-019-0256-8>
- Thomas, S., Gambrill, M., Gilsdorf, R.J., Diagne, N.A., 2018. 3 hard truths about the global sanitation crisis [WWW Document]. *World Bank Blogs*. URL <https://blogs.worldbank.org/water/3-hard-truths-about-global-sanitation-crisis> (accessed 11.11.19).
- UN-Water, 2016. *Towards a Worldwide Assessment of Freshwater Quality: a UN-Water Analytical Brief*, UN-Water Analytical Brief. Geneva. <https://doi.org/10.1177/0891988715606233>
- UN Water, 2016. *Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development* 48.
- UNICEF, 2016. *Water and Sanitation Budget Brief*.
- UNICEF, WHO, 2019. *Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities*, Main report *Progress on Drinking Water, Sanitation and Hygiene*. New York.
- United Nations, 2015. *Transforming our world: the 2030 Agenda for Sustainable Development*, A/RES/70/1. <https://doi.org/10.1201/b20466-7>
- Van Minh, H., Hung, N.V., 2011. Economic Aspects of Sanitation in Developing Countries. *Environ. Health Insights* 5, 63–70. <https://doi.org/10.4137/EHI.S8199>
- Victora, C.G., Vaughan, J.P., Kirkwood, B.R., Martines, J.C., Barcelos, L.B., 1986. Risk factors for malnutrition in Brazilian children: The role of social and environmental variables. *Bull. World Health Organ.* 64, 299–309.
- Waage, J., Yap, C., Bell, S., Levy, C., Mace, G., Pegram, T., Unterhalter, E., Dasandi, N., Hudson, D., Kock, R., Mayhew, S., Marx, C., Poole, N., 2015. Governing the UN sustainable development goals: Interactions, infrastructures, and institutions. *Lancet Glob. Heal.* 3, e251–e252. [https://doi.org/10.1016/S2214-109X\(15\)70112-9](https://doi.org/10.1016/S2214-109X(15)70112-9)
- World Bank, ILO, WaterAid, WHO, 2019. *Health, Safety and Dignity of Sanitation Workers: An Initial Assessment*. World Bank, Washington, DC. <https://doi.org/10.1596/32640>
- World Health Organization, 2018. *Sanitation* [WWW Document]. URL <https://www.who.int/topics/sanitation/en/> (accessed 12.2.18).
- World Water Council, 2018. *Increasing Financial Flows for Urban Sanitation*. Marseille.
- Zasoski, R., Edmonds, R., Bledsoe, C., Henry, C., Vogt, D., Vogt, K., Cole, D., 1984. Municipal sewage sludge use in forests of the pacific northwest, U.S.A.: Environmental concerns. *Waste Manag. Res.* 2, 227–246. [https://doi.org/10.1016/0734-242X\(84\)90029-6](https://doi.org/10.1016/0734-242X(84)90029-6)
- Zhou, X., Li, Z., Zheng, T., Yan, Y., Li, P., Odey, E.A., Mang, H.P., Uddin, S.M.N., 2018. Review of global sanitation development. *Environ. Int.* 120, 246–261. <https://doi.org/10.1016/j.envint.2018.07.047>