Food and Agriculture
Organization of the
United Nations

LAND AND
WATER
DISCUSSION
PAPER

ISSN 1729-0554

19

Revaluing multiple-use water services for food and water security

LAND AND WATER DISCUSSION PAPER 19

Revaluing multiple-use water services for food and water security

by
Wendy Jepson and Matt Stellbauer
Texas A&M AgriLife Research; Texas A&M University

and
Patrick Thomson,
Oxford University

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2023

Required citation:
Jepson, W., Stellbauer, M. & Thomson, P. 2023. *Revaluing multiple-use water services for food and water security.* FAO Land and Water Discussion Paper No. 19. Rome, FAO. https://doi.org/10.4060/cc7317en

ISBN 978-92-5-138064-2

Contents

Foreword

Water is an indispensable resource that lies at the heart of sustenance and prosperity for communities worldwide. In low- and middle-income countries, households and communities have long relied on a single water source to fulfil a multitude of needs, encompassing drinking, washing, cooking, livestock raising, and irrigation. Traditional water supply systems have served as hydraulic structures for multiple purposes, catering to diverse water requirements.

As countries progressed towards modernization, the emphasis shifted towards single-use water infrastructure, inadvertently neglecting the multifaceted nature of water demands that contribute to people's livelihoods. In developing countries, water resources management centered around large-scale irrigation and water development projects to spur economic growth. Infrastructure, institutions, policies, and practices were organized around single-use sectors. Consequently, prevailing models of water modernization unintentionally disregarded or even discouraged the acknowledgement of multiple uses.

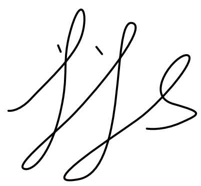
In recent decades, water practitioners have discerned the economic and productive benefits that stem from multiple water uses originating from a single source. In the late 1990s, the international development community spearheaded multiple-use water services (MUS) projects, recognizing the limitations of top-down planning that only considered single water uses, whether domestic or irrigation. These projects aimed to enhance community access to water, improve health outcomes, and uplift livelihoods. The significance of MUS projects lay in their ability to transcend the prevalent inclination towards technology-centric solutions and instead compelled researchers and water management communities to adopt a holistic perspective, considering water systems as integral components of broader social-technical systems that respond to local water needs, trade-offs, and dynamics.

These early efforts envisioned MUS as a participatory and integrated poverty reduction strategy, addressing a spectrum of water needs in resource-limited communities. By acknowledging that water service uses extend beyond sectoral divisions, MUS emerged as a framework capable of accommodating the diverse livelihood strategies. Nevertheless, institutional and technical barriers impeded the full integration of MUS in policy, practice, and investment, constraining its potential to facilitate integrated development and to alleviate poverty.

The time has come to reevaluate the significance of MUS. The interplay of climate change, emerging technologies, evolving research on the household-level water-nutrition-food nexus, and the persistence of self-supply and decentralized water provision have presented new opportunities to harness MUS in support of the Sustainable Development Goals (SDGs). FAO is contributing to steer global water management strategies in this direction, with programs already implemented in different countries, in Africa, Asia and the Near East.

This technical report, produced by FAO in collaboration with Texas A&M AgriLife Research and Texas A&M University, aims to enrich the debate by providing an overview of MUS in international development. Its objective is to enable a fresh assessment of MUS as a means to achieve the goals of nutrition and food security, water security, and human health, in line with the 2030 Agenda for Sustainable Development. Considering the background information and identifying the evidence gaps, the report presents a new framework for continued research, policy development, and targeted investment in MUS interventions. These interventions have the potential to enhance water, food, and nutrition security while advancing the social goal of gender empowerment.

The publication advocates for policymakers to focus on targeted interventions that leverage existing infrastructure and institutions, integrating the private sector into next-generation technologies. By doing so, we can overcome previous barriers and move beyond pilot programs to foster global initiatives that leave no one behind.



Lifeng Li
Director – Land and Water Division
Food and Agriculture Organization of the United Nations

Acronyms and abbreviations

CPWF	Challenge Programme on Water and Food
FAO	Food and Agriculture Organization of the United Nations
ICT	information and communications technologies
ILSSI	Innovation Lab for Small-Scale Irrigation/USAID
IFPRI	International Food Policy Research Institute
IIMI	International Irrigation Management Institute
MUS	multiple-use water services
SDGs	Sustainable Development Goals
SWIM	System-Wide Initiative on Water Management
IWMI	International Water Management Institute
WASH	water, sanitation and hygiene
WTP	willingness to pay

Acknowledgements

The Land and Water Division of the Food and Agriculture Organization of the United Nations (FAO) supported a study on sustainable multiple-use household water security for rural development. Smallholder farmers in rural areas rely on water resources for various purposes, from domestic household use to agricultural production, to support their livelihoods and ensure their food and water security. This technical report, Revaluing multiple-use water services for food and water security, is a collaborative effort between the Land and Water Division of FAO (NSL) and Texas A&M University, with the contribution and support from Oxford University to examine household/homestead agriculture water management, linking irrigation with WASH investments for synergistic nutrition and health outcomes.

The study supported two workshops, which brought together participants from FAO, IRC-WASH, Oxfam, Haramaya University, Water for People, Innovation Lab for Small-Scale Irrigation/USAID (ILSSI), Arizona State University, Oxford University, UNC Greensboro, International Food Policy Research Institute (IFPRI), Northwestern University and the Institute for Advancing Health through Agriculture, to share their knowledge and experiences on multiple-use water services (MUS). The workshops sought to define priority actions to increase the value of MUS in the water-food security nexus policy space and to revisit MUS as a means to guide sustainable development and investment opportunities that support rural communities and small-scale farmers.

The authors acknowledge the overall guidance and support, as well as the conception, review and direction of the work programme provided by Sasha Koo-Oshima, Deputy Director, Land and Water Division of FAO.

The authors also recognize the contributions provided by Stef Smits (IRC-WASH), Paulo Dias (FAO), Omar Elhassan (FAO), Eva Peck (FAO), Maher Salman (FAO), Jayne Vonk (Oxfam), Kedir Teji Roba (Haramaya University), Tupac Amaru Medina (Water for People) and Matt Stellbauer (ILSSI), Neetu Choudhar (Arizona State University), Josh Miller (University of North Carolina), Patrick Thomson (Oxford University), Cassandra Workman (UNC Greensboro), Nicole Lefore (Innovation Lab for Small-Scale Irrigation/USAID), Claudia Ringler (IFPRI), Sera Young (Northwestern University), Regan Bailey (Institute for Advancing Health through Agriculture) and Elizabeth Parker (Institute for Advancing Health through Agriculture).

1. Introduction

Across low- and middle-income countries, households and communities have traditionally drawn on a single water source for multiple purposes, whether for drinking, washing, cooking, livestock raising, or irrigation. Traditional water supply systems in central and southwest Asia (known as *karezes*) are typically hydraulic structures or subterranean aqueducts that source water for multiple purposes (Hussain *et al.*, 2008). Modern, single-use infrastructure is often used *de facto* for multiple uses that contribute to peoples' livelihoods. In Pakistan, for example, communal tanks provide irrigation water for domestic uses through individual pipelines (Boelee, Laamrani and Van der Hoek, 2007). Rural communities in Senegal use reticulated water for domestic activities, such as cooking and bathing, as well as for household gardens and rearing livestock (Hall, Vance and Van Houweling, 2014). In India, the multiple uses of water diversify farming systems, contributing to the livelihoods of the poor through improved food supply, employment, and income (Behera, Panigrahi and Sarangi, 2012). In Pakistan, seepage from irrigation canals is directly linked to the recharge of shallow wells used for drinking and cooking by rural households (Van der Hoek, Feenstra and Konradsen, 2002). These practices have largely remained outside state-led water policy and management regimes.

Water resources management in developing nations previously followed a strategy based on the promotion of large-scale irrigation and water development projects to increase economic development (Swyngedouw, 2015; Sultana, 2013; Sneddon, 2015; Rusca *et al.*, 2019; Molle, Mollinga and Wester, 2009). As countries modernized their water resources management and infrastructure, the water sector organized its institutions, policies and practices around single uses or sectors (Linton, 2010; Barnes, 2014). Even as policymakers advanced decentralized water governance models, the institutional foundation for modern water management has continued to be sector-based, limiting the capacity of countries to recognize, support and invest in multiple-use water services (Mutondo, Farolfi and Dinar, 2016). Water-user groups reflect the sectoral responsibility of government agencies and thus further entrench the division across water uses. In short, models of water modernization have locked in regulatory, institutional, engineering design and investment pathways that produce conditions that passively ignore multiple uses or even actively discourage them.

Despite the sector-based structure of water management paradigms, some development practitioners have recognized that multiple water uses from a single source offer important economic and productive benefits. In the late 1990s, the international development community advanced MUS projects to address the observed shortcomings of top-down planning approaches that only consider a single water use, either domestic or irrigation (Smits *et al.*, 2010). The projects sought to increase community access to water to improve health and enhance livelihoods. The attention to MUS was significant because such integrated solution sets transcended the often-prescribed technology solutions to water resources challenges. The MUS approach forced the research and water management communities to look beyond the technologies and consider how water systems are part of a larger social-technical system that responds to local water needs, trade-offs and dynamics.

These early efforts envisioned MUS as a participatory and integrated poverty reduction development strategy to address a range of water needs in resource-limited communities. They recognized that water service uses by households and communities transcend sectoral divisions. Multiple-use water services emerged as a framework that cut across the diverse livelihood strategies that characterize many households in low and middle-income countries. However, institutional and technical barriers prevented the full integration of MUS in policy, practice and investment, limiting its promise to support integrated development and poverty alleviation. And with single-sector thinking unchallenged and implicitly viewed as superior in the Global North, efforts to operationalize MUS did not gain significant traction in policy agendas or in development investment portfolios after the initial research efforts ended.

1.1 WHY RECONSIDER MULTIPLE-USE WATER SERVICES NOW?

Climate change, emerging technologies, new research on the household-level water-nutrition-food nexus, and the persistence of self-supply and decentralized water provision have introduced new opportunities to reevaluate MUS as a means to support the United Nations Sustainable Development Goals (SDGs). This report draws on expert discussions at virtual workshops and a comprehensive scoping review of published scholarship on MUS. This included a comprehensive search for peer-reviewed research on multiple-use water services published between 1990 and 2022. We focused on MUS in rural and peri-urban areas in low and middle-income contexts, which led to the identification of more than 175 articles. A full text review of these articles was conducted to assess their applicability to the technical report, and 40 were closely analysed for this report. We supplemented this review with citation tracing, a technique that has been used in other scoping studies (Garrick *et al.*, 2019) and an examination of high quality "grey literature," non-peer reviewed publications that are often produced by non-governmental organizations (NGOs), development consultants and other agencies.

This technical report provides an overview of multiple-use water services in international development . The aim is to enable a new assessment of MUS as a means to achieve the goals of nutrition and food security, water security and human health. Drawing on this background and considering the evidence gaps, the report offers a new framework for continued research, policy development and targeted investment in MUS interventions with the potential to increase water, food and nutrition security while advancing social goal of gender empowerment. Unlike previous studies, which proposed full-scale systems change, we advocate that policymakers focus on targeted interventions that leverage existing infrastructure and institutions while integrating the private sector into next generation technologies, like solar, nanotech for water filtration and information and communications technologies (ICT), to overcome previous barriers to advancing MUS beyond pilot programmes. Policy models for top-down investment and implementation are discouraged.

© FAO/Giuseppe Bizzarri

2. Multiple-use water services in development

Using single water sources for multiple uses is not new. However, in recent decades, international development agencies have attempted to standardize and scale-up MUS within a broader integrated water development paradigm. In this section, we review the research on MUS in development and describe the two basic MUS modalities: irrigation plus and domestic plus.

2.1 MULTIPLE-USE WATER SERVICES RESEARCH FOR DEVELOPMENT

The international research community endeavoured to implement MUS for development between the mid-1990s and into the 2000s. In 1995, the International Irrigation Management Institute (IIMI) (since renamed the International Water Management Institute or IWMI) established the System-Wide Initiative on Water Management (SWIM). The initiative focused on enhancing the productivity of water and established a framework, terminology, and performance indicators for three levels or scales of water resource use (Molden, 1997). Following SWIM, the CGIAR commissioned the Challenge Programme on Water and Food (CPWF) in 2004, which in turn created the Multiple-Use Systems Programme (Koppen *et al.*, 2009; Smits *et al.*, 2010). The CPWF was an international, multi-institutional research-for-development initiative that aimed to enhance efforts by the global community to increase food production and achieve international food security and poverty eradication targets by 2015. Multiple-use water services were even seen as an means to "operationalize the Dublin Statement" (Hall, Vance and Van Houweling, 2014, p. 482).

The CPWF attempted to fill an important gap: studies on the capacity of MUS to improve livelihoods were rare. Indeed, as one researcher remarked, "[r]esearch on multiple systems and services is much needed since the benefit and costs are not fully worked out and hard scientific proof of value of the concept [is] required before donors will be convinced to support major activities in upscaling" (Vries, 2007, p. 93). As a result, the international community piloted and assessed MUS projects in twenty-two countries (Clement, Pradhan and Van Koppen, 2019).

Early efforts to scale up MUS models contributed to a supportive multi-user platform at the subnational, national and global levels called a "learning alliance" (Vries, 2007). As part of this researcher-community effort, team members sought to develop a conceptual framework of principles that could enhance the implementation and scaling of MUS as a development strategy. While there is no standard definition of MUS, the study established a working description:

> Multiple-use Water Services (MUS) are water services by the public sector or private sector that take rural and peri-urban people's multiple water needs, which are met from multiple sources, **as the starting point of planning and design.** This participatory, integrated planning approach fully recognizes and strengthens the often informal ways in which communities have been developing and managing their water resources (Van Koppen *et al.*, 2014).

Early efforts to advance MUS sought to understand a range of water resources, its uses, appropriate technologies, adequate financing mechanisms and institutional arrangements needed to manage communal systems and enable the equitable availability of water. They focused on rural and peri-urban areas, small-scale infrastructure, and prioritizing the needs of people (Van Koppen *et al.*, 2009). The first MUS principle is that livelihoods and existing practices act as the main drivers for water service planning and design. This is a bottom-up approach as opposed to one that is driven and designed by sectoral needs. In other words, the starting point for the MUS approach is household and community needs, not managing water resources at the basin level.

2.2 AN OVERVIEW OF MULTIPLE-USE WATER SERVICES APPROACHES

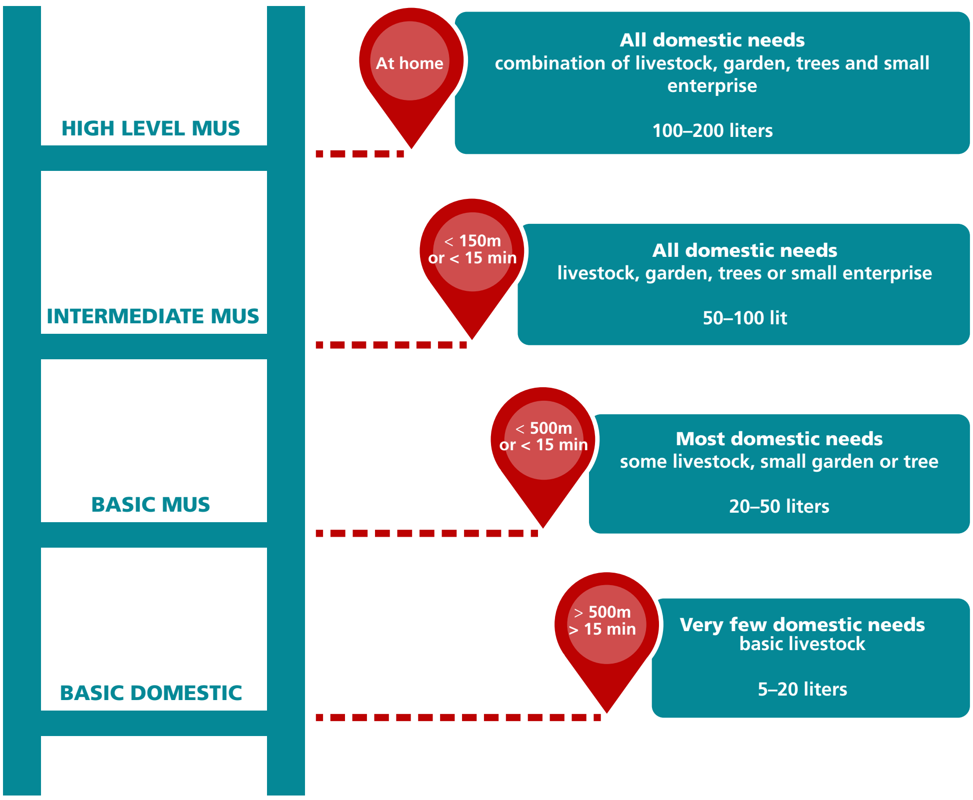
The MUS project identified, tested, and analysed multiple-use water services at the homestead and community scales (Van Koppen, Smits and Mikhail, 2009; Van Koppen, Moriarty and Boelee, 2006). Homestead MUS involve the use of water for both domestic and productive purposes. Homestead multiple-water use services are often *de facto* responses to livelihoods requirements and are not necessarily sanctioned by institutions or policymakers. Community-scale MUS consider all uses, users, use sites, and water resources and infrastructure holistically. As an example, a cooperative effort between the Governments of Nepal and Finland sought to develop institutional arrangements for MUS through local water committees as a mechanism for transforming water services at the community level in Nepal (Rautanen, Van Koppen and Wagle, 2014).

For our purposes, we considered all MUS regimes whether informal or sanctioned. *De facto* MUS occur when homesteads or communities divert water from one sanctioned use or service to other purposes. Multiple-use water services *by design* are understood as public services managed and operated to provide water for multiple uses. In *by design* services, the beneficiary population and service coverage are clearly defined, provided capacity building support, and included in the support needed to manage such services. Multiple-use water services *by design* may be a response by institutions to *de facto MU* to formalize and support what is already happening. In MUS *by design*, public sector agencies prioritize single-use mandates but also recognize and encourage other uses in order to scale and operationalize MUS in a way that facilitates access to clean water and increases incomes while avoiding the negative impacts of unplanned uses (Van Koppen and Schreiner, 2014). This perspective seeks to open new technological potential, including novel water sources, the integration of existing infrastructure into new designs, and economies of scale in sharing bulk infrastructure.

Multiple-use water services integrate into irrigation and the water, sanitation and hygiene (WASH) subsectors through two models: 1) domestic plus and 2) irrigation plus. These models include domestic water for production (domestic plus) and irrigation water that supports domestic needs and other productive activities (irrigation plus). The goal of both models is to increase water access for development. Through community involvement, some argue that these strategies could be scaled up by leveraging both existing financing streams and the technical expertise of the subsectors, creating long-term water resource management strategies (Smits *et al.*, 2010).

Domestic plus. Domestic-plus services primarily provide water for domestic use while allowing sufficient resources for productive activities such as home gardens, livestock and home-based enterprises (Moriarty and Butterworth, 2004; Van Koppen *et al.*, 2014). Domestic-plus services take various forms. A domestic-plus system could include a single piped rural water supply system designed to serve both domestic and productive uses at the homestead. In addition, domestic standpipes may also provide water to multiple homesteads, co-located with productive uses such as communal gardens, cattle troughs or small-scale industries.

FIGURE 1
The MUS water ladder



Sources: Renwick, M., Joshi, D., Huang, M., Kong, S., Petrova, S., Bennett, G., Bingham, R., Fonseca, C., Moriarty, P. & Smits, S. 2007. *Multiple-use water services for the poor: assessing the state of knowledge.* Arlington, USA, Winrock International. https://winrock.org/document/multiple-use-water-services-for-the-poor-assessing-the-state-of-knowledge/

Van Koppen, B. 2009. *Climbing the water ladder: multiple-use water services for poverty reduction.* Colombo, Sri Lanka, IWMI. https://www.ircwash.org/resources/climbing-water-ladder-multiple-use-water-services-poverty-reduction

To illustrate how MUS may help communities benefit from a greater availability of water, development practitioners created the water ladder framework (Renwick *et al.*, 2007; Van Koppen, 2009). This framework designates quantities of water used to service levels of access to safe water. The framework assumes that at the levels of 20, 50, and up to 100 litres per capita per day (LPCD), water is being used for productive as well as domestic purposes. Water quality was not considered.

Domestic plus allows households to leverage their existing water resources to support diverse livelihoods, and it has been documented across low- and middle-income countries. For example, Hall, Van Koppen and Van Houweling (2014) compared households in Senegal (N=1 860), Colombia (N=1 819), and Kenya (N=1 916), learning that between 54 and 61 percent engaged in productive activities using piped water. In the same study, the authors found that between 34 and 43 percent of households earned income from activities supported by piped water. Some have argued that specific kinds of domestic-plus services, such as *gravity-fed* systems, common in rural mountainous regions, hold the most promise because of the low cost of providing water as compared to groundwater systems where energy inputs for pumping and distribution is required (Dominguez *et al.*, 2014).

Irrigation plus. In the second MUS model – irrigation plus – water resource managers set priorities for irrigated agriculture while non-irrigation uses are tolerated or supported. Here, the prioritization of water for crops is maintained, but not at the exclusion of other uses (Meinzen-Dick and Van der Hoek, 2001). Studies have found that non-irrigation water uses are often only a small proportion of the volumes used for irrigation. In practice, irrigation plus involves enabling access to water for non-irrigation uses such as watering cattle, washing, laundry and drinking water (Hall, Van Koppen and Van Houweling, 2014; Hall, Vance and Van Houweling, 2014; Van Koppen *et al.*, 2014). In larger irrigation schemes, irrigation plus may include designated irrigation canals delivering water year-round to reservoirs for domestic or animal water consumption. In some areas of Morocco, for example, water pumped from irrigation canals or directly diverted are conveyed to village storage facilities for use by the population (Boelee and Laamrani, 2004). In this case, communal tanks, called metfia, are used by families and, in some cases, provide employment for professional water sellers. Irrigation canals also offer structures for other household activities, including laundry, cleaning household items, and watering livestock (Boelee *et al.*, 2007).

The prioritization of water for productive uses distinguishes irrigation-plus systems from other multiple use water models. Irrigation-plus systems are not limited to irrigation canals and tanks; they can take many forms, including rainwater harvesting structures and shallow ground wells. In India, for example, an integrated farming system (IFS) allows resource-poor farmers to judiciously apply water for multiple uses to help optimize water productivity and improve their livelihoods (Behera *et al.*, 2012). Similarly, in the Limpopo Basin of Zimbabwe, small irrigation dams offer communities the opportunity to increase water access for livestock raising, domestic water use, and brick making (Senzanje, Boelee and Rusere, 2008).


© Benedicte Kurzen/NOOR for FAO

3. Multiple use of water system performance and limitations

While some evidence supports the claim that MUS advances gender empowerment, enhances human health and offers direct and indirect economic benefits, few independent or systematic evaluations substantiate these claims. The evidence that illustrates MUS benefits either arises from the original MUS project (with little independent assessment or evaluation) or comes from case studies with limited generalizability. This is a serious shortcoming that limits the ability to make policy recommendations. Notwithstanding these limitations, this report outlines existing data on MUS performance and identifies critical limitations and barriers to scaling and institutionalizing multiple-use water services beyond pilot development projects as we evaluate new opportunities.

3.1 MULTIPLE-USE WATER SERVICES PERFORMANCE

Advocates of MUS have argued that the approach offers important opportunities to increase income, improve gender empowerment and provide safe water for human health. Some have even tied these opportunities to the UN Sustainable Development Goals (Hall, Ranganathan and GC, 2017). While published work summarizes the benefits of MUS, the evidentiary basis for the case that MUS can achieve development goals is thin. Any new MUS agenda and investment will require more robust analytics and metrics, as we will discuss in a subsequent report.

3.1.1 Economic benefits

Multiple-use water services offer households the opportunity to increase water availability for more diverse productive and domestic activities. While the evidence for this assessment is again limited, there are indications of clear economic benefits. Some studies suggest that increased water availability has positive economic impacts. In the case of domestic-plus systems, households may use the income generated from their productive activities to pay for upgrading rural water supplies. Studies have shown that the potential income from productive uses of water is often sufficient to pay for infrastructure investment and operational costs within 0.5 to 3 years (Van Koppen and Smits, 2009). In some contexts, domestic plus may double or triple current water supplies up to an intermediate MUS level of 50 to 100 LPCD, of which at least 3 to 5 LPCD should be safe for drinking and cooking (Van Koppen *et al.*, 2014). Intermediate MUS levels of 50 LPCD, for example, promote more significant productive uses worth several hundreds of US dollars per household. In Nepal, for example, access to more water increased the capacity of households to generate income through improved vegetable production and handicrafts (Sharma *et al.*, 2010). Renwick *et al.* (2007) document the income benefits of MUS systems given relatively low payback periods (3–24 months) for upgrading single-use systems to multiple-use water services.

Hall, Van Koppen and Van Houweling (2014) and Hall, Vance and Van Houweling (2015) report the most convincing evidence of economic benefits for MUS, in this case, domestic-plus services. The studies examined rural electric-powered pumped borehole systems (with limited distribution) in 8 of Senegal's 14 regions. The systems were designed to provide water for domestic use, but a significant number provide water that is used for livestock and, to a lesser extent, agriculture. The studies confirmed that domestic-plus water supports important supplemental income generation or food production for a large proportion of rural households. For example, water-based income accounts for half of total household income for households engaged in income-generating water-based activities.

Research also demonstrates the potential economic benefits of irrigation-plus systems. First, irrigation-plus systems increase water availability throughout the year and, in some cases, can act as a significant source – sometimes the only source – of domestic water supply. Second, irrigation systems supply water for field crops as well as for home gardens, trees and other vegetation and livestock through elevated water tables. This enables the cultivation of groundwater-fed crops in home gardens, providing income-generating opportunities (Raut *et al.*, 2021). Irrigation systems are also water sources for livelihood activities such as fishing, harvesting of aquatic plants and raising livestock, in addition to microenterprises such as brickmaking (Senzanje *et al.*, 2008).

Managing water resources through MUS does not require new technologies, but it often calls for an upgrade and integration of existing water technologies to make more water available in ways that best suit the needs of water users and increase overall water productivity for the user. Given the economic benefits described above, studies have shown that individuals in rural communities are willing to pay for improved water delivery systems (Kanyoka, Farolfi and Morardet, 2008). Sakketa and Prowse (2018) showed that farmers' willingness to pay (WTP) is based on several factors, including gender, the prevalence of waterborne diseases, the time required to collect water, contact with extension services, access to credit, level of income and location. Willingness to pay is an important indicator of the economic value of a reliable source of freshwater for productive and domestic uses.

3.1.2 Gender empowerment and the human right to water

Some have argued that that the modernist, sectoral paradigm of water development has been gendered in discourse and practice such that women lose opportunities to benefit from water infrastructures and resources (Laurie, 2005; Siemiatycki, Enright and Valverde, 2020; Zwarteveen 2008; Shrestha and Clement, 2019; Zwarteveen, 2017). In the move to create and assign formal water rights to address issues of allocation and increased competition for water, secondary water uses, which are often domestic or at the homestead level, have been ignored. Those who use water for such purposes, most often women, have lost water access (Meinzen-Dick and Bakker, 2001). As such, MUS are seen as having a corrective role to play in limiting to this marginalization and even providing a pathway to higher levels of gender empowerment alongside other societal benefits.

Multiple-use water services may reduce the distance between household water sources and the homestead and create new economic opportunities that use water for productive uses like home gardens, brewing and livestock raising. Both have potential positive impacts on women. Women and girls play the central role in fetching water around the world; reducing the time needed to collect and convey water frees up their time for development and economic opportunities. Women are also key to many small-scale productive activities that could benefit from increased water access through MUS. Not only do women gain economic benefits from such activities, evidence suggests that increased income also improves the family's well-being (Winter, Darmstadt and Davis, 2021; Jeil, Abass and Ganle, 2020; Van Koppen, 2018).

There is evidence that domestic-plus services have positive impacts on women's lives. A study in Senegal found that the construction of piped water systems helped facilitate livelihood diversification activities among women in addition to increasing their incomes (Van Houweling *et al.*, 2012). The combination of time savings and improved water access brought about by the piped systems led to increased opportunities for women's commercial activities, such as vegetable production. Using MUS, women were able to grow a variety of crops, which were both sold in local markets and saved for home consumption. The extra income contributed to household food security during the lean months, while also providing vegetables that were lacking in local diets. In Nepal, upgraded or newly installed drinking water systems reduced the time women spent fetching water for domestic purposes and facilitated their productive engagement in vegetable farming (Leder, Clement and Karki, 2017).

Proponents of domestic plus argue that it holds "untapped potential…to realize the human right to water" because "people can co-create norms and practices for meeting their human rights" (Hall, Van Koppen and Van Houweling, 2014, p. 851). The argument follows that if water providers prioritize providing safe drinking water over allowing households to use water for productive activities they, in practice, breach the intent of Article 12 of the UN Resolution on the Human Right to Water (2010) (Hall, Van Koppen and Van Houweling, 2014).

3.1.3 Health and nutrition benefits

There are several mechanisms by which MUS can lead to improved human health. Several direct and indirect pathways are theorized as households increase access to water and they move up the water ladder beyond the minimum requirements for consumption (Boelee *et al.*, 2007). First, greater household water availability, in terms of quantity and proximity, increases the likelihood for improved personal hygiene and safe food preparation, which can reduce the risk of waterborne and water-washed diseases (Wang and Hunter, 2010). Changes in water availability and proximity to the homestead may also reduce personal injury, especially among women and girls, by reducing water-fetching distances (Venkataramanan *et al.*, 2020; Geere *et al.*, 2017).

Moving squarely into the MUS paradigm, increased domestic water access has the potential to improve nutrition (Ringler and Dias, 2020; Blakstad *et al.*, 2022). This is the case under both the domestic-plus and the irrigation-plus MUS models. Home gardens can be created when there is a greater availability of water, primarily for domestic use or through the diversion of irrigation water. In the latter case, even if overall crop yields do not increase, the range of crops gown may expand, leading to dietary diversity (Blakstad *et al.*, 2021). As activities move beyond subsistence agriculture to income generation, an increased water supply can improve economic activity, with expected indirect benefits that include greater food security and more resources to invest in preventative health interventions (Mutero, McCartney and Boelee, 2006) and a reduction in the cost of illness (Hall *et al.*, 2017).

The greatest concern around the irrigation-plus MUS is water quality. Van der Hoek, Konradsen and Jehangir (1999) reported a case study in Pakistan that saw the recharge of shallow wells from irrigation water seepage used for domestic purposes. The domestic use water was of higher quality than the irrigation water, but it did not reduce the incidence of dysentery within the household. Rather, instances of dysentery were explained by the absence of storage facilities and level of hygiene. We also see muted impacts on expected nutritional outcomes as Usman and Gerber (2020) concluded that the domestic use of irrigation water has a limited effect on stunting. Common across health studies of irrigation-plus systems are confounding factors, such as distance to source and storage practices. Such factors could undermine possible the health and nutrition benefits that would be expected with greater water availability, but they also undermine the capacity of the studies to produce conclusive findings. In two recent Ethiopian studies (Usman and Gerber, 2020; Usman and Gerber, 2021), for example, there is insufficient evidence to suggest that domestic use of irrigation water exacerbates diarrhea prevalence, but the risk of water contamination is more than expected for irrigation households in general. Moreover, the distance between a household and an irrigation water source is a better predictor of household water quality than the use of irrigation water for domestic purposes. Taken together, irrigation-plus MUS does not exacerbate existing water quality-related health and nutritional challenges in households, but the expected health benefits of more access to water are unrealized. This may be due to the persistent challenge of water quality undermining possible co-benefits.

While there are potential and theoretical benefits of MUS for human health, the peer-reviewed, empirical evidence in this regard is very sparse. Moreover, as recent reviews of WASH interventions have noted, increased access to water and other hygiene interventions do not necessarily lead to better health outcomes (Pickering *et al.*, 2019). Assumptions around WASH outcomes need to be scrutinized since confounding factors have significantly undermined the capacity of safe water interventions to improve hygiene (Smiley and Stoler, 2020; Pickering *et al.*, 2019).

3.2 BARRIERS TO MULTIPLE-USE WATER SERVICES IMPLEMENTATION

While considerable efforts have been made to pilot and examine various MUS types, operationalization and investment have been limited. A broad assessment of research results and expert consultations identified technical challenges, governance barriers and valuation uncertainties that limited the institutionalization of MUS.

3.2.1 Technical challenges

Both irrigation and water supply systems follow common engineering designs that reflect technical specifications needed for a single sector. Such designs limit the quantity of water, for example, due to pipe size, dam height or other design requirements that comply with pre-existing water-use agreements, regulatory standards or permits. For drinking water systems, use outside the system design may lead to operational failures, unanticipated levels of equipment depreciation and low water pressure, which has the potential to compromise water quality for the entire customer base.

Water efficiency strategies created to support water productivity in irrigation systems provide key examples of design barriers to MUS. For example, lining irrigation canals with concrete facilitates irrigation water conveyance and extends the irrigated land area. However, as one study demonstrated, the consequent reduction of seepage negatively affects shallow wells by lowering groundwater levels and reducing household water availability (Meijer *et al.*, 2006). In this case, engineering strategies to increase water productivity and the value of water for irrigation impacted household access. A siloed mindset views seepage purely as waste, whereas an MUS lens might view seepage as recharge that supports domestic use and lowers the cost of canal construction.

Water quality risks represent a significant technical challenge to MUS, especially in irrigation- plus systems (Van der Hoek *et al.*, 1999). Irrigation water is not treated to accommodate human use. The domestic use of irrigation water increases potential health risks by increasing exposure to pathogens, *E.coli*, and agrochemicals (Evans *et al.*, 2019: Boelee *et al.*, 2007). Untreated irrigation water may transmit fecal-oral diseases such as diarrhea, dysentery, and hepatitis. Poor sanitation facilities located close to irrigation canals can further contaminate irrigation water. Thus, poor quality or contaminated irrigation water undermines the potential health and nutritional benefits of increased water availability, as we have seen in the case studies discussed above. Any irrigation-plus MUS system must include some form of water treatment, for example household-level chlorination or filtration, if human consumption is to be considered. This will add capital costs and generate a maintenance burden. The additional cost may not be small but is likely to lower than the cost of a separate drinking water system.

3.2.2 Regulatory and governance barriers

Multiple-use water services research consistently demonstrates that sectoral boundaries have created blind spots among water agencies, with most not realizing that MUS are commonly practiced at the local level or homestead scale. Even if they had knowledge of such practices, little effort has been made to formally evaluate the implications for service delivery (Meinzen-Dick and Bakker, 1999). Expert consensus is that the MUS approach lost steam, failing to scale beyond the pilot projects of the 2000s. For some, the institutionalization of MUS is a necessary condition of scaling, and that has not occurred. As one paper bluntly stated, "[T]he MUS approach has hardly gained institutional recognition in water policy or public projects" (Clement *et al.*, 2019, p. 408).

FIGURE 2
Barriers to MUS institutionalization

Legal barriers (e.g. misalignment between legally-sanctioned water use and MUS system demands)

Persistence of water-sector silos and associated regulatory guidelines

Lack of common policy and technical guidelines for implementation

Discursive barriers (MUS as intervention, lack of problem framing, unclear rationale)

Several regulatory and governance barriers have been identified by researchers; these are summarized in Figure 2. Regulations and water policies continue to forbid unsanctioned uses, despite the fact that these reflect people's norms and meet basic livelihood expectations (Hall, Van Koppen and Van Houweling, 2014, p. 859). An extreme example of misalignment between governance and practice occurs when the reappropriation of water from one sector to another is not ignored but deemed illegal. A study from South Africa showed that regulation or policies often penalized non-planned uses of water, going so far as to declare them illegal (Van der Horst and Hebinck, 2017). Water designated for domestic purposes was used to irrigate crops in home gardens as well as to provide water for livestock. The study highlighted how the policy environment in post-apartheid South Africa steered some farmers to undertake "irrigation by night," whereby they unlawfully appropriate piped water to produce food and generate income.

Only one study has explicitly assessed the non-institutionalization of MUS, and it is worth reviewing as the findings help us to understand the barriers to scaling MUS as a development strategy (Clement *et al.*, 2019). Despite a major international collaboration, Nepal's Ministry of Population and Environment's efforts to install MUS as a "climate-smart technology" with local institutional structures (e.g. farmer-managed irrigation systems, water-user master plans) in 30 of Nepal's 77 districts was not successful. Multiple-use water services did not find "a place in national water policy debates, institutions, and programs…nor did it secure a place in the national budget," and there is "no mention of MUS in any of the sectoral or multisectoral water policy documents nor in the guidelines of the sectoral water line departments" (Clement *et al.*, 2019, p. 414). A contributing factor might be that MUS fall outside the definitions used for SDG 6.1, which focuses on drinking water and is often a key driver of water policies. Irrigation-plus water cannot be classed as "safely managed" water without additional treatment. Any additional health or livelihood improvements from domestic-plus MUS will not be considered against the SDG 6.1 metrics.

The Clement *et al.* study examined how stakeholder and organizations have framed MUS and identified the perceived barriers and missed opportunities to its institutionalization in Nepal. Several key problems were identified. First, the authors noted the persistence of water sector siloes. Second, there was a lack of a common policy and technical guidelines for MUS. International NGOs and development agencies followed different procedures than local and national agencies. This misalignment made it difficult to modify regulations to better support MUS efforts. Third, the researchers found that the fragmentation of the water sector, and its of misaligned guidelines, created legal barriers that prevented communities from taking advantage of investment opportunities for MUS independent of the pilot projects. In addition to these challenges, the study also recognized discursive barriers to the institutionalization of MUS: policymakers, regulators and local actors were not able to align meanings and values to support common, sustainable, and scalable forms of MUS outside the pilot projects.

Taken together, these technical and design challenges, paired with governance barriers, reduced the capacity of political actors to take up MUS as a policy issue, thus limiting its ability to achieve development goals. The technical designs of water systems and water quality requirements make it even more difficult to reap the potential benefits of MUS. Evidence indicates that, thus far, sectoral biases within water management institutions are unable to shift away from entrenched path dependencies, systems design, and regulatory models to bring MUS practices into existing governance regimes. Therefore, any revaluing of MUS for food, nutrition, and water security needs to address, confront or work around these technical and institutional structures.

© FAO/Daniel Hayduk

4. Revaluing multiple-use water services for food and water security

Several factors call for a revaluation of MUS for future water policy and investment. The increasing impact of climate change on water and food security in low- and middle-income countries poses unique challenges. Threats of climate change also come at a time of technological and conceptual innovations. First, emerging technologies in energy systems (e.g. decentralized solar) and water filtration (e.g. nanofiltration) may offer some opportunities to overcome previous challenges and risks faced by water users in prior MUS systems. Over the past decade, decentralized or off-grid renewable energy systems, information and communication technology and water treatment have reached levels of operationalization that can be leveraged to enhance water security (Alvarez *et al.*, 2018). These technological advances pair with an emerging recognition that water security goes beyond access; there are new opportunities to enhance synergies between water and food and nutrition at the household scale through MUS for sustainable development and climate-resilient futures.

4.1 NEW TECHNOLOGIES: HIGH-PERFORMANCE WATER TREATMENT AND INFORMATION AND COMMUNICATIONS TECHNOLOGIES FOR MONITORING

New models of modular, adaptive, and decentralized (MAD) water systems are emerging – often with new opportunities for coordination that can expand their reach and scale (Stoler *et al.*, 2022). Modular, adaptive and decentralized water and the use of off-grid or decentralized systems are predicated on two factors: 1) decentralized or distributed community water systems, small-scale irrigation, and self-supply of water domestic use continues; in some cases, they are expanding (Sutton and Butterworth, 2021; Minh *et al.*, 2020; Lefore *et al.*, 2019); and 2) significant advances in engineering technology for water treatment and monitoring offer new opportunities to overcome the challenge of water quality outside reticulated, centralized networks (Dongare *et al.*, 2017). In many cases, MAD water systems are made possible by novel technologies, institutions and practices that produce, transport and store safe water and often operate in the absence of – or are or integrated alongside – existing formal, centralized systems of water provision (Arora *et al.*, 2015). In other cases, previously overlooked MAD water systems, such as rainwater harvesting, are receiving new attention from scholars and practitioners as a way to address a range of water challenges across low- and middle-income countries (Staddon *et al.*, 2018; Gomes *et al.*, 2014). A revaluation of MUS provides the opportunity to consider how to best leverage these technologies to address barriers to MUS and optimize synergies across water, food, and nutrition security.

Major advances in modular water treatments over the past decade are transforming the future of potable water access, especially in low-resource settings where reliable standard chemical treatment is difficult (Arnal *et al.*, 2001; Peter-Varbanets *et al.*, 2009). High-performance small-sized modular treatment systems, such as carbon block, nanofiltration, graphene or reverse osmosis filtration and UV disinfection are designed to provide fit-for-purpose water quality treatments that are nearly or already commercially available and can be rapidly installed by non-specialists (Aumeier *et al.*, 2020). Gravity-driven membrane filtration systems offer household-scale solutions with low annual costs (Xu *et al.*, 2021), while solar-powered microfiltration may offer other benefits that would justify investment in these systems (Pichel, Vivar and Fuentes, 2019; Richards and Schäfer, 2021).

It is important that the new systems are modular or small scale but yield significant results. Researchers developed and deployed, for example, the "Water Box," a programme to address local water pollution issues faced by rural tribal communities in the in the United States of America. The decentralized, 100 percent automatic, solar-powered water filtration system installed at groundwater well sites provides safe drinking water at around 4 000 litres of potable water per day (Stoler *et al.*, 2022). Such "mid-technologies," as opposed to centralized technical systems, ideally meet technical specifications but also align with the specifications and constraints of the local context (Mattos *et al.*, 2021). They could be the key to unlocking the potential of irrigation-plus MUS, which is currently limited by the water quality issue.

A third technological advance has been in ICT and the remote monitoring of operations and water quality. The operation and management (O&M) of water infrastructure poses considerable challenges in a low-resource context and, in the case of decentralized systems, a system breakdown, even for a few days, can pose major human health risks. New ICT systems can be deployed to address the challenges of system O&M – by monitoring the performance of decentralized systems and, in some cases, can introduce new opportunities for economic development and employment in the water sector (Mao *et al.*, 2020; Thomson, 2021). An example can be seen in the use of "smart handpumps" in rural Kenya, where groundwater handpumps outfitted with GSM transmitters dramatically reduce pump downtime by sending messages to local mechanics when there is a mechanical failure (Thomson, Hope and Foster, 2012a; Colchester *et al.*, 2017). Moreover, with the increased accessibility of mobile technologies, ICT offer the means to support the local financing of such systems (Koehler, Thomson and Hope, 2015; Thomson, Hope and Foster, 2012b). Other examples include using QR-codes linked to distributed sanitation systems to monitor performance (Saul and Gebauer, 2018) and low-cost Arduino-based sensors to monitor water levels and quality in rainwater harvesting systems (Haque *et al.*, 2021).

4.2 NEW APPROACHES TO RESOURCE SECURITIES – FOOD, NUTRITION, AND WATER

The research community also has moved beyond water access, the basis for early MUS research, to include water security as a critical factor for human development and wellbeing. Moreover, there is an increased empirical and conceptual acknowledgement of a water–food–nutrition security nexus, a synergy that can be leveraged to revalue MUS for development moving forward.

Household water security not only requires access to safe water, but also entails affordability, adequacy, reliability for all water needs, including biophysical, cultural needs, and social requirements. Household water insecurity incorporates the interacting, co-present cumulative physical and psychosocial experiences of such hydro-social relations. Attention to the various domains of water insecurity effectively defines the human right to water based on the lived and relational experiences that contribute to human flourishing and wellbeing (Jepson *et al.*, 2017; Jepson, Wutich and Harris, 2019; Zeitoun *et al.*, 2016). Such an approach requires that we reconsider our work to include various aspects or dimension of water beyond water quantity as defined by LPCD or access (Jepson, 2014; Obeng-Odoom, 2012).

Over the past decade, quantitative and qualitative research has demonstrated how the complex experiences of household water insecurity affect the material, social, physical, psychosocial and cultural dimensions of peoples' lives. Moreover, scholars have developed new metrics to assess water insecurity in ways that help to explain its foundational impact on many dimensions of human development (Young *et al.*, 2019; Young, Collins *et al.*, 2019; Wutich *et al.*, 2021; Young *et al.*, 2021). This expansive research agenda has demonstrated the relationship between water insecurity experiences and worry and mental health (Wutich and Ragsdale, 2008; Wutich *et al.*, 2015; Wutich, Brewis and Tsai, 2020; Mushavi *et al.*, 2020), physical health (Brewis, Choudhary and Wutich, 2019; Jepson *et al.*, 2021; Krumdieck *et al.*, 2016; Rosinger, 2018; Rosinger and Young, 2020; Choudhary *et al.*, 2021; Collins *et al.*, 2019), socioeconomic relations, such as reciprocity and water sharing (Brewis *et al.*, 2019; Wutich *et al.*, 2018; Stoler *et al.*, 2019; Rosinger *et al.*, 2020), household expenditures (Stoler *et al.*, 2020), perceptions of water quality (Jepson, 2014; Jepson and Brown, 2014), and governance and citizenship status (Jepson and Vandewalle, 2016; Miller *et al.*, 2020).

A major outcome of this work is a clear indication that household water insecurity affects food security and nutrition through several critical pathways (Young, Frongillo *et al.*, 2021; Miller *et al.*, 2021; Wutich and Brewis, 2014). Brewis *et al.* (2020) were the first to quantitively investigate how household water insecurity predicts household food insecurity more commonly than the other way around. Their paper illustrates that: 1) as household water quantity and quality decrease and/or the time allocated to water management increases, food insecurity increases;

and 2) water insecurity forces people to change what they eat. Extensive reviews have further demonstrated the complex interaction between water insecurity and nutrition (Nounkeu and Dharod, 2021; Young, Frongillo *et al.*, 2021; Choudhary *et al.*, 2021) and WASH and nutrition (Zavala *et al.*, 2021).

Drawing on this research, there are clear opportunities, given the right design and technology, for MUS to enhance household water insecurity. As some have noted, the "interlink water provision for WASH and irrigation purposes provides a useful basis upon which water–nutrition linkages can be further developed" (Young, Frongillo *et al.*, 2021). Opportunities to leverage the positive linkages between food–water–nutrition security within or across both agricultural and WASH services could be designed for or enhance existing MUS regimes. However, as previously noted, water quality would have to be addressed as part of any such intervention. As discussed below, there are targeted design approaches that could be developed to achieve this beneficial synergy.

5. Policy opportunities for multiple-use water services in rural communities: Targeted innovations

Based on a thorough review of the scientific literature and consultation with experts, MUS-focused policy and investment offer three opportunities or innovations to advance MUS in support of the SDGs in low- and middle-income countries. New knowledge and engineering innovation may support a revitalized agenda for MUS, an agenda that targets context-specific synergistic pathways to enhance water, nutrition, and food security rather than simply focusing on water access. Therefore, the persistence of *de facto* MUS and self-supply, paired with climate threats and new technologies may finally persuade water management institutions to adjust their local institutional and governance regimes to support MUS opportunities. There is one important caveat to this conclusion. While this technical report reviewed the potential of MUS to advance food–water–nutrition security synergies, it also revealed that ***the empirical basis for MUS performance is very limited***. Case studies are dated and restricted to the original MUS project, and other studies are spotty and limit our confidence in their generalizability.

A common thread in assessments of the barriers to advancing MUS reflects a paradox: MUS benefits are derived from everyday water needs and context-specific resources and limits. Multiple-use water services operate locally in communities, geographies and with resource realities that preclude top-down management. Local actors interpret interventions in their own way, reassembling and integrating different elements of these interventions into their water use practices. In so doing, MUS create sui generis forms of water governance that recognize and build on established community norms in ways that government institutions and sectoral systems cannot. However, institutionalization (and access to finance and investment) demand that MUS be governed by a common policy and technical guidelines, which, as noted, belie the documented reality of these services. The question is: what policy frameworks can provide opportunities for investment and financial accountability without standardizing the MUS approach to the point the benefits are not realized? More critically, what policy frameworks can overcome the technical and regulatory barriers to MUS institutionalization without compromising promised benefits?

5.1 TARGETED INNOVATIONS

Multiple-use water services may be most successful if they are not scaled, but rather based on a ***targeted and transferable model***. Such services have the potential to address specific water, food, and nutrition security challenges. As such, interventions to enhance water, food and nutrition security should be built on existing practices rather than challenging the sectoral structures that are governed from national levels to local agencies. Instead, investment should focus on multiple-use water systems that are small-scale and decentralized or even off-grid; such systems have the institutional and design flexibility to overcome sectoral barriers. Many reports on MUS reflect this call for flexibility. As discussed above, the benefits of MUS are best realized through a multipurpose infrastructure, whether *de facto* or *by design* (Holm *et al.*, 2021). Multiple use water systems can support small-scale irrigation, rainwater harvesting, or small-scale rural water supply systems when the institutional arrangements or governance remain at the local scale where these technical and political measures can best be managed.

The principle of supporting water provision at a smaller scale is called “system scaffolding” (Walters *et al.*, 2022). The scaffold concept suggests that interventions are designed to strengthen existing system structures. Some research has suggested that such interventions could enhance MUS in existing rural water systems (Holm *et al.*, 2021). For example, a study in Malawi found that a maximum of 25 household beneficiaries of a multiple-use water use system designed around a shallow well with a handpump is optimal. They also noted that stored rainwater, if made accessible, could also increase community access to water for domestic and productive purposes. While conditions across low- and middle- income countries differ, the consensus is that working with existing systems rather than establishing new ones may yield faster returns. The strategy is to work around institutional path dependencies and offer change that, however modest, may lead to significant progress (Furlong, 2011).

Some studies have indicated the potential for small-scale irrigation to kick-start irrigation-plus MUS (Stedman *et al.*, 2018), but note that this needs to be combined with a set of interventions that include reliable and sustainable local technology for lifting water and improved access to markets and inputs to support high-value cash crops on irrigated land. Small-scale irrigation brings together local water governance systems that include community-level irrigation and borehole committees, the private sector, local government ministries and development partners. This local approach would support the optimization of water for productive activities while balancing the quantity and quality of water available for household activities.

Next generation investment in MUS needs to fund the development of critical supply chains, capacity building and maintenance regimes ***to support novel technology packages that improve water quality***. Water quality is the major weakness of irrigation-plus MUS. As discussed above, any benefit of increased water availability – be it improved nutrition, food security, water security, productivity or health outcomes – can be quickly eroded if water quality is not maintained. There are opportunities to address this challenge by using novel technologies – solar, nanotechnology water filtration and purification and ICT – to address the major vulnerability of MUS.

Novel technologies offer opportunities to address the key technical challenges of water quality and conveyance that were not previously available to earlier MUS projects and interventions. Advances in these areas and, in some cases, a combination of technologies, like solar-powered water filtration (Kain *et al.*, 2017), hold the promise to overcome barriers that prevented rural households and communities from reaping the benefits of increased water availability. As research has demonstrated, MUS can generate economic benefits, and the willingness to pay for water improvements may provide sustainable opportunities to improve water quality to support health and nutrition outcomes. While it is beyond the scope of this report to detail the full range and configuration of such technologies, their use could support MUS in low- and middle-income countries in ways that enhance the benefits and overcome the barriers. The following examples illustrate how this might work in rural communities.

a) Solar-driven nanofiltration. Solar-driven systems for off-grid nanofiltration (NF) and electrification can support household water and energy needs, and introduce opportunities for households to use domestic water for a broad range of productive activities (domestic plus). Cutting-edge research has demonstrated that household-scale, solar-driven NF system designs are can satisfy point-of-use water purification objectives for which central infrastructure is economically infeasible (Monjezi *et al.*, 2020). A system, developed by Monjezi *et al.* (2020) with the Navajo Nation in the United States of America, produced 378 litres of water per day from contaminated groundwater and 2 kilowatt-hours of excess electrical energy for nighttime use. In the context of the MUS water ladder, this volume of water, while not calculated per capita, represents a significant increase of water services (100 LPCD) for productive and domestic tasks. The results, while preliminary, illustrate the practical utility of off-grid infrastructure development that can be applied in similarly isolated communities with modestly different demands for water and power. Further assessments are necessary to determine willingness to pay, operational training needs and maintenance requirements for these systems. Moreover, we recognize that water quality issues are highly variable across low- and middle-income countries and local contexts, and clearly the effectiveness of solar-driven NF will require considerable research to address those specifications. However, the potential to support domestic-plus systems and increase clean water for a range of uses with these technologies merits further exploration.

b) Solar-powered pumping and water filtration for small-scale irrigators. Distributed, renewable energy sources are making limited inroads in rural communities in the form of solar power for water lifting and irrigation (Lefore, Closas and Schmitter, 2021; Rahman *et al.*, 2022; Guno and Agaton, 2022; Assefa *et al.*, 2020). Solar pumps have been proven to be a reliable economic solution for irrigation. Solar pump systems include supply chain linkages, capacity building and other support needed for small-scale irrigators to benefit. For example, as noted above, current work with small-scale irrigators in sub-Saharan Africa engages private sector supply chains and microfinancing to support solar water lifting technologies. For small-scale irrigators utilizing solar energy for productive purposes, further benefits may be generated by codesigning these systems to lift water for irrigation and to clean water for domestic use. The results of willingness-to-pay studies provide some evidence that farmers may support system upgrades (Stedman *et al.*, 2018.)

c) Improving water quality for rainwater capture. Brazilian policies to support rainwater harvesting in rural areas for both productive and domestic water uses are well known (Gomes *et al.*, 2014). However water quality has been a confounding factor in optimizing the potential benefits. Brazilian scientists have recently tested ultrafiltration to conclude that treated rainwater meets the requirements of Brazilian regulations and the European Directive on the quality of water for human consumption. (Miorando, Brião and Girardelli, 2017). The two tested membrane technologies satisfactorily removed the parameters that made rainwater unfit for human consumption. Rainwater is easy to capture and of reasonable quality. The fact that the ultrafiltration process is sufficient to make it drinkable is an opportunity for MUS.

5.2 RESEARCH FOR DEVELOPMENT

A new research-for-development (R4D) architecture is needed to support investment in MUS due to the uneven evidentiary and monitoring basis for achieving critical goals. This report has identified major gaps in scientific evidence for MUS benefits, especially related to health outcomes. Researchers on MUS have recognized that transferring or extending MUS in new projects is often not feasible "due to the lack of a unified data collection and modeling framework" (Hall *et al.*, 2017). A thorough review of the peer-reviewed science reveals this major gap in basic understanding of the benefits and limitations of MUS. In response, Hall *et al.* (2017) proposed a unified modeling framework with multilevel models that consider local contexts and constraints to MUS interventions. This effort, while admirable, has not been sufficient to provide the evidentiary basis needed to sustain a new generation of MUS development. The technologies are too new and the contexts are too dynamic. Moreover, a lack of direct metrics for modeling and evaluation limits the possibilities for institutional investment. Therefore, to optimize existing efforts, especially with the integration of new technology, there is a major need to establish a ***research platform and monitoring systems*** that tracks a broad range of benefits and synergies of different forms of MUS that incorporate the technologies into deployment, performance and governance.

FAO defines resilience as:

"The ability to prevent disasters and crises as well as to anticipate, absorb, accommodate, or recover from them in a timely, efficient, and sustainable manner. This includes protecting, restoring, and improving livelihoods systems in the face of threats that impact agriculture, nutrition, food security and food safety."

5.3 POLICY OPPORTUNITIES TO ALIGN WITH FAO STRATEGIES: ENHANCING THE CLIMATE RESILIENCE OF RURAL LIVELIHOODS

Resilience in the face of climate shocks and stresses requires innovation to create opportunities for vulnerable communities to avert disasters and anticipate, absorb, or recover from them in a timely manner. Resilience strategies need to be embedded in the institutional, social, economic and environmental dimensions of decision-making in local communities. Moreover, there is a need for a common yet integrated framework that addresses risk reduction anchored to short- and longer-term interventions. Cross-sectoral coordination is needed to reduce risks and build resilience against climate change. As FAO's *The State of the World's Land and Water Resources for Agriculture* (2022) notes, the status of land, soil and water resources have deteriorated to a breaking point: "The impacts of climate change are already constraining rainfed and irrigated production over and above the environmental consequences resulting from decades of unsustainable use." (FAO, 2022, p. xvi).

The pressing needs for climate resilience described above stand in stark relief to the poor record of resiliency planning by the water sector. Just 45 percent of responding countries in the 2021/22 Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) Survey – published by the World Health Organization and UN Water – reported that their country addresses climate change risk to WASH services in at least one national WASH policy or plan (WHO, 2022). Similar results are seen for climate resilience of WASH technologies and management systems. This leaves billions of people who lack safely-managed WASH services at high risk from climate shocks. In many regions, these poorly-served communities live in areas that are vulnerable to droughts, wildfires, coastal storms, or sea level rise. Climate shocks have immediate impact but, in the long-term, climate stress will also undermine community access to secure water for enhancing livelihoods.

The policy opportunities presented in this technical report offer climate-smart avenues for rethinking our response to the drivers, pressures and impacts of increasing resource challenges. The world needs a paradigm shift in how to diversify water access to ensure universal household access to a safe, reliable, affordable water supply in an era of climate change and socio-environmental disruption. To address this urgent need, policies to support MUS must take advantage of new technologies that can be reconfigured to produce, transport, and store clean water for increased water efficiency, productivity and cross-sector synergies (food–water–nutrition) in the absence of, or alongside, centralized water infrastructure. A revalued MUS approach may provide opportunities to support the people that public policies consistently fail and that are the most vulnerable to climate shocks and stress.

Policies to support decentralized and innovative MUS align with the aspirations of the FAO strategic framework and those of member countries for: "better production, better nutrition, a better environment and a better life." (FAO, 2021) Such an approach to MUS opens up opportunities to increase household water security and pathways to food and nutrition security, especially if it uses novel technologies to address water quality risks. This aligns with FAO's *State of Land and Water Resources Report* (2022), Action Area III, which calls for embracing innovative technologies and management that enhance "better nutrition per drop," linking water, agriculture, and nutrition. A commitment to novel technologies – solar, nanotechnology water filtration and purification, and ICT– in ways that address the major vulnerability of MUS will be needed to ensure the benefits of water–food–nutrition security. In the end, innovative MUS investments can enhance the capacity of communities to build the resiliency of water and food systems.

References

Alvarez, P.J., Chan, C.K., Elimelech, M., Halas, N.J. & Villagrán D. 2018. Emerging opportunities for nanotechnology to enhance water security. *Nature Nanotechnology,* 13: 634–641.

Arnal, J.A., Fernández, M.S., Verdú, G.M. & García, J.L. 2001. Design of a membrane facility for water potabilization and its application to Third World countries. *Desalination,* 137: 63–69.

Arora, M., Malano, H. Davidson, B., Nelson, R. & George, B. 2015. Interactions between centralized and decentralized water systems in urban context: a review. *Wiley Interdisciplinary Reviews: Water,* 2**:** 623–634.

Assefa, T.T., Adametie, T.F., Yimam, A.Y., Belay, S.A., Degu, Y.M., Hailemeskel, S.T., Tilahun, S.A., Reyes, M.R. & Prasad, P.V. 2020. Evaluating irrigation and farming systems with solar MajiPump in Ethiopia. *Agronomy*, 11: 17.

Aumeier, B.M., Graul, H., Müller, A.-K., Lackmann, C., Wünsch, R., Wintgens, T., Hollert, H. & Wessling, M. 2020. The hydrothermal solution for self-sustaining drinking water purification at point of use. *Water Research,* 170: 115338.

Barnes, J. 2014. *Cultivating the Nile: the everyday politics of water in Egypt*. Durham, USA, Duke University Press.

Behera, U.K., Panigrahi, P. & Sarangi, A. 2012. Multiple water use protocols in integrated farming system for enhancing productivity. *Water Resources Management,* 26: 2605–2623.

Blakstad, M.M., Mosha, D., Bellows, A.L., Canavan, C.R., Chen, J.T., Mlalama, K., Noor, R.A., Kinabo, J., Masanja, H. & Fawzi, W.W. 2021. Home gardening improves dietary diversity, a cluster‐randomized controlled trial among Tanzanian women. *Maternal & Child Nutrition,* 17: e13096.

Blakstad, M.M., Mosha, D., Bliznashka, L., Bellows, A.L., Canavan, C.R., Yussuf, M.H., Mlalama, K., Madzorera, I., Chen, J.T. & Noor, R.A. 2022. Are home gardening programs a sustainable way to improve nutrition? Lessons from a cluster-randomized controlled trial in Rufiji, Tanzania. *Food Policy,* 109: 102248.

Boelee, E. & Laamrani, H. 2004. Environmental control of schistosomiasis through community participation in a Moroccan oasis. *Tropical Medicine & International Health,* 9: 997–1004.

Boelee, E., Laamrani, H. & Van der Hoek, W. 2007. Multiple use of irrigation water for improved health in dry regions of Africa and South Asia. *Irrigation and Drainage,* 56: 43–51.

Brewis, A., Choudhary, N. & Wutich, A. 2019. Low water access as a gendered physiological stressor: blood pressure evidence from Nepal. *American Journal of Human Biology,* 31: e23234.

Brewis, A., Rosinger, A., Wutich, A., Adams, E., Cronk, L., Pearson, A., Workman, C., Young, S. & Household Water Insecurity Experiences – Research Coordination Network (HWISE – RCN). 2019. Water sharing, reciprocity and need: a comparative study of interhousehold water transfers in sub‐Saharan Africa. *Economic Anthropology,* 6: 208–221.

Brewis A, Workman C, Wutich A, Jepson W, Young S; Household Water Insecurity Experiences - Research Coordination Network (HWISE-RCN). Household water insecurity is strongly associated with food insecurity: Evidence from 27 sites in low- and middle-income countries. Am J Hum Biol. 2020 Jan;32(1):e23309. doi: 10.1002/ajhb.23309. Epub 2019 Aug 24. PMID: 31444940; PMCID: PMC9942689.

Choudhary, N., Schuster, R.C., Brewis, A. & Wutich, A. 2021. Household water insecurity affects child nutrition through alternative pathways to WASH: evidence from India. *Food and Nutrition Bulletin,* 42: 170–187.

Clement, F., Pradhan, P. & Van Koppen, B. 2019. Understanding the non-institutionalization of a socio-technical innovation: the case of multiple-use water services (MUS) in Nepal. *Water International,* 44: 408–426.

Colchester, F.E., Marais, H.G., Thomson, P., Hope, R. & Clifton, D.A. 2017. Accidental infrastructure for groundwater monitoring in Africa. *Environmental Modelling & Software,* 91: 241–250.

Collins, S.M., Mbullo Owuor, P., Miller, J.D., Boateng, G.O., Wekesa, P., Onono, M. & Young, S.L. 2019. "I know how stressful it is to lack water!" Exploring the lived experiences of household water insecurity among pregnant and postpartum women in western Kenya. *Global Public Health,* 14: 649–662.

Dominguez, I.C., Torres-López, W., Restrepo-Tarquino, I., Oviedo-Ocaña, R. & Smout, I. 2014. Livelihoods, access to water and water consumption in a rural system for multiple uses. *Ingenieria y Universidad,* 18.

Dongare, P.D., Alabastri, A., Pedersen, S., Zodrow, K.R., Hogan, N.J., Neumann, O., Wu, J., Wang, T., Deshmukh, A. & Elimelech, M. 2017. Nanophotonics-enabled solar membrane distillation for off-grid water purification. *Proceedings of the National Academy of Sciences,* 114: 6936–6941.

Evans, A.E., Mateo-Sagasta, J., Qadir, M., Boelee E. & Ippolito, A. 2019. Agricultural water pollution: key knowledge gaps and research needs. *Current Opinion in Environmental Sustainability,* 36: 20–27.

FAO (Food and Agriculture Organization of the United Nations). 2022 *The State of the World's Land and Water Resources for Food and Agriculture – systems at breaking point*. Main report. Rome. https://doi.org/10.4060/cb9910en

FAO Capacity Development, 2023. https://www.fao.org/capacity-development/resources/good-practices/resilience/en/#:~:text=FAO%20defines%20resilience%20as%20%22the,timely%2C%20efficient%20and%20sustainable%20manner.

FAO (Food and Agriculture Organization of the United Nations) 2021 Strategic Framework 2022-31. Rome. www.fao.org/pwb

Furlong, K. 2011. Small technologies, big change: rethinking infrastructure through STS and geography. *Progress in Human Geography,* 35: 460–482.

Garrick, D., De Stefano, L., Yu, W., Jorgensen, I., O'Donnell, E., Turley, L., Aguilar-Barajas, I., Dai, X., de Souza Leão, R. & Punjabi, B. 2019. Rural water for thirsty cities: a systematic review of water reallocation from rural to urban regions. *Environmental Research Letters,* 14: 043003.

Geere, J.-A.L., Cortobius, M., Geere, J.H., Hammer, C.C. & Hunter, P.R. 2017. Is water carriage associated with the water carrier's health? A systematic review of quantitative and qualitative evidence. *BMJ Global Health, 3(3): e000764.*

Gomes, U.A., Heller, L., Cairncross, S., Domenèch. L. & Pena, J.L. 2014. Subsidizing the sustainability of rural water supply: the experience of the Brazilian rural rainwater-harvesting programme. *Water International,* 39: 606–619.

Guno, C.S. & Agaton, C.B. 2022. Socio-economic and environmental analyses of solar irrigation systems for sustainable agricultural production. *Sustainability*, 14: 6834.

Hall, R., Van Koppen, B. & Van Houweling, E. 2014. The human right to water: the importance of domestic and productive water rights. *Science and Engineering Ethics,* 20, 849–868.

Hall, R., Vance, E. & Van Houweling, E. 2014. The productive use of rural piped water in Senegal. *Water Alternatives, 7.*

Hall, R., Vance, E. & Van Houweling, E. 2015. Upgrading domestic-plus systems in rural Senegal: an incremental income-cost (ic) analysis. *Water Alternatives,* 8.

Hall, R., Ranganathan, S. & GC, R.K. 2017. A general micro-level modeling approach to analyzing interconnected SDGs: achieving SDG 6 and more through multiple-use water services (MUS). *Sustainability,* 9: 314.

Haque, M.S.S., Al Islam, W., Ferdousi, T.R., Oyshee. S.S. & Tamim, T.M. 2021. An approach of implementing IoT-based rooftop rainwater harvesting & monitoring. In: *2021 IEEE International Conference on Robotics, Automation, Artificial-Intelligence and Internet-of-Things (RAAICON)*, 60–63. IEEE Held 3-4 December 2021, Dhaka, Bangladesh..

Holm, R.H., Hall, R.P., Muthukrishnan, S., Munthali, T. & Sinda, M. 2021. Promoting multiple-use water services by leveraging existing rural water supply and smallholder farmer groups, Malawi. *International Journal of Water Resources Development,* 37: 321–338.

Hussain, I., Abu-Rizaiza, O.S., Habib, M.A.A. & Ashfaq, M. 2008. Revitalizing a traditional dryland water supply system: the karezes in Afghanistan, Iran, Pakistan and the Kingdom of Saudi Arabia. *Water International,* 33: 333–349.

Jeil, E.B., Abass, K. & Ganle, J.K. 2020. "We are free when water is available." Gendered livelihood implications of sporadic water supply in Northern Ghana. *Local Environment,* 25: 320–335.

Jepson, W. 2014. Measuring 'no-win' waterscapes: experience-based scales and classification approaches to assess household water security in colonias on the US–Mexico border. *Geoforum,* 51: 107–120.

Jepson, W. & Brown, H.L. 2014. 'If no gasoline, no water': privatizing drinking water quality in South Texas colonias. *Environment and Planning A,* 46: 1032–1048.

Jepson, W., Budds, J., Eichelberger, L., Harris, L., Norman, E., O'Reilly, K., Pearson, A., Shah, S., Shinn, J., Staddon, C., Stoler, J., Wutich, A. & Young, S. 2017. Advancing human capabilities for water security: a relational approach. *Water Security,* 1: 46–52.

Jepson, W. & Vandewalle, E. 2016. Household water insecurity in the Global North: a study of rural and periurban settlements on the Texas–Mexico border. *The Professional Geographer,* 68: 66–81.

Jepson, W., Wutich, A. & Harris, L. 2019. Water-security capabilities and the Human Right to Water. In: F. Sultana & A. Loftus, eds. *Water Politics,* New York, Earthscan.

Jepson, W.E., Stoler, J., Baek, J., Martínez, J.M., Salas, F.J.U. & Carrillo, G. 2021. Cross-sectional study to measure household water insecurity and its health outcomes in urban Mexico. *BMJ Open,* 11: e040825.

Kain, G., Hunt, R., Noto, J., Prine, J., Brown, C. & Compere, M. 2017. Off-grid solar powered water purification and community development in Haiti's Artibonite valley, the heart of Haiti's cholera epidemic. *2017 IEEE Global Humanitarian Technology Conference (GHTC)*, 1-11. IEEE. California USA – October 19 – 22, 2017

Kanyoka, P., Farolfi, S. & Morardet. S. 2008. Households' preferences and willingness to pay for multiple-use water services in rural areas of South Africa: an analysis based on choice modelling. *Water SA,* 34: 715–723.

Koehler, J., Thomson, P. & Hope, R. 2015. Pump-priming payments for sustainable water services in rural Africa. *World Development,* 74: 397–411.

Krumdieck, N.R., Collins, S.M., Wekesa, P., Mbullo, P., Boateng, G.O., Onono, M. & Young, S.L. 2016. Household water insecurity is associated with a range of negative consequences among pregnant Kenyan women of mixed HIV status. *Journal of Water and Health,* 14: 1028–1031.

Laurie, N. 2005. Establishing development orthodoxy: negotiating masculinities in the water sector. *Development and Change,* 36: 527–549.

Leder, S., Clement, F. & E. Karki, E. 2017. Reframing women's empowerment in water security programmes in Western Nepal. *Gender & Development,* 25, 235–251.

Lefore, N., Giordano, M.A., Ringler, C. & Barron, J. 2019. Sustainable and equitable growth in farmer-led irrigation in sub-Saharan Africa: what will it take? *Water Alternatives*, 12(1): 156–168.

Lefore, N., Closas, A. & Schmitter, P. 2021. Solar for all: a framework to deliver inclusive and environmentally sustainable solar irrigation for smallholder agriculture. *Energy Policy*, 154: 112313.

Linton, J. 2010. *What is water?: The history of a modern abstraction*. Vancouver, Canada, University of British Columbia Press.

Mao, F., Khamis, K., Clark, J., Krause, S., Buytaert, W., Ochoa-Tocachi, B.F. & Hannah, D.M. 2020. Moving beyond the technology: a socio-technical roadmap for low-cost water sensor network applications. *Environmental Science & Technology*, 54(15): 9145–9158.

Mattos, K., Warren, J., Eichelberger, L., Kaminsky, J. & Linden, K.G. 2021. Pathways to the successful function and use of mid-tech household water and sanitation systems. *Journal of Water, Sanitation and Hygiene for Development,* 11: 994–1005.

Meijer, K., Boelee, E., Augustijn, D. & Van der Molen, I. 2006. Impacts of concrete lining of irrigation canals on availability of water for domestic use in southern Sri Lanka. *Agricultural Water Management,* 83: 243–251.

Meinzen-Dick, R. 2001. Water rights and multiple water uses framework and application to Kirindi Oya Irrigation System Sri Lanka. *Irrigation and Drainage Systems,* 15: 129–148.

Meinzen-Dick, R. & Bakker, M. 1999. Irrigation systems as multiple-use commons: water use in Kirindi Oya, Sri Lanka. *Agriculture and Human Values,* 16: 281–293.

Meinzen-Dick, R. & Van der Hoek, W. 2001. Multiple uses of water in irrigated areas. *Irrigation and Drainage Systems,* 15: 93–98.

Miller, J.D., Vonk, J., Staddon, C. & Young, S.L. 2020. Is household water insecurity a link between water governance and well-being? A multi-site analysis. *Journal of Water, Sanitation and Hygiene for Development,* 10: 320–334.

Miller, J.D., Workman, C.L., Panchang, S.V., Sneegas, G., Adams, E.A., Young, S.L. & Thompson, A.L. 2021. Water security and nutrition: current knowledge and research opportunities. *Advances in Nutrition,* 12: 2525–2539.

Minh, T., Cofie, O., Lefore, N. & Schmitter, P. 2020. Multi-stakeholder dialogue space on farmer-led irrigation development in Ghana: an instrument driving systemic change with private sector initiatives. *Knowledge Management for Development Journal,* 15: 98–118.

Miorando, T., Brião, V.B. & Girardelli, L. 2017. Potabilização de água da chuva por ultrafiltração. *Engenharia Sanitaria e Ambiental,* 22: 481–490.

Molden, D. 1997. *Accounting for water use and productivity*. Colombo, Sri Lanka, IWMI (International Water Management Institute).

Molle, F., Mollinga, P.P. & Wester, P. 2009. Hydraulic bureaucracies and the hydraulic mission: flows of water, flows of power. *Water Alternatives,* 2: 328-349.

Monjezi, A.A., Chen, Y., Vepa, R., Kashyout, A.E.-H.B., Hassan, G., Fath, H.E.-B., Kassem, A.E.-W. & Shaheed, M.H. 2020. Development of an off-grid solar energy powered reverse osmosis desalination system for continuous production of freshwater with integrated photovoltaic thermal (PVT) cooling. *Desalination,* 495: 114679.

Moriarty, P. & Butterworth, J.A. 2004. *Beyond domestic: case studies on poverty and productive uses of water at the household level.* The Hague, Netherlands, IRC International Water and Sanitation Centre.

Mushavi, R.C., Burns, B.F., Kakuhikire, B., Owembabazi, M., Vořechovská, D., McDonough, A.Q., Cooper-Vince, C.E., Baguma, C., Rasmussen, J.D. & Bangsberg, D.R. 2020. "When you have no water, it means you have no peace": a mixed-methods, whole-population study of water insecurity and depression in rural Uganda. *Social Science & Medicine,* 245: 112561.

Mutero, C.M., McCartney, M. & Boelee, E. 2006. Agriculture, malaria, and water-associated diseases: understanding the links between agriculture and health. Washington, DC, IFPRI (International Food Policy Research Institute).

Mutondo, J., Farolfi, S. & Dinar, A. 2016. *Water governance decentralization in sub-Saharan Africa: between myth and reality*. Berlin, Springer.

Nounkeu, C.D. & Dharod, J.M. 2021. Integrated approach in addressing undernutrition in developing countries: a scoping review of integrated water access, sanitation, and hygiene (WASH)+ nutrition interventions. *Current Developments in Nutrition,* 5: nzab087.

Obeng-Odoom, F. 2012. Beyond access to water. *Development in Practice,* 22: 1135–1146.

Peter-Varbanets, M., , Zurbrügg, C., Swartz, C. & Pronk, W. 2009. Decentralized systems for potable water and the potential of membrane technology. *Water Research,* 43: 245–265.

Pichel, N., Vivar, M. & Fuentes, M. 2019. The problem of drinking water access: a review of disinfection technologies with an emphasis on solar treatment methods. *Chemosphere,* 218: 1014–1030.

Pickering, A.J., Null, C., Winch, P.J., Mangwadu, G., Arnold, B.F., Prendergast, A.J., Njenga, S.M., Rahman, M., Ntozini, R. & Benjamin-Chung, J. 2019. The WASH benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health,* 7: e1139-e1146.

Rahman, M.M., Khan, I., Field, D.L., Techato, K. & Alameh, K. 2022. Powering agriculture: present status, future potential, and challenges of renewable energy applications. *Renewable Energy*, 188: 731–749.

Raut, N., Shakya, A., Gurung, S. & Dahal, B.M. 2021. Adoption of a multiple use water system (MUWS) to ensure water security for Nepalese hill farmers. *Water Policy,* 23: 239–254.

Rautanen, S.-L., Van Koppen, B. & Wagle, N. 2014. Community-driven multiple use water services: lessons learned by the Rural Village Water Resources Management Project in Nepal. *Water Alternatives,* 7.

Renwick, M., Joshi, D., Huang, M., Kong, S., Petrova, S., Bennett, G., Bingham, R., Fonseca, C., Moriarty, P. & Smits, S. 2007. *Multiple-use water services for the poor: assessing the state of knowledge*. Arlington, USA, Winrock International.

Richards, B.S. & Schäfer, A.I.. 2021. Renewable energy‐powered nanofiltration. *Nanofiltration: Principles, Applications, and New Materials,* 2: 961–1020.

Ringler, C. & Dias, P. 2020. *Water and nutrition: harmonizing action for the United Nations Decade of Action on Nutrition and the United Nations Water Action Decade*. Report of the UN Standing Committee on Nutrition. New York, United Nations (UN).

Rosinger, A.Y. 2018. Household water insecurity after a historic flood: diarrhea and dehydration in the Bolivian Amazon. *Social Science & Medicine,* 197: 192–202.

Rosinger, A.Y., Brewis, A., Wutich, A., Jepson, W., Staddon, C., Stoler, J. & Young, S.L. 2020. Water borrowing is consistently practiced globally and is associated with water-related system failures across diverse environments. *Global Environmental Change,* 64: 102148.

Rosinger, A.Y. & Young, S.L. 2020. The toll of household water insecurity on health and human biology: current understandings and future directions. *Wiley Interdisciplinary Reviews: Water*, e1468.

Rusca, M., dos Santos, T., Menga, F., Mirumachi, N., Schwartz, K. & Hordijk, M. 2019. Space, state-building and the hydraulic mission: crafting the Mozambican state. *Environment and Planning C: Politics and Space,* 37: 868–888.

Sakketa, T. & Prowse, M. 2018. Women, wealth and waterborne disease: smallholders' willingness to pay for a multiple-use water scheme in Ethiopia. *The Journal of Development Studies,* 54: 2018.

Saul, C.J. & Gebauer, H. 2018. Digital transformation as an enabler for advanced services in the sanitation sector. *Sustainability,* 10: 752.

Senzanje, A., Boelee, E. & Rusere, S. 2008. Multiple use of water and water productivity of communal small dams in the Limpopo Basin, Zimbabwe. *Irrigation and Drainage Systems,* 22, 225–237.

Sharma, B.R., Riaz, M., Pant, D., Adhikary, D., Bhatt, B. & Rahman, H. 2010. *Water poverty in the northeastern hill region (India): potential alleviation through multiple-use water systems: cross-learnings from Nepal Hills*. Colombo, Sri Lanka, IWMI.

Shrestha, G. & Clement, F. 2019. Unravelling gendered practices in the public water sector in Nepal. *Water Policy,* 21: 1017–1033.

Siemiatycki, M., Enright, T. & Valverde, M. 2020. The gendered production of infrastructure. *Progress in Human Geography,* 44: 297–314.

Smiley, S.L. & Stoler, J. 2020. Socio-environmental confounders of safe water interventions. *Wiley Interdisciplinary Reviews: Water,* 7: e1438.

Smits, S., Van Koppen, B., Moriarty, P. & Butterworth, J. 2010. Multiple-use services as alternative to rural water supply services – a characterisation of the approach. *Water Alternatives,* 3: 102.

Sneddon, C. 2015. *Concrete revolution: large dams, Cold War geopolitics, and the US Bureau of Reclamation*. Chicago, USA, University of Chicago Press.

Staddon, C., Rogers, J., Warriner, C., Ward, S. & Powell, W. 2018. Why doesn't every family practice rainwater harvesting? Factors that affect the decision to adopt rainwater harvesting as a household water security strategy in central Uganda. *Water International,* 43: 1114–1135.

Stedman, S., Mnyimbiri, A.M., Kawonga, Z., Malota, M., Njera, D., Hall, R.P. & Holm, R.H. 2018. Using irrigation to kick-start multiple-use water services for small-scale farmers in Malawi: a case study of the Nkhata Bay District. *Irrigation and Drainage,* 67: 645–653.

Stoler, J., Brewis, A., Harris, L.M., Wutich, A., Pearson, A.L., Rosinger, A.Y., Schuster, R.C. & Young, S.L. 2019. Household water sharing: a missing link in international health. *International Health,* 11: 163–165.

Stoler, J., Jepson, W., Wutich, A., Velasco, C.A., Thomson, P., Staddon, C. & Westerhoff, P. 2022. Modular, adaptive, and decentralised water infrastructure: promises and perils for water justice. *Current Opinion in Environmental Sustainability,* 57: 101202.

Stoler, J., Pearson, A.L., Staddon, C., Wutich, A., Mack, E., Brewis, A., Rosinger, A.Y., Adams, E., Ahmed, J.F. & Alexander, M. 2020. Cash water expenditures are associated with household water insecurity, food insecurity, and perceived stress in study sites across 20 low-and middle-income countries. *Science of the Total Environment,* 716: 135881.

Sultana, F. 2013. Water, technology, and development: transformations of development technonatures in changing waterscapes. *Environment and Planning D: Society and Space,* 31: 337-353.

Sutton, S. & Butterworth, J. 2021. *Self-supply: filling the gaps in public water supply provision*. Rugby, UK, Practical Action Publishing.

Swyngedouw, E. 2015. *Liquid power: contested hydro-modernities in twentieth-century Spain*. Cambridge, USA, The MIT Press.

Thomson, P. 2021. Remote monitoring of rural water systems: a pathway to improved performance and sustainability? *Wiley Interdisciplinary Reviews: Water,* 8: e1502.

Thomson, P., Hope, R. & Foster, T. 2012a. GSM-enabled remote monitoring of rural handpumps: a proof-of-concept study. *Journal of Hydroinformatics,* 14: 829–839.

Thomson, P., Hope, R. & Foster, T. 2012b. Is silence golden? Of mobiles, monitoring, and rural water supplies. *Waterlines*, 31(4): 280–292.

Usman, M.A. & Gerber, N. 2020. Irrigation, drinking water quality, and child nutritional status in northern Ethiopia. *Journal of Water, Sanitation and Hygiene for Development,* 10: 425–434.

Usman, M.A. & Gerber, N. 2021. Assessing the effect of irrigation on household water quality and health: a case study in rural Ethiopia. *International Journal of Environmental Health Research,* 31: 433–452.

Van der Hoek, W., Feenstra, S.G. & Konradsen, F. 2002. Availability of irrigation water for domestic use in Pakistan: its impact on prevalence of diarrhoea and nutritional status of children. *Journal of Health, Population and Nutrition*, 20(1): 77–84.

Van der Horst, B. & Hebinck, P. 2017. 'Irrigation by night'in the Eastern Cape, South Africa. *Water SA,* 43: 28–35.

Van Der Hoek, W., Konradsen, F. & Jehangir, W.A. 1999. Domestic use of irrigation water: health hazard or opportunity? *International Journal of Water Resources Development,* 15: 107–119.

Van Houweling, E., Hall, R.P., Diop, A.S., Davis, J. & Seiss, M. 2012. The role of productive water use in women's livelihoods: evidence from rural Senegal. *Water Alternatives,* 5(3): 658–677.

Van Koppen, B. 2009. *Climbing the water ladder: multiple-use water services for poverty reduction*. Colombo, Sri Lanka, IWMI.

Van Koppen, B. 2018. Gender and water. In: K. Conca and E. Weithal, eds. *The Oxford handbook of water politics and policy*, pp. 76–99. Oxford, UK, Oxford University Press.

Van Koppen, B., Moriarty, P. & Boelee, E. 2006. *Multiple-use water services to advance the millennium development goals*. Colombo, Sri Lanka, IWMI.

Van Koppen, B. & Schreiner, B. 2014. Moving beyond integrated water resource management: developmental water management in South Africa. *International Journal of Water Resources Development,* 30: 543–558.

Van Koppen, B., Smits, S., del Rio, C.R. & Thomas, J. 2014. *Scaling up multiple-use water services: accountability in the water sector*. Colombo, Sri Lanka, IWMI.

Van Koppen, B., Smits, S. & Mikhail, M. 2009. Homestead-and community-scale multiple-use water services: unlocking new investment opportunities to achieve the Millennium Development Goals. *Irrigation and Drainage,* 58: S73–S86.

Van Koppen, B., Smits, S., Moriarty, P., de Vries, F.P., Mikhail, M. & Boelee, E. 2009. The multiple-use water services (MUS) project. *CPWF Project Report CGIAR, CGSpaceA Repository of Agricultural Research Outputs* .

Venkataramanan, V., Geere, J.-A.L., Thomae, B., Stoler, J., Hunter, P.R. & Young, S.L. 2020. In pursuit of 'safe'water: the burden of personal injury from water fetching in 21 low-income and middle-income countries. *BMJ Global Health,* 5: e003328.

Vries, F.W. 2007. Learning alliances for the broad implementation of an integrated approach to multiple sources, multiple uses and multiple users of water. *Water Resources Management,* 21: 79–95.

Walters, J., Valcourt, N., Linden, K., Javernick-Will, A. & Lockwood, H. 2022. Challenges and solutions to rural water service sustainability in East African countries: a 'systems scaffolding'perspective. *Environmental Science & Policy,* 136: 564–574.

Wang, X. & Hunter, P.R. 2010. A systematic review and meta-analysis of the association between self-reported diarrheal disease and distance from home to water source. *The American Journal of Tropical Medicine and Hygiene,* 83(3): 582–584.

Winter, J.C., Darmstadt, G.L. & Davis, J. 2021. The role of piped water supplies in advancing health, economic development, and gender equality in rural communities. *Social Science & Medicine,* 270: 113599.

World Health Organization. 2022. *Strong systems and sound investments: evidence on and key insights into accelerating progress on sanitation, drinking-water and hygiene. The UN-Water global analysis and assessment of sanitation and drinking-water (GLAAS) 2022 report*. Geneva, Switzerland.

Wutich, A. & Brewis, A. 2014. Food, water, and scarcity: toward a broader anthropology of resource insecurity. *Current Anthropology,* 55: 444–468.

Wutich, A., Brewis, A., Chavez, J.B.R. & Jaiswal, C.L. 2015. Water, worry, and Dona Paloma: why water security is fundamental to global mental health. In: B.A. Kohrt & E. Mendenhall, eds. *Global Mental Health: Anthropological Perspectives,* pp. 57–71.

Wutich, A., Brewis, A. & Tsai, A. 2020. Water and mental health. *WIREs Water*: e1461.

Wutich, A., Budds, J., Jepson, W., Harris, L.M., Adams, E., Brewis, A., Cronk, L., DeMyers, C., Maes, K. & Marley, T. 2018. Household water sharing: a review of water gifts, exchanges, and transfers across cultures. *Wiley Interdisciplinary Reviews: Water,* 5: e1309.

Wutich, A., Jepson, W.E., Stoler, J., Thomson, P., Kooy, M., Brewis, A., Staddon, C. & Meehan, K. 2021. A global agenda for household water security: measurement, monitoring, and management. *Journal of the American Water Resources Association,* 57: 530–538.

Wutich, A. & Ragsdale, K. 2008. Water insecurity and emotional distress: coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement. *Social Science & Medicine,* 67: 2116–2125.

Xu, S., Lu, D., Qi, J., Wang, P., Zhao, Y., Zhang, H. & Ma, J. 2021. Gravity-driven multifunctional microporous membranes for household water treatment: simultaneous pathogenic disinfection, metal recycling, and biofouling mitigation. *Chemical Engineering Journal,* 410: 128289.

Young, S.L., Bethancourt, H.J., Ritter, Z.R. & Frongillo, E.A. 2021. The Individual Water Insecurity Experiences (IWISE) Scale: reliability, equivalence and validity of an individual-level measure of water security. *BMJ Global Health,* 6, e006460.

Young, S.L., Boateng, G.O., Jamaluddine, Z., Miller, J.D., Frongillo, E.A., Neilands, T.B., Collins, S.M., Wutich, A., Jepson, W.E. & Stoler. J. 2019. The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. *BMJ Global Health,* 4: e001750.

Young, S.L., Collins, S.M., Boateng, G.O., Neilands, T.B., Jamaluddine, Z., Miller, J.D., Brewis, A.A., Frongillo, E.A., Jepson, W.E. & Melgar-Quiñonez, H. 2019. Development and validation protocol for an instrument to measure household water insecurity across cultures and ecologies: the Household Water InSecurity Experiences (HWISE) Scale. *BMJ Open,* 9: bmjopen-2018-023558.

Young, S.L., Frongillo, E.A., Jamaluddine, Z., Melgar-Quiñonez, H., Pérez-Escamilla, R., Ringler, C. & Rosinger, A.Y. 2021. Perspective: the importance of water security for ensuring food security, good nutrition, and well-being. *Advances in Nutrition,* 12: 1058–1073.

Zavala, E., King, S.E., Sawadogo-Lewis. T. & Roberton, T. 2021. Leveraging water, sanitation and hygiene for nutrition in low- and middle-income countries: a conceptual framework. *Maternal & Child Nutrition,* 17: e13202.

Zeitoun, M., Lankford, B., Krueger, T., Forsyth, T., Carter, R., Hoekstra, A.Y., Taylor, R., Varis, O.,Cleaver, F. & Boelens, R. 2016. Reductionist and integrative research approaches to complex water security policy challenges. *Global Environmental Change,* 39: 143–154.

Zwarteveen, M. 2008. Men, masculinities and water powers in irrigation. *Water Alternatives,* 1(1): 111–130.

Zwarteveen, M. 2017. Hydrocracies, engineers and power: questioning masculinities in water. *Engineering Studies,* 9: 78–94.

19
LAND AND WATER DISCUSSION PAPER

Revaluing multiple-use water services for food and water security

Water is an indispensable resource that lies at the heart of sustenance and prosperity for communities worldwide. In lower and middle-income countries, households and communities have long relied on a single water source to fulfill a multitude of needs, encompassing drinking, washing, cooking, livestock raising, and irrigation. Traditional water supply systems have served as hydraulic structures for multiple purposes, catering to diverse water requirements.

As countries progressed towards modernization, the emphasis shifted towards single-use water infrastructure, inadvertently neglecting the multifaceted nature of water demands that contribute to people's livelihoods. In developing countries, water resources management centered around large-scale irrigation and water development projects to spur economic growth. Infrastructure, institutions, policies, and practices were organized around single-use sectors. Consequently, prevailing models of water modernization unintentionally disregarded or even discouraged the acknowledgement of multiple uses.

This technical report, produced by FAO in collaboration with the Texas A&M University, aims to provide an overview of multiple-use water services (MUS) in international development. Its objective is to enable a fresh assessment of MUS as a means to achieve the goals of nutrition and food security, water security, and human health, in line with the 2030 Agenda for Sustainable Development. Considering the background information and identifying the evidence gaps, the report presents a new framework for continued research, policy development, and targeted investment in MUS interventions. These interventions have the potential to enhance water, food, and nutrition security while advancing the social goal of gender empowerment.

The publication advocates for policymakers to focus on targeted interventions that leverage existing infrastructure and institutions, integrating the private sector into next-generation technologies. By doing so, we can overcome previous barriers and move beyond pilot programs to foster global initiatives that leave no one behind.

ISBN 978-92-5-138064-2 ISSN 1729-0554
9 789251 380642
CC7317EN/1/08.23