SUMMARY REPORT

CHARACTERIZING NON-TECHNICAL BARRIERS FOR ON-SITE ALTERNATIVE WATER SYSTEMS

An overview of findings from peer-reviewed literature

March 2021

What do we know about on-site alternative water systems?

Urbanization, climate change and depletion of natural resources increasingly challenge the conventional paradigm of centralized water supply, treatment, and reuse [1–3]. There is growing evidence that addressing key challenges for urban water management requires more flexible, modular, decentralized or small-grid water systems that are implemented in parallel with or as a substitute to expansive sewer-based systems [3,4]; referred to here as on-site alternative water systems.

The term on-site is defined by Sharvelle et al. (2017) as systems where "local sources of water (e.g., roof runoff, stormwater, graywater, and wastewater) are collected, treated, and reused at the building, neighborhood, and/or district scale, generally at a location near the point of generation of the source of water" [5]. While initial adoption has begun [6–8], cities have encountered various non-technical challenges in adopting and diffusing on-site reuse technologies [9–12], such as risk aversion due to the risk to public health, lack of legitimacy and user acceptance, and challenges in creating new governance frameworks that clarify different actor's roles in designing, installing, and operating on-site reuse systems.

These challenges are an inherent part of the transition process. In the same way that centralized water and wastewater utilities have established actors, roles, regulation, and buy-in from end users and the public in the past, a fitting institutional support structure needs to be developed for on-site alternative water systems.

Existing work has addressed this issue using a variety of different perspectives. Case studies around the world have looked at institutional support structures for different types of recovery, such as stormwater capture [13–17]. greywater reuse [5,9,18–21], reuse of the full wastewater stream [22–26], and source separation [27–31], The academic article associated with this summary report pulled together the wealth of knowledge scattered in different types of literature within a conceptual framework designed to present a more organized approach for what is need for successful transitions. Based on work done on enabling environments for urban water management [32,33] and technological innovation systems [34], different dimensions were combined in one holistic framework (see figure 1). A new governance system is needed for adoption of any on-site alternative water system, and six components were identified as necessary conditions for successful implementation: equity, financial investment, knowledge and capabilities, legal and regulatory frameworks, legitimacy, and market structures [35–41].

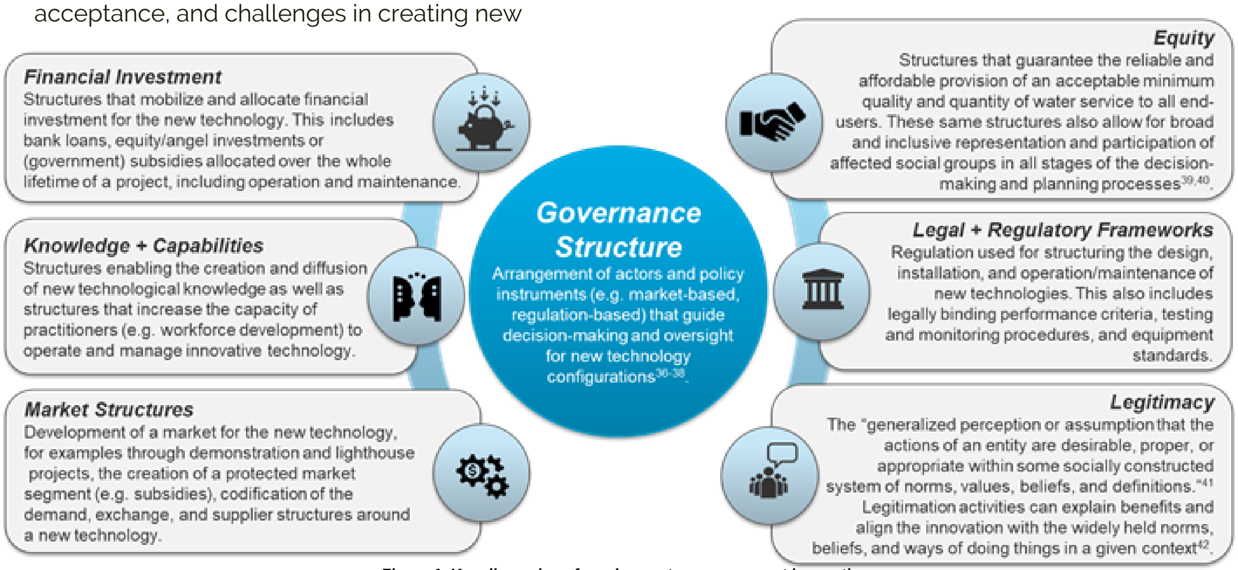

Figure 1. Key dimensions for urban water management innovation.

This summary is based off of recently published work in Environmental Science and Technology: **https://doi.org/10.1021/acs.est.0c07947**

Global reach of on-site alternative water systems

A systematic review of over 350 articles shows that about two thirds of peer-reviewed literature on on-site alternative water systems in urban areas focus on developed economies (mostly in Australia, the USA, Spain, Germany, the United Kingdom, and Sweden). One third focus on developing and emerging economies (mostly China, India, and South Africa). Of these studies, only a small handful mention socio-technical challenges, which we focused on in more detail.

Not all on-site systems experience the same institutional hurdles: a breakdown

Figure 2 shows the results of an in-depth coding of 39 articles that dealt most deeply with non-technical challenges for on-site alternative water systems in an urban context. Relevant challenges differed systematically between types of configurations.

Challenges for **stormwater capture** mostly revolve around financial issues, like the initial cost for installation and finding a way to incentivize end users. In some cases, there has been enthusiasm for rainwater harvesting, but building owners were constrained by existing regulations. For example, it was illegal for a period to capture rainwater on-site in Colorado (USA) [42] and building owners in the City of Johannesburg (South Africa) needed to obtain permission before installation [16], creating additional administrative hurdles.

Greywater systems for non-potable use still lack widely accepted definitions and standardized regulations. For example, systems recycling greywater for indoor purposes might be subject to different requirements than outdoor purposes. Similarly, the scale of the system (e.g., building vs. district) can also affect the challenges encountered [5]. These nuanced aspects to system design required tailored regulation. Regulations for on-site greywater recycling can be constrained by existing regulations and market structures developed for centralized systems, highlighting the need for more flexible and tailored regulations and financial incentive/pricing structures. Efforts have been taken to address these challenges. For example, in the United States, the National Blue Ribbon Commission for On-Site Non-Potable Water Systems developed guidance for implementing a risk-based regulatory framework for on-site alternative water systems [5].

Recycling of the full **wastewater** stream brings additional concerns for impacts to public health, sometimes resulting in stricter regulations to avoid risk. Similar to greywater systems, the need for a tailored approach to regulating and monitoring on-site systems was observed in multiple countries. In one example, government officials transposed regulations from another country due to the technology development, but issues with enforcement emerged [23]. The amount of treatment for these systems requires additional financial investment, which can create a hurdle for developers and building owners. A business case for recycling wastewater on-site remains a challenge in every country mentioned in the literature.

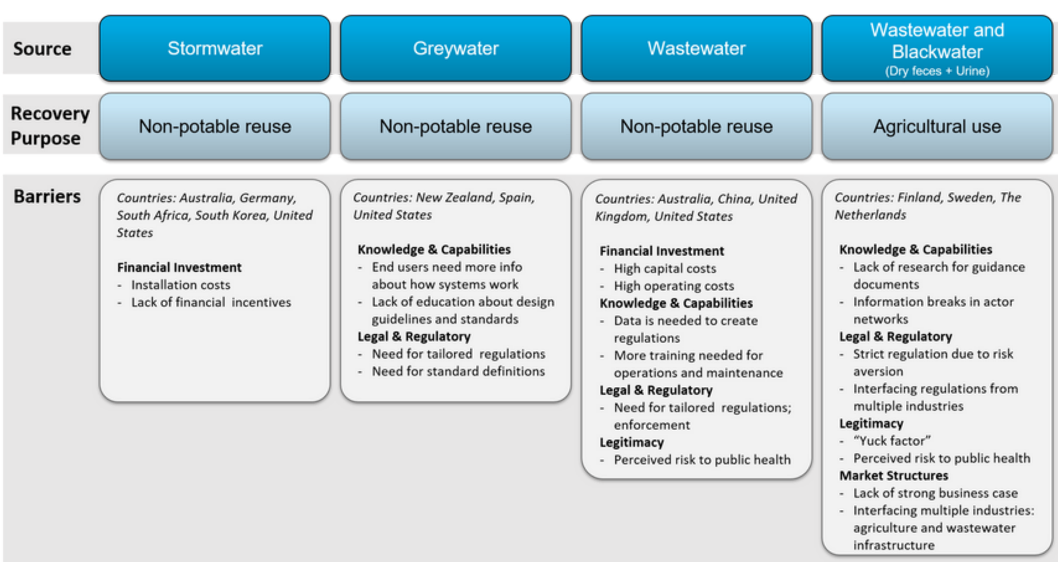

Figure 2. Distribution of institutional barriers across alternative water systems (i.e. combinations of sources and recovery purposes) with some examples from literature .

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Finally, **nutrient recovery systems**, like source separation or composting toilets experience challenges with regulatory frameworks for a variety of reasons. First, designs for these systems (e.g., urine-separating toilets) might be different from what end users are familiar with, requiring more legitimation to improve perception of the technology. This and the perceived increase risk to public health leads to stricter regulations. Second, the fertilizer that is produced has to meet standards in both the wastewater and agricultural industries. In some cases, regulations are non-existent or are ill-fitted for the alternative system. Extra effort is needed to overcome these existing industry structures and create a protected space for nutrient recovery and its end use (i.e. fertilizer products).

Socio-technical complexity of on-site alternative water systems

From these findings, we observed that as the technical complexity of on-site alternative water systems and potential risk to human health increase, so does the number of dimensions from figure 1 that need to be addressed when diffusing the respective solutions (socio-technical complexity). As decision-makers look to introduce different types of systems beyond the pilot-scale, it can be helpful to reflect upon their socio-technical complexity and the types and breadth of non-technical barriers that are most likely to be encountered in the process.

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References

(1) Gleick, P. H. Water in Crisis: Paths to Sustainable Water Use. Ecol. Appl. 1998, 8 (3), 571–579. https://doi.org/10.1890/1051-0761(1998)008[0571:WICPTS]2.0.CO;2.

(2) Hering, J. G.; Waite, T. D.; Luthy, R. G.; Drewes, J. E.; Sedlak, D. L. A Changing Framework for Urban Water Systems. Environ. Sci. Technol. 2013, 47 (19), 10721–10726. https://doi.org/10.1021/es4007096.

(3) Larsen, T. A.; Hoffmann, S.; Lüthi, C.; Truffer, B.; Maurer, M. Emerging Solutions to the Water Challenges of an Urbanizing World. Science 2016, 352 (6288), 928–933. https://doi.org/10.1126/science.aad8641.

(4) Hoffmann, S.; Feldmann, U.; Bach, P. M.; Binz, C.; Farrelly, M.; Frantzeskaki, N.; Hiessl, H.; Inauen, J.;Larsen, T. A.; Lienert, J.; Londong, J.; Lüthi, C.; Maurer, M.; Mitchell, C.; Morgenroth, E.; Nelson, K. L.; Scholten, L.; Truffer, B.; Udert, K. M. A Research Agenda for the Future of Urban Water Management: Exploring the Potential of Nongrid, Small-Grid, and Hybrid Solutions. Environ. Sci. Technol. 2020, 54 (9), 5312–5322. https://doi.org/10.1021/acs.est.9b05222.

(5) Sharvelle, S.; Ashbolt, N.; Clerico, E.; Hultquist, R.; Leverenz, H.; Olivieri, A. Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems; SIWM10C15; Water Environment & Reuse Foundation: Alexandria, VA, USA, 2017.

(6) Lackey, K.; Sharkey, S.; Sharvelle, S.; Kehoe, P.; Chang, T. Decentralized Water Reuse: Implementing and Regulating Onsite Nonpotable Water Systems. J. Sustain. Water Built Environ. 2020, 6 (1), 02519001. https://doi.org/10.1061/JSWBAY.0000891.

(7) Arden, S.; Morelli, B.; Cashman, S.; Ma, X. (Cissy); Jahne, M.; Garland, J. Onsite Non-Potable Reuse for Large Buildings: Environmental and Economic Suitability as a Function of Building Characteristics and Location. Water Res. 2021, 191, 116635. https://doi.org/10.1016/j.watres.2020.116635.

(8) WJW Foundation. Onsite Non-Potable Water Reuse Practice Guide. William J. Worthen Foundation 2018.

(9) Rupiper, A. M.; Loge, F. J. Identifying and Overcoming Barriers to Onsite Non-Potable Water Reuse in California from Local Stakeholder Perspectives. Resour. Conserv. Recycl. X2019, 4, 100018. https://doi.org/10.1016/j.rcrx.2019.100018.

10) Columbia University; NYC DEP. OPPORTUNITIES AND CHALLENGES FOR WATER REUSE POLICY IN NEW YORK CITY: APPLYING LESSONS LEARNED FROM THE US AND BEYOND; Workshop in Applied Earth Systems Management; Columbia University: New York, N.Y., 2020.

(11) de Haan, F. J.; Rogers, B. C.; Frantzeskaki, N.; Brown, R. R. Transitions through a Lens of Urban Water. Environ. Innov. Soc. Transit. 2015, 15, 1–10. https://doi.org/10.1016/j.eist.2014.11.005.

(12) Thaher, R. A.; Mahmoud, N.; Al-Khatib, I. A.; Hung, Y.-T. Reasons of Acceptance and Barriers of House Onsite Greywater Treatment and Reuse in Palestinian Rural Areas. Water 2020, 12 (6), 1679. https://doi.org/10.3390/w12061679.

(13) Campisano, A.; Butler, D.; Ward, S.; Burns, M. J.; Friedler, E.; DeBusk, K.; Fisher-Jeffes, L. N.; Ghisi, E.; Rahman, A.; Furumai, H.; Han, M. Urban Rainwater Harvesting Systems: Research, Implementation and Future Perspectives. Water Res. 2017, 115, 195–209. https://doi.org/10.1016/j.watres.2017.02.056.

This summary is based off of recently published work in Environmental Science and Technology: **https://doi.org/10.1021/acs.est.0c07947**

References (cont'd)

(14) Lee, J. Y.; Han, M. Y.; Kim, H. Review on Codes and Application of Urban Rainwater Harvesting Utilization: Focused on Case Study in South Korea. Int. J. Urban Sci. 2010, 14 (3), 307–319. https://doi.org/10.1080/12265934.2010.9693687.

(15) Starkl, M.; Brunner, N.; Feil, M.; Hauser, A. Ensuring Sustainability of Non-Networked Sanitation Technologies: An Approach to Standardization. Environ. Sci. Technol. 2015, 49 (11), 6411–6418. https://doi.org/10.1021/acs.est.5b00887.

(16) Ndeketeya, A.; Dundu, M. Maximising the Benefits of Rainwater Harvesting Technology towards Sustainability in Urban Areas of South Africa: A Case Study. Urban Water J. 2019, 16 (2), 163–169. https://doi.org/10.1080/1573062X.2019.1637907.

(17) Schuetze, T. Rainwater Harvesting and Management - Policy and Regulations in Germany. Water Sci. Technol.-Water Supply 2013, 13 (2), 376–385. https://doi.org/10.2166/ws.2013.035.

(18) Cook, C. Regulating the Risks of Domestic Greywater Reuse: A Comparison of England and California. 2016, 42 (2), 230–242. https://doi.org/10.2148/benv.42.2.230.

(19) Domenech, L.; March, H.; Valles, M.; Sauri, D. Learning Processes during Regime Shifts: Empirical Evidence from the Diffusion of Greywater Recycling in Spain. Environ. Innov. Soc. Transit.2015, 15, 26–41. https://doi.org/10.1016/j.eist.2014.01.001.

(20) US Water Alliance. A Guidebook for Developing and Implementing Regulations for Onsite Non-Potable Water Systems. US Water Alliance; Water Environment & Research Foundation; Water Research Foundation 2017.

(21) Bint, L.; Garnett, A.; Siggins, A.; Jaques, R. Alternative Water Sources in New Zealand's Commercial Buildings. Water Supply 2019, 19 (2), 371–381. https://doi.org/10.2166/ws.2018.082.

(22) Wilcox, J.; Nasiri, F.; Bell, S.; Rahaman, Md. S. Urban Water Reuse: A Triple Bottom Line Assessment Framework and Review. Sustain. Cities Soc. 2016, 27, 448–456. https://doi.org/10.1016/j.scs.2016.06.021.

(23) Binz, C.; Truffer, B. Anchoring Global Networks in Urban Niches. How on-Site Water Recycling Emerged in Three Chinese Cities. In Urban Sustainability Transitions; 2017; pp 23–36.

(24) Neighbour, D.; Qi, Y. Identifying Implementation Gaps in Water Recycling Policy of Beijing Municipality. Chin. J. Popul. Resour. Environ. 2018, 16 (4), 355–363. https://doi.org/10.1080/10042857.2018.1544750.

(25) West, C.; Kenway, S.; Hassall, M.; Yuan, Z. Expert Opinion on Risks to the Long-Term Viability of Residential Recycled Water Schemes: An Australian Study. Water Res. 2017, 120, 133–145. https://doi.org/10.1016/j.watres.2017.04.077.

(26) Parkinson, J.; Tayler, K. Decentralized Wastewater Management in Peri-Urban Areas in Low-Income Countries. Environ. Urban. 2003, 15 (1), 75–90. https://doi.org/10.1177/095624780301500119.

(27) Ebert, B.; Schramm, E.; Wang, B.; Winker, M. Governance Instruments for Optimising Source Separation in Novel Urban Water Systems: The Case of Cross-Connections in Urban Water Systems. Water Policy 2019, 21 (2), 412–427. https://doi.org/10.2166/wp.2019.183.

(28) Simha, P.; Ganesapillai, M. Ecological Sanitation and Nutrient Recovery from Human Urine: How Far Have We Come? A Review. Sustain. Environ. Res. 2017, 27 (3), 107–116. https://doi.org/10.1016/j.serj.2016.12.001.

(29) Ormerod, K. J. Illuminating elimination: public perception and the production of potable water reuse. Wiley Interdiscip. Rev. Water 2016, 3 (4), 537–547. https://doi.org/10.1002/wat2.1149.

(30) Brands, E. Prospects and Challenges for Sustainable Sanitation in Developed Nations: A Critical Review. Environ. Rev. 2014, 22 (4), 346–363. https://doi.org/10.1139/er-2013-0082.

(31) Anand, C. K.; Apul, D. S. Composting Toilets as a Sustainable Alternative to Urban Sanitation – A Review. Waste Manag. 2014, 34 (2), 329–343. https://doi.org/10.1016/j.wasman.2013.10.006.

(32) Luethi, C.; Morel, A.; Tilley, E.; Ulrich, L. Community-Led Urban Environmental Sanitation Planning: CLUES - Complete Guidelines for Decision-Makers with 30 Tools.; Eawag-Sandec, WSSCC, UN-HABITAT: Duebendorf, Switzerland, 2011.

(33) Klinger, M.; Ulrich, L.; Wolf, A. T.; Reynaud, N.; Philip, L.; Luethi, C. Technology, Implementation and Operation of Small-Scale Sanitation in India – Performance Analysis and Policy Recommendations.; 4S Project Report Vol. I.; Eawag-Sandec.: Duebendorf, Switzerland, 2019.

(34) Bergek, A.; Jacobsson, S.; Carlsson, B.; Lindmark, S.; Rickne, A. Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis. Res. Policy 2008, 37 (3), 407–429. https://doi.org/10.1016/j.respol.2007.12.003.

(35) Pakizer, K.; Lieberherr, E. Alternative Governance Arrangements for Modular Water Infrastructure: An Exploratory Review. Compet. Regul. Netw. Ind. 2018, 19 (1–2), 53–68. https://doi.org/10.1177/1783591718814426.

(36) Schramm, E.; Kerber, H.; Trapp, J. H.; Zimmermann, M.; Winker, M. Novel Urban Water Systems in Germany: Governance Structures to Encourage Transformation. Urban Water J.2018, 15 (6), 534–543. https://doi.org/10.1080/1573062X.2017.1293694.

(37) Hufty, M. Investigating Policy Processes: The Governance Analytical Framework (GAF); SSRN Scholarly Paper ID 2019005; Social Science Research Network: Rochester, NY, 2011.

(38) US Water Alliance. AN EQUITABLE WATER FUTURE: A National Briefing Paper; 2017.

(39) Fauconnier, I. The Privatization of Residential Water Supply and Sanitation Services: Social Equity Issues in the California and International Contexts. Berkeley Plan. J. 1999, 13 (1). https://doi.org/10.5070/BP313113030.

(40) Suchman, M. C. Managing Legitimacy: Strategic and Institutional Approaches. Acad. Manage. Rev. 1995, 20 (3), 571–610. https://doi.org/10.2307/258788.

(41) Harris-Lovett, S. R.; Binz, C.; Sedlak, D. L.; Kiparsky, M.; Truffer, B. Beyond User Acceptance: A Legitimacy Framework for Potable Water Reuse in California. Environ. Sci. Technol. 2015, 49 (13), 7552–7561. https://doi.org/10.1021/acs.est.5b00504.

(42) Meehan, K. M.; Moore, A. W. Downspout Politics, Upstream Conflict: Formalizing Rainwater Harvesting in the United States. Water Int. 2014, 39 (4), 417–430. https://doi.org/10.1080/02508060.2014.921849

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