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Increasing resilience through nudges in the urban water cycle: An integrative conceptual framework to support policy decision-making

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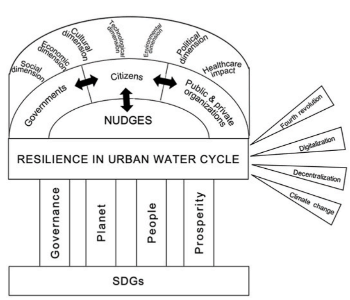
HIGHLIGHTS

- This framework extends the use of nudges to the overall urban water cycle.
- It considers 4th water revolution, digitalization, decentralization, climate change.
- It could be used by decision-makers in transit to a sustainable urban water cycle.

GRAPHICAL ABSTRACT



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ABSTRACT

Relevant challenges associated with the urban water cycle must be overcome to meet the United Nations Sustainable Development Goals (SDGs) and improve resilience. Unlike previous studies that focused only on the provision of drinking water, we propose a framework that extends the use of the theory of nudges to all stages of the overall urban water cycle (drinking water and wastewater services), and to agents of influence (citizens, organizations, and governments) at different levels of decision making. The framework integrates four main drivers (the fourth water revolution, digitalization, decentralization, and climate change), which influence how customers, water utilities and regulators approach the challenges posed by the urban water cycle. The proposed framework, based on the theory of nudges first advanced by the Nobel Prize in behavioral economics Richard H. Thaler and Cass R. Sunstein (Thaler and Sunstein, 2009), serves as a reference for policymakers to define medium- and long-term strategies and policies for improving the sustainability and resilience of the urban water

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cycle. Finally, we provide new insights for further research on resilience approaches to the management of the urban water cycle as an element to support the more efficient formulation of policies.

1. Introduction

Planning, designing and managing sustainable urban water systems in the context of climate change, population growth and aging infrastructure pose some of the greatest challenges for the 21st century (Larsen et al., 2016; Tortajada, 2020). To address these challenges, the water sector is undergoing a paradigmatic change (Sedlak, 2014): along with the traditional criteria (i.e. water quality/quantity, cost efficiency), decision-making now needs to include desiderates such as resilience and sustainable development goals (SDGs). Indeed, the United Nations explicitly recognized access to water and sanitation as human rights and the key role of such access in the realization of other human rights (United Nations, 2014). Moreover, the 6th Sustainable Development Goal (SDG) is to "ensure availability and sustainable management of water and sanitation for all" (United Nations, 2021). In turn, a more "resilient" water sector (Quitana et al., 2020; Kumar et al., 2020) is one that is able to safeguard a pertinent state within the socioecological system to support ecosystems and biomes, to maintain the stability of local weather and climate systems, and to boost the capability of the hydrological cycle to ensure a steady water supply for humans, all while protecting the current state of the biosphere and the Earth. Moving toward a resilient urban water cycle has been identified as an opportunity to tackle urban water challenges by providing a systemic approach to delivering water supply and sanitation services in a more sustainable, inclusive, and efficient way (Howard et al., 2021; Liu et al., 2022).

So far, this transformation in the urban water management has been addressed from a perspective which privileged technical solutions (Pahl Wostl, 2015). Thus, considerable advances have been registered in technologies such as reuse of wastewater and grey water or rainwater harvesting, known to improve the resilience and sustainability management of urban water systems (Peña-Guzmán et al., 2017). However, while the technical and economic aspects of this paradigm shift have been extensively explored, its socio-cognitive aspects remain largely understudied. The 'human dimension' of water management, entailing behavioral, political and societal complexities needs to be given enhanced consideration (Pahl Wostl, 2015).

To address this gap, this paper proposes a theoretical framework for decision-making in the water sector based on "nudge theory", first advanced by the Nobel Prize in behavioral economics Richard H. Thaler and Cass R. Sunstein (Thaler and Sunstein, 2009). This theory draws on latest advances in economics, evolutionary psychology, and cognitive science to propose policies based not on bans and impositions but on positive reinforcement and indirect suggestions and incentives as ways to shape the behavior and decision-making of groups or individuals (Thaler and Sunstein, 2009). In other words, nudges are intended to persuade people to make better judgments and engage in desirable practices while preserving their autonomy.

The concept of "nudge", as employed in this paper, is inspired by the observation of human behavior in situations when individuals need to take decisions, especially those that have delayed consequences, are challenging, infrequent, and do not give immediate feedback. It also applies to choices for which the connection between experiences and consequences is ambiguous. In these cases, people tend to react if "nudged" or encouraged to act in a certain direction. A set of options helps in nudging people in the direction of socially acceptable behaviors. The goal has been to determine how effective voluntary techniques may be in influencing positive behavioral change (Shove, 2010).

The research on the use of nudges in the urban water cycle is not new but, so far, studies have been limited to water conservation goals (see Section 2). We argue for a more holistic framework to facilitate both resilience and the pursuit of SDGs in the water sector: extending and operationalizing the potential use of nudges to the entire urban water cycle, thus integrating both drinking water and sanitation services in this conceptual toolbox. Moreover, the framework aims to increase the array of agents targeted by nudges, beyond the water users currently considered in the literature. Including water and sanitation providers and water regulators would make the nudges system more robust and able to enhance the resilience in the provision of drinking water and sanitation services.

Past research has addressed water-related topics such as resilience, driving forces for a new paradigm in urban water cycle and SDGs individually. However, the urban water cycle is a volatile, uncertain, complex and ambiguous (VUCA) system whose management needs a deliberately and socio-technical approach (Makropoulos and Savić, 2019). In this context and, as a first approximation to be developed and verified by future studies focused on case studies, we propose a conceptual framework to rethink the urban water cycle (i.e., water and sanitation services, considered as a complex system) and increase its resilience based on the use of nudges and integrating the pillars for resilience and the SDGs.

Our framework addresses the limitations of previous studies by considering the whole urban water cycle (i.e., both drinking water and wastewater services) and by proposing the use of nudges with various agents of action (citizens, organizations, and governments). The proposed framework could be used by decision-makers to facilitate the transition to a resilient and sustainable urban water cycle considering the ongoing transformation of and current challenges posed by urban water management.

Section 2 of this article introduces the concept of resilience of the urban water cycle, presenting the pillars for resilient development that are aligned with the SDGs and addressing the concept of resilience through nudges. Section 3 synthesizes previous insights in the application of the concept of resilience to the urban water cycle, both in the drinking water system and in the urban wastewater system. Section 4 describes the driving forces, as well as the agents and dimensions involved in the resilience of the urban water cycle. Finally, by applying the insights from the literature as a whole. Section 5 presents our new conceptual resilience framework for the urban water system.

2. Enhancing the resilience in the urban water cycle through nudges

The concept of resilience is critical to sustainability research. From Holling's early work and applications to socioecological systems (Holling, 1986), including in terms of adaptive management, and Pimm (1991) efforts to operationalize the concept clearly captures an important idea: the capacity of systems to resist the impact of forces, conserve their basic characteristics and, potentially, bounce back. Policies meant to enhance the resilience of urban socio-natural systems are closely linked to the SDGs, including SDG6 on clean water and sanitation for all, as they provide a roadmap for sustainable urbanization. The SDGs were adopted as a universal call to action to end poverty, protect the planet, and ensure that by 2030, all people enjoy peace and prosperity. The 2030 Agenda is a game-changing plan of action for governance, the planet, people, and prosperity (see later), which represent the four pillars for resilient development (Chidozie and Oluwatobi, 2017; Fox and Stoett, 2016; World Economic Forum, 2022). As a result, there is a constant focus on data collection and the requirement of consistently monitoring and reporting on SDG indicators to achieve resilience (Hatton et al., 2019).

Pursuing these goals as a society entails complex policymaking taking into account individual variables – attitudes, values, behaviors - and collective or governance components. Regarding the latter, climate change and managing common resources imply action dilemmas that require cooperation between individuals and communities (Velez and Moros, 2021). The urban water cycle is a VUCA system and therefore, increasing its resilience also requires cooperation among the stakeholders involved in its management (i.e., governments and organizations) and water users (i.e., citizens).

However, there are several socio-cognitive impediments or biases to human cooperation and coordination (Weber, 2017). Drawing on aspects of both psychology and economics, Kahneman and Tversky (1979) developed what later became known as behavioral economics and relied on the idea that cognitive biases often prevent people from making the best possible (or perfectly rational) decisions. The notion of situated or bounded rationality came across as a useful balance for the dominant and limiting concept of individual rationality: as humans, we take into consideration value frameworks, intersubjective relations, therefore we reason according to our concrete situation (Bendor, 2001). In the words of Richard Thaler and Cook et al. (2018), we are "humans" not "econs". These biases might be partially overcome by the presence of intrinsic types of motivation such as nudges (Festré and Garrouste, 2015).

A nudge is a policy intervention for redirecting an agent's choices by very slightly altering their choice conditions (Thaler and Sunstein, 2009). It contrasts with traditional public policies, which typically rely on bans, commands or manipulations of choice incentives (Mongin and Cozic, 2018). A nudge is any aspect of the choice architecture that alters people's behavior in a predictable way, without significantly changing their economic incentives (Thaler and Sunstein, 2009). Hence, nudges could be very useful to increase the resilience of the urban water cycle, as they address concomitantly individual and the collective components, driving motivation for desirable environmental behaviors.

Prior studies evidenced that policies based on nudges can help to implement effective and sustainable strategies in the urban water cycle (Miranda et al., 2020; Moglia et al., 2018; Nayar and Kanaka, 2017; Seger et al., 2019; Tortajada et al., 2019; Yoon et al., 2019). Nudges were previously used in urban water systems, mostly to minimize water use (Velez and Moros, 2021). The use of nudges in terms of social incentives in Cape Town resulted in an average reduction in water usage between 0.6% and 1.3% (Visser et al., 2021). Neighborhood comparisons in Costa Rica reduced drinking water by 4.9% relative to the control group, whereas a planning postcard intervention led to a reduction of 4.8% (Miranda et al., 2020). Another study found that after behavioral interventions in hotels, guests reduced their water consumption, even though they did not have any monetary incentive to do so (Joo et al., 2018). From a water quality perspective, positive and incremental effects could be found from all behavioral nudges applied to promote water treatment among rural households in Kenya and urban slums in Bangladesh (Luoto et al., 2014). In a broader context, the use of nudges exerted positive effects from an urban water regulation perspective (Bardelli, 2021). Finally, Yoon et al. proposed introducing policies in the form of a nudge within a framework of assisting decision-makers in selecting the most sustainable wastewater treatment alternative (Yoon et al., 2019).

Although nudges have been used in the past, there are scholars who are still skeptical about their effectiveness arguing that people should be allowed to make their own decisions, including errors, and learn from them (Hausman and Welch, 2010). Nudges have been criticized for being manipulative or coercive (Doorn, 2021; White, 2013) or they tap into decision-making that is not completely autonomous (Bovens, 2009). Nevertheless, we maintain that a proper operationalization of the theory can bypass these ethical concerns for autonomy by designing policies that are transparent and offer opt-out rights (Thaler and Sunstein, 2009).

3. Applying the concept of resilience to the urban water cycle

3.1. Resilience and drinking water

In the drinking water industry, resilience is defined as the ability of a water system to continuously supply water at a quality that meets the health standards during and after the occurrence of a disastrous event (Hatton et al., 2019; Quitana et al., 2020). To be resilient, communities must be viewed as instigators and contributors to resilience efforts at both the infrastructural and organizational levels (Hatton et al., 2019). Hence, resilience for drinking water supplies need to consider both infrastructure and management decisions taking place at city and household level (Charles et al., 2022).

Previous studies have identified numerous hazards that can threaten the continuity and quality of supply and thus the resilience of the drinking water system. They can have an impact on any of the three components of the urban water system: i) the source of raw water, ii) drinking water production and iii) drinking water supply (Table 1).

i) The source of raw water: water resources such as surface water or groundwater may be exposed to overutilization, environmental changes affecting quality and quantity and damage to infrastructure (due to natural or anthropogenic hazards), among others (Vega et al., 2018).
ii) Drinking water production: physical infrastructure (pumps, pipes, dosing stations) and digital infrastructure may be exposed to failures. Treatment may experience quantity failures (loss of water) or quality failures (unacceptable water quality). Quantity failures are easier to detect and can be rectified with storage tanks, whereas quality failures cannot be rectified and may lead to a cessation of water delivery (Rosén et al., 2010).
iii) Drinking water supply: demand management is mainly affected by the availability of source water and demographic changes or changes in the usage of water by different actors. Impacts on any component of these subsystems are likely to ultimately affect end consumers, who could eventually suffer from water scarcity, discontinuity in the water supply and issues related to hydraulic conditions and water quality (Cubillo and Martínez-Codina, 2017).

Table 1
Potential hazards to the resilience of the drinking water system (proposal based on (Quitana et al., 2020); * See section 4.2 for further details).

Drinking water subsystem	Resilience level*	Hazards
Source water	Infrastructural	Damage to infrastructure (anthropogenic or natural hazards) Contamination Climate change – droughts
	Organizational	Conflicts of interest
Drinking water production	Infrastructural	Damage to infrastructure (e.g., pumps, pipes, wells, dosing devices, digital infrastructure) Contamination
	Organizational	Cross-dependencies with the chemical industry and power supply (lack of chemical reagents and power supply) • Personnel dependence
Drinking water supply	Infrastructural	Damage to infrastructure (e.g., pipe breaks) leading to water loss or contamination. Availability of source water reduced by natural/anthropogenic hazards and not meeting consumer demand
	Organizational	Community not engaged in water conservation practices
	Community	Discontinuity of water supply, water shortages

From a risk management perspective, water utilities need to build a resilient supply chain, which not only seeks to reduce risks but also is prepared to rapidly adjust and recover from any anticipated supply chain disruptions (Deloitte Global, 2021). From a technical point of view, critical indicators have been used to measure and enhance resilience of drinking water systems (Xu et al., 2021; Rathnayaka et al., 2022; Martin et al., 2022). Another approach widely used to quantify resilience of urban water systems is the construction and assessment of resilience curves which illustrate the evolution of water system performance before, during, and after a disruption (Assad et al., 2019; He and Yuan, 2019; Poulin and Kane, 2021).

In addition to technical assessment, community resilience can be built at the drinking water supply level to engage citizens in water conservation practices, reduce water consumption and promote rapid responses to hazards. Increasing the understanding of the risks posed to drinking water systems would help communities in taking actions to increase resilience (Hatton et al., 2019). In this sense, the nudges reported in the literature aimed at reducing water consumption (Miranda et al., 2020; Visser et al., 2021) or sharing resilience information through bills (Hatton et al., 2019).

3.2. Resilience and the urban wastewater system

Regarding the resilience of the wastewater system, a critical review of studies that deal with resilience in the wastewater treatment sector highlighted the lack of consensus in the definition of resilience and the lack of a comprehensive framework for resilience assessment (Juan-García et al., 2017). The paper recommended connecting resilience assessment to broader asset management plans as a means of unlocking investment and handling uncertainty. In turn, a framework showing how threats to a water system can result in consequences for society, the economy and the environment was proposed (Butler et al., 2017). The same framework was used to evaluate the relationship between the reliability, risk and resilience of urban wastewater systems (Sweetapple et al., 2018). In the same vein, a framework for model-based resilience assessment was developed (Juan-García et al., 2021).

As in the case of drinking water systems, several indicators and composite indicators have been proposed and used to evaluate the resilience of both sanitation systems and wastewater treatment technologies (Guo et al., 2021; Holloway et al., 2021; Chambers et al., 2022; Zhang et al., 2022). Moreover, a non-negligible number of studies focused on discussing the relevance of implementing decentralized wastewater treatment systems as an alternative to conventional centralized facilities to enhance resilience by increasing redundancy (Vázquez-Rowe et al., 2017; Bernal et al., 2021; Pasciucco et al., 2022).

Previous studies have identified hazards that pose risks for wastewater treatment and reuse and potentially damage receiving media, thereby threatening the resilience of the wastewater system; these hazards can act at any of the four subsystems of the urban wastewater system: sewer catchment, wastewater treatment plants, water reclamation plants, and receiving media (Table 2).

Table 2
Hazards to the resilience of the wastewater system (proposal based on Juan-García et al., 2021, 2017), * See section 4.2 for further details).

Urban wastewater subsystem	Resilience level*	Detected hazards
Sewer and stormwater systems	Infrastructural	Damage to infrastructure (anthropogenic or natural hazards, incl. Infrastructure aging)
		Equipment (mechanical) failures
		Stormwater impacts (flooding, combined sewer overflows)
		Climate change
		Power outages
		Changing energy prices, changes in the electricity production emission factor
	Community	Change in the impervious catchment area
		Increasing water use
		Population growth
Wastewater treatment plants	Infrastructural	Influent variation (stormwater)
		Overloading (shock load, chemical oxygen demand (COD), nitrogen (N), suspended solids (SS))
		Damage to infrastructure
		Equipment failures
		Biological operational problems
		Power outage
		Rising energy prices, changes in the electricity production emission factor
	Organizational	Stringent legislation (noncompliance)
	Community	Structural urban changes
		Increase in water use
		Population growth
Water reclamation plants	Infrastructural	Failure of disinfection methods
		Production of dibutyl phthalates (DBPs)
		Change in energy prices, change in the electricity production emission factor
	Community	Consumer acceptance of reclaimed water
Receiving media		Deterioration of water quality (chemical composition and biological pollutants)
		Changes in water temperature
		Deterioration in receiving water ecology

Table 3
What does each driving force enable (proposal based on Garrido-Baserba et al., 2020; Sedlak, 2014; Vázquez-Rowe et al., 2017)?

Driver	What it enables
4th water revolution	New business models
	Closure of the urban water cycle
	Increase in resilience, including water reuse
Digitalization	Ease of reporting data and acquiring data
	Open platforms for knowledge sharing
	Community engagement through public consultation, participatory processes.
Decentralization	Increase in the redundance and interdependence of water systems
	Changes in the business model of (traditional) centralized systems
	Additional environmental benefits and socioeconomic co-benefits
Climate change	Increase in awareness – increase in community engagement

4. Factors associated with resilience in the urban water cycle

4.1. Driving forces of resilience in the urban water cycle

Past research discussing the need of rethink the urban water cycle, i.e., adopting a new paradigm in the provision of water and sanitation services, has been expanding over the last decade (Leveque et al., 2021). As a result of a systematic review, in this paper we look at four major driving forces, often overlapping, that have an influence on the evolution of the urban water cycle, and hence its resilience, as follows: i) the "fourth water revolution", ii) digitalization, iii) climate change and iv) decentralization (Garrido-Baserba et al., 2020; Nansubuga et al., 2016; Poch et al., 2020) (see Table 3 and Table 4).

The "fourth water revolution": The so called "fourth water revolution" refers to a change in the way we approach water resource management, especially in the Global North, by making it more logical and sustainable, for instance via an increased use of techniques such as wastewater reuse, stormwater capture, etc. It provides a tremendous untapped possibility for achieving economic and environmental sustainability via resilience in the operation, maintenance, and repair of urban water infrastructure (Sedlak, 2014). Our capacity to transform our urban wastewater, stormwater, and other water sources into a stable and sustainable water supply system should not rely solely on traditional water sources (surface water and groundwater) to meet our water needs. Innovation activities in the water sector have also been explored in

Table 4
Nudges proposed to agents for resilience practices.

Agent	Examples of potential nudges (What can accelerate resilience practices?)
Citizens	Personalized information campaign about the real risk of future droughts to nudge customers into consuming less water. Helping consumers understand the risks associated with the absence of resilience practices to increase their willingness to pay for sustainability related services Installing opt-out smart meters instead of obligatory ones to nudge consumers into willingly adopt water conservation
Governments *(regulators, etc)*	'Peer pressure' platforms for reporting resilience metrics to nudge regulators into improving performance by comparison Financial incentives targeting SDGs Tax exemption for new constructions implementing decentralized water systems and circular economy solutions
Public and private organizations *(water utilities, etc)*	Increasing use of digital solutions (e.g., to overcome the challenges posed by the COVID-19 outbreak for organizational resilience) Accessing alternative funding options (e.g., low-interest loans for water system upgrades, discounts on property rates)

middle- and low-income countries (Adams et al., 2020; Kydyrbekova et al., 2022) because they are essential to ensure water security.

Digitalization in the water sector: By 2025, between 80% and 50% of the water utilities in industrialized counties and developing countries will have undergone some form of digital transformation (Garrido-Baserba et al., 2020). The COVID-19 pandemic has accelerated, at least in some countries, the digitalization of the water industry (Lawson et al., 2022). To monitor the SARS-CoV-2, many authorities have turned to wastewater-based epidemiology as useful tools for assessing and management the pandemic. However, there are divergent ethical–political implications of the deployment of artificial intelligence and Big Data analytics in urban water management (Popartan et al., 2022).

Decentralization and circularity of the water sector: Centralized municipal water systems face serious challenges such as the need for considerable investments in maintaining existing infrastructure or setting up new one for adequate sanitation in developing countries. As a result, alternative approaches that do not rely upon centralized sewer systems are gaining traction (Rabaey et al., 2020). Decentralized water systems (DWSs) are emerging as a form of resilient, personalized urban water systems that would make it possible to tailor their water consumption to their personal preferences (Garrido-Baserba et al., 2022; Rabaey et al., 2020). DWS are also a strategic approach for circular water management in cities, which can help boost the sustainability and thus the overall resilience of the water system (Lu et al., 2019). Circular water management integrates water reclamation and reuse from wastewater or greywater to decrease pressure on natural water sources. Ideally, not only is the transport and pollution of water minimized, but energy and nutrient recovery are also maximized, and rainwater is harvested and used locally (Oral et al., 2021). Although many conventional wastewater treatment technologies can be implemented in decentralized settings (Capodaglio and Olsson, 2019), nature-based solutions (see Langergraber et al., 2020) are emerging as a more sustainable alternative to help close the water management loops in cities contributing to the transition to more livable and resilient cities Castellar et al., (2021).

Climate change: Resilience is one of the most important indicators of adaptation to climate change (Sun et al., 2020). As a result of climate change and according to the predictions of the Intergovernmental Panel on Climate Change (IPCC), annual average river flow and water availability are expected to increase at high latitudes and in tropical habitats by the middle of the twenty-first century but decrease at mid-latitudes and in the dry tropics. Flooding and drought are expected to become more common in many places as the intensity and unpredictability of extremes of precipitation rise. The amount of water stored in glaciers and the amount of snow on the ground are expected to decrease during the next century. Water quality will be impacted by higher water temperatures and variations in extremes, such as floods and droughts, which will worsen many types of water pollution. Food availability, stability, access, and use are predicted to be impacted by changes in water quantity and quality as a result of climate change. Current water management systems may not be able to withstand the effects of climate change. Climate change may cause current water management methods to fail (Dickin et al., 2020; Grasham et al., 2021).

4.2. Agents and dimensions involved in the resilience of the urban water cycle based on nudges

Considering the parties involved in the urban water cycle, we have identified three different sets of agents on whom nudges might act: i) individuals, ii) organizations and iii) institutions (Table 3). Individual agents are citizens in their role as consumers, utility workers, etc. Collective agents are the public and private organizations that have the responsibility to provide drinking water and sanitation services (e.g., water utilities), and institutional agents include governmental and regulatory institutions. Several types of factors (in our terminology "dimensions") influence the three types of agents: social, economic, cultural, technological, political, healthcare, and environmental. The interrelationships between agents and dimensions contribute to the complexity of the urban water system (Marques et al., 2015; Pinto et al., 2017). While each agent is influenced by the described multidimensional factors, the lack of a resilient urban water cycle negatively impacts on the individual agents. Therefore, although nudges can be implemented for these three different types of agents, they have a direct impact on individual behavior.

Notably, from a decision-making perspective, resilience has different meanings for each type of agent. For example, for individual agents, resilience means taking actions in the daily life that contribute to reducing the consumption of water, either for personal use or to avoid this resource for technological reasons. For organizations, resilience means implementing a set of policies, processes, and procedures for a versatile managerial system that could include, for example, the decentralization of the water sector. For institutional agents, resilience involves regulatory changes, for example, by providing incentives to use rainwater and graywater. This difference in what resilience implies for each type of agent should be considered when nudges are defined and implemented to improve the resilience of the urban water cycle.

5. Integrative conceptual resilience model for the urban water system

This section integrates the main ideas from the previous sections into a conceptual framework to better the potential of nudges to act towards a resilient urban water cycle (Fig. 1). The SDGs, especially SDG6 on clean water and sanitation for all, are connected to improving the resilience in the urban water cycle, which is a central issue in both developed and developing countries. The four pillars for resilience developed by the 2030 Agenda of the United Nations, namely, people, the planet, governance and prosperity, are essential for advancing the achievement of the SDGs and, therefore, improving resilience (Chidozie and Oluwatobi, 2017; Fox and Stoett, 2016). As noted, in the last several years, exacerbated by the COVID-19 pandemic (Garrido-Baserba et al., 2020), the urban water industry has been experiencing an evolution driven by four main forces: the fourth water revolution, digitalization, decentralization and climate change. These drivers are changing the way consumers, water utilities and regulators approach the new challenges posed by the urban water cycle, including its resilience against both anthropogenic and natural hazards. With this framework, we

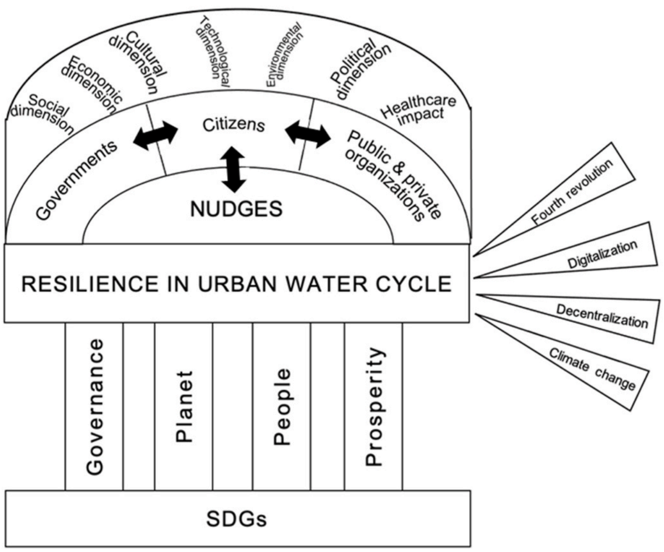

Fig. 1. An integrative conceptual framework of resilience in the urban water system.

propose extending the use of nudges to all stages of the urban water cycle, i.e., drinking water and wastewater services, and to three types of agents of action (citizens, governments and other public and private agents in the water sector) that might influence the decision-making process at different scales and levels to improve the resilience of the urban water cycle. In the framework, we also portray the agents interacting in the implementation of nudges considering that resilience might be understood differently for each of them.

We emphasize that these agents do not act in isolation; rather, they are influenced by a common set of dimensions (social, economic, cultural, technological, political, healthcare, and environmental dimensions) that should also be analyzed and considered before defining and implementing nudges for enhancing the resilience of the urban water cycle. Therefore, the integrative framework has been proposed, bearing in mind the multidimensional factors that influence each agent. The impacts on the three types of agents are distributed across the four pillars of the resilience cycle.

An example of the interconnection between the driving forces of resilience and agents involved is the impact of climate change. It has accentuated the occurrence and magnitude of droughts (Cook et al., 2018) which has promoted: i) the adoption of national and international laws by governments to regulate water reuse; ii) the use of alternative water sources by organizations for providing drinking water and; iii) the improvement of the acceptability of water reuse by citizens (Glick et al., 2019). Decentralization of urban water systems is another example of the potential impact of the driving forces for resilience and its integration with the three levels of agents. Because most of the urban water and sanitation infrastructure is already built, decentralization will hardly be adopted spontaneously. In contrast, governments could use nudges to incentive both water utilities (organizations) and citizens to adopt decentralization approaches.

6. Conclusions

Water management is not merely a technical field but a socio-political one that involves human values, behavior and organization (Linton and Budds, 2014). In this context, the "hydrosocial cycle" has been widely used to refer to the inseparable social and physical dimensions of water (McCulligh et al., 2020; Laituri, 2020). According to Linton and Budds (2014), the hydrosocial cycle "relates a variety of heterogeneous entities including social power and structures of governance, technologies, infrastructure, political policies, and water itself".

In line with this holistic and interdisciplinary conception of the urban water cycle, this paper proposed a theoretical-conceptual framework based on the theory of nudges. Previous experiences with the use of nudges in the context of the urban water cycle have revealed their potential role in influencing the behavior of people, mainly about reducing drinking water consumption. This study integrates structures of decision (agents), pillars of resilience (social and governance issues) and driving forces (technology and water itself) and therefore, it could be considered an integrative framework for increasing resilience in the urban water cycle based on a hydrosocial cycle approach.

According to the proposed conceptual framework, research on nudges for the resilience in the urban water cycle should be further explored based on real or simulated case studies. The results of such empirical applications will be useful for feedback and adjust the conceptual framework proposed. We emphasize the need of integrating the three levels of agents, i.e., governments, organizations and citizens in decision-making related to urban water cycle resilience. Water utilities are responsible of providing drinking water and wastewater services. They are regulated and monitored by governments (water regulators and agencies). Moreover, the citizens as water users play a relevant role in resilience achievement. If resilience is assessed from only one of these perspectives, it is an incomplete assessment because the three agents and their decisions are interconnected. Hence, we encourage policy makers and researchers to assess resilience from a holistic and integrative point of view because the urban water cycle is a VUCA system.

Author contributions statement

Manel Poch: Conceptualization, Resources, Writing-Original Draft, Supervision; Carolina Aldao: Literature Review, Methodology, Writing-Original Draft, Formal Analysis; Lluis Godo-Pla: Investigation, Literature Review, Writing-Original Draft; Hèctor Monclús: Investigation, Methodology, Formal Analysis; Lucia Alexandra Popartan: Investigation, Methodology, Formal analysis, Review and Editing; Joaquim Comas: Literature review, Methodology, Formal analysis; Manuel Cermerón-Romero: Validation, Review and Editing; Sebastià Puig: Investigation, Methodology, Formal analysis, Review and Editing; María Molinos-Senante: Conceptualization, Writing-Original draft, Review and Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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References

Adams, E.A., Zulu, L., Ouellette-Kray, Q., 2020. Community water governance for urban water security in the Global South: status, lessons, and prospects. Wiley Interdisciplinary Reviews: Water 7 (5). https://doi.org/10.1002/wat2.1466 art. no. e1466.

Assad, A., Moselhi, O., Zayed, T., 2019. A new metric for assessing resilience of water distribution networks. Water (Switzerland) 11 (8), 1701. https://doi.org/10.3390/w11081701.

Bardelli, L., 2021. Economics and choice architecture: what can be learnt from water regulation in Italy. Industria 42, 241–273. https://doi.org/10.1430/99919.

Bendor, J., 2001. Bounded Rationality, vol. 1303. International Encyclopedia of the Social & Behavioral Sciences, p. 1307.

Bernal, D., Restrepo, I., Grueso-Casquete, S., 2021. Key criteria for considering decentralization in municipal wastewater management. Heliyon 7 (3), e06375. https://doi.org/10.1016/j.heliyon.2021.e06375.

Bovens, L., 2009. The Ethics of Nudge, Preference Change. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-2593-7_10.

Butler, D., Ward, S., Sweetapple, C., Astaraie-Imani, M., Diao, K., Farmani, R., Fu, G., 2017. Reliable, resilient and sustainable water management: the Safe & SuRe approach. Glob. Challenges 1, 63–77. https://doi.org/10.1002/GCH2.1010.

Capodaglio, A.G., Olsson, G., 2019. Energy issues in sustainable urban wastewater management: use, demand reduction and recovery in the urban water cycle, 2020 Sustain. Times 12, 266. https://doi.org/10.3390/SU12010266. Page 266 12.

Castellar, J.A.C., Popartan, L.A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Corominas, L., Comas, J., Acuña, V., 2021. Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. Sci. Total Environ. 77920. Article number 146237.

Chambers, K.G., Sheridan, P.M., Cook, S.M., 2022. Sanitation criteria: a comprehensive review of existing sustainability and resilience evaluation criteria for sanitation systems. Environ. Sci. Technol. Lett. 9 (7), 583–591. https://doi.org/10.1021/acs.estlett.2c00267.

Charles, K.J., Howard, G., Villalobos Prats, E., Thomas, J.M., Campbell-Lendrum, D., 2022. Infrastructure alone cannot ensure resilience to weather events in drinking water supplies. Sci. Total Environ. 813, 151876 https://doi.org/10.1016/j.scitotenv.2021.151876.

Chidozie, F., Oluwatobi, O., 2017. International organizations and global governance Agenda: SDGs as a paragon | chidoz. Acta Univ. Danubius, Relat. 10, 43–60.

Cook, B.I., Mankin, J.S., Anchukaitis, K.J., 2018. Climate change and drought: from past to future. Curr. Clim. Change Rep. 4 (2), 164–179. https://doi.org/10.1007/s40641-018-0093-2.

Cubillo, F., Martínez-Codina, Á., 2017. A metric approach to measure resilience in water supply systems, 67–78. https://doi.org/10.1080/23249676.2017.1355758 7. https://doi.org/10.1080/23249676.2017.1355758.

Dickin, S., Bayoumi, M., Giné, R., Andersson, K., Jiménez, A., 2020. Sustainable sanitation and gaps in global climate policy and financing, 2020 npj Clean Water 31 3, 1–7. https://doi.org/10.1038/s41545-020-0072-8.

Doorn, N., 2021. Artificial intelligence in the water domain: opportunities for responsible use. Sci. Total Environ. 755, 142561 https://doi.org/10.1016/J.SCITOTENV.2020.142561.

Festré, A., Garrouste, P., 2015. Theory and evidence in psychology and economics about motivation crowding out: a possible convergence? J. Econ. Surv. 29 (2), 339–356. https://doi.org/10.1111/joes.12059.

Fox, O., Stoett, P., 2016. Citizen participation in the UN sustainable development goals consultation process: toward global democratic governance? Glob. Gov. A Rev. Multilater. Int. Organ. 22, 555–573. https://doi.org/10.1163/19426720-02204007.

Garrido-Baserba, M., Corominas, L., Cortés, U., Rosso, D., Poch, M., 2020. The fourth-revolution in the water sector encounters the digital revolution. Environ. Sci. Technol. 54, 4698–4705. https://doi.org/10.1021/ACS.EST.9B04251/ASSET/IMAGES/MEDIUM/ES9B04251_0003 (GIF).

Garrido-Baserba, M., Barnosell, I., Molinos-Senante, M., Sedlak, D.L., Rabaey, K., Schraa, O., Verdaguer, M., Rosso, D., Poch, M., 2022. The third route: a techno-economic evaluation of extreme water and wastewater decentralization. Water Res. 218, 118408 https://doi.org/10.1016/J.WATRES.2022.118408.

Glick, D.M., Goldfarb, J.L., Heiger-Bernays, W., Kriner, D.L., 2019. Public knowledge, contaminant concerns, and support for recycled Water in the United States. Resour. Conserv. Recycl. 150, 104419 https://doi.org/10.1016/j.resconrec.2019.104419.

Global, Deloitte, 2021. Managing Supply Chain Risk and Disruption: COVID-19.

Grasham, C.F., Calow, R., Casey, V., Charles, K.J., de Wit, S., Dyer, E., Fullwood-Thomas, J., Hirons, M., Hope, R., Hoque, S.F., Jepson, W., Korzenevica, M., Murphy, R., Plastow, J., Ross, I., Ruiz-Apilánez, I., Schipper, E.L.F., Trevor, J., Walmsley, N., Zaidi, H., 2021. Engaging with the politics of climate resilience towards clean water and sanitation for all. npj Clean Water 41 4, 1–4. https://doi.org/10.1038/s41545-021-00133-2, 2021.

Guo, D., Shan, M., Owusu, E.K., 2021. Resilience assessment frameworks of critical infrastructures: state-of-the-art review. Buildings 11 (10), 464. https://doi.org/10.3390/buildings11100464.

Hatton, T., Kay, E., Naderpajouh, N., Aldrich, D., 2019. Resilience Shift Primer: Potable Water. An Industry Guide to Enhancing Resilience - the Resilience Shift.

Hausman, D.M., Welch, B., 2010. Debate: to nudge or not to nudge. J. Polit. Philos. 18, 123–136. https://doi.org/10.1111/J.1467-9760.2009.00351.X.

He, X., Yuan, Y., 2019. A framework of identifying critical water distribution pipelines from recovery resilience. Water Resour. Manag. 33 (11), 3691–3706. https://doi.org/10.1007/s11269-019-02328-2.

Holling, C.S., 1986. Resilience of terrestrial ecosystems: local surprise and global change. In: Clark, W.C., Munn, R.E. (Eds.), Sustainable Development of the Biosphere. Cambridge University Press.

Holloway, T.G., Williams, J.B., Ouelhadj, D., Yang, G., 2021. Dynamic resilience for biological wastewater treatment processes: interpreting data for process management and the potential for knowledge discovery. J. Water Proc. Eng. 42, 102170 https://doi.org/10.1016/j.jwpe.2021.102170.

Howard, G., Nijhawan, A., Flint, A., Baidya, M., Pregnolato, M., Ghimire, A., Poudel, M., Lo, E., Sharma, S., Mengustu, B., Ayele, D.M., Geremew, A., Wondim, T., 2021. The how tough is WASH framework for assessing the climate resilience of water and sanitation. npj Clean Water 1–10. https://doi.org/10.1038/s41545-021-00130-5, 2021 41 4.

Joo, H.H., Lee, J., Park, S., 2018. Every drop counts: a water conservation experiment with hotel guests. Econ. Inq. 56, 1788–1808. https://doi.org/10.1111/ECIN.12563.

Juan-García, P., Butler, D., Comas, J., Darch, G., Sweetapple, C., Thornton, A., Corominas, L., 2017. Resilience theory incorporated into urban wastewater systems management. State of the art. Water Res. 115, 149–161. https://doi.org/10.1016/J.WATRES.2017.02.047.

Juan-García, P., Rieger, L., Darch, G., Schraa, O., Corominas, L., 2021. A framework for model-based assessment of resilience in water resource recovery facilities against power outage. Water Res. 202, 117459 https://doi.org/10.1016/J.WATRES.2021.117459.

Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision under risk. Econometrica 47 (2), 263–291.

Kumar, M., Munoz-Arriola, F., Furumai, H., Chaminda, T., 2020. Resilience, Response, and Risk in Water Systems. Shifting Management and Natural Forcings Paradigms. Springer, Berlin.

Kydyrbekova, A., Meiramkulova, K., Tolysbayev, B., Kydyrbekova, A., 2022. Dynamics of innovation in the use of water resources in emerging markets. International Journal of Innovation Studies 6 (3), 142–155. https://doi.org/10.1016/j.ijis.2022.05.002.

Laituri, M., 2020. The hydrosocial cycle in rapidly urbanizing watersheds. Front. Earth Sci. 14 (2), 256–267. https://doi.org/10.1007/s11707-020-0823-3.

Langergraber, G., Pucher, B., Simperler, L., Kisser, J., Katsou, E., Buehler, D., Carmen, M., Mateo, G., Atanasova, N., 2020. Implementing nature-based solutions for creating a resourceful circular city. Blue-Green Syst. 2, 173–185. https://doi.org/10.2166/BGS.2020.933.

Larsen, T.A., Hoffmann, S., Lüthi, C., Truffer, B., Maurer, M., 2016. Emerging solutions to the water challenges of an urbanizing world. Science 352, 928–933. https://doi.org/10.1126/SCIENCE.AAD8641.

Lawson, E., Bunney, S., Cotterill, S., Farmani, R., Melville-Shreeve, P., Butler, D., 2022. COVID-19 and the UK water sector: exploring organizational responses through a resilience framework. Water Environ. J. 36 (1), 161–171. https://doi.org/10.1111/wej.12737.

Leveque, B., Burnet, J.-B., Dorner, S., Bichai, F., 2021. Impact of climate change on the vulnerability of drinking water intakes in a northern region. Sustain. Cities Soc. 66, 102656 https://doi.org/10.1016/j.scs.2020.102656.

Linton, J., Budds, J., 2014. The hydrosocial cycle: defining and mobilizing a relational-dialectical approach to water. Geoforum 57, 170–180. https://doi.org/10.1016/j.geoforum.2013.10.008.

Liu, S.K., Lin, Z.E., Chiueh, P. Te, 2022. Improving urban sustainability and resilience with the optimal arrangement of water-energy-food related practices. Sci. Total Environ. 812, 152559 https://doi.org/10.1016/J.SCITOTENV.2021.152559.

Lu, Z., Mo, W., Dilkina, B., Gardner, K., Stang, S., Huang, J.C., Foreman, M.C., 2019. Decentralized water collection systems for households and communities: household preferences in Atlanta and Boston. Water Res. 167, 115134 https://doi.org/10.1016/J.WATRES.2019.115134.

Luoto, J., Levine, D., Albert, J., Luby, S., 2014. Nudging to use: achieving safe water behaviors in Kenya and Bangladesh. J. Dev. Econ. 110, 13–21. https://doi.org/10.1016/J.JDEVECO.2014.02.010.

Makropoulos, C., Savić, D.A., 2019. Urban hydroinformatics: past, present and future. Water 11 (10), 1959. https://doi.org/10.3390/w11101959.

Marques, R.C., da Cruz, N.F., Pires, J., 2015. Measuring the sustainability of urban water services. Environ. Sci. Pol. 54, 142–151. https://doi.org/10.1016/J.ENVSCI.2015.07.003.

Martin, S., Erdlenbruch, K., Alvarez, I., Huet, S., Smadi, C., 2022. Viability,efficiency, resilience and equity: using very diverse indicators to deal with uncertainties of future events. Environ. Sci. Pol. 138, 56–75. https://doi.org/10.1016/j.envsci.2022.09.011.

McCulligh, C., Arellano-García, L., Casas-Beltrán, D., 2020. Unsafe waters: the hydrosocial cycle of drinking water in Western Mexico. Local Environ. 25 (8), 576–596. https://doi.org/10.1080/13549839.2020.1805598.

Miranda, J.J., Datta, S., Zoratto, L., 2020. Saving water with a nudge (or two): evidence from Costa Rica on the effectiveness and limits of low-cost behavioral interventions on water use. World bank econ. Rev. 34, 444–463. https://doi.org/10.1093/WBER/LHY025.

Moglia, M., Cook, S., Tapsuwan, S., 2018. Promoting water conservation: where to from here? Water 10, 1510. https://doi.org/10.3390/W10111510, 2018.

Mongin, P., Cozic, M., 2018. Rethinking nudge: not one but three concepts. Behavioural Public Policy 2 (1), 107–124. https://doi.org/10.1017/bpp.2016.16.

Nansubuga, I., Banadda, N., Verstraete, W., Rabaey, K., 2016. A review of sustainable sanitation systems in Africa. Rev. Environ. Sci. Biotechnol. 15, 465–478. https://doi.org/10.1007/S11157-016-9400-3.

Nayar, A., Kanaka, S., 2017. Nudging urban water conservation: evidence from India on the effect of behavior economics on water consumption. Eur. J. Res. Soc. Sci. 5.
Oral, H.V., Radinja, M., Rizzo, A., Kearney, K., Andersen, T.R., Krzeminski, P., Buttiglieri, G., Ayral-Cinar, D., Comas, J., Gajewska, M., Hartl, M., Finger, D.C., Kazak, J.K., Mattila, H., Vieira, P., Piro, P., Palermo, S.A., Turco, M., Pirouz, B., Stefanakis, A., Regelsberger, M., Ursino, N., Carvalho, P.N., 2021. Management of urban waters with nature-based solutions in circular cities—exemplified through seven urban circularity challenges. Water 2021 13. https://doi.org/10.3390/W13233334, 3334 13, 3334.
Pasciucco, F., Pecorini, I., Iannelli, R., 2022. Planning the centralization level in wastewater collection and treatment: a review of assessment methods. J. Clean. Prod. 375, 134092 https://doi.org/10.1016/j.jclepro.2022.134092.
Peña-Guzmán, C.A., Melgarejo, J., Lopez-Ortiz, I., Mesa, D.J., 2017. Simulation of infrastructure options for urban water management in two urban catchments in bogotá, Colombia, 2017 Water 9, 858. https://doi.org/10.3390/W9110858. Page 858 9.
Pimm, S.L., 1991. The Balance of Nature? Ecological Issues in the Conservation of Species and Communities. University of Chicago Press, Chicago.
Pinto, F.S., Simões, P., Marques, R.C., 2017. Raising the bar: the role of governance in performance assessments. Util. Pol. 49, 38–47. https://doi.org/10.1016/J.JUP.2017.09.001.
Poch, M., Garrido-Baserba, M., Corominas, L., Perelló-Moragues, A., Monclús, H., Cermerón-Romero, M., Melitas, N., Jiang, S.C., Rosso, D., 2020. When the fourth water and digital revolution encountered COVID-19. Sci. Total Environ. 744, 140980 https://doi.org/10.1016/J.SCITOTENV.2020.140980.
Popartan, L.A., Cortés, À., Garrido-Baserba, M., Verdaguer, M., Poch, M., Gibert, K., 2022. The digital revolution in the urban water cycle and its ethical–political implications: a critical perspective. Appl. Sci. 12 (5), 2511. https://doi.org/10.3390/app12052511.
Poulin, C., Kane, M.B., 2021. Infrastructure resilience curves: performance measures and summary metrics. Reliab. Eng. Syst. Saf. 216, 107926 https://doi.org/10.1016/j.ress.2021.107926.
Quitana, G., Molinos-Senante, M., Chamorro, A., 2020. Resilience of critical infrastructure to natural hazards: a review focused on drinking water systems. Int. J. Disaster Risk Reduc. 48, 101575 https://doi.org/10.1016/J.IJDRR.2020.101575.
Rabaey, K., Vandekerckhove, T., de Walle, A. Van, Sedlak, D.L., 2020. The third route: using extreme decentralization to create resilient urban water systems. Water Res. 185, 116276 https://doi.org/10.1016/J.WATRES.2020.116276.
Rathnayaka, B., Siriwardana, C., Robert, D., Amaratunga, D., Setunge, S., 2022. Improving the resilience of critical infrastructures: evidence-based insights from a systematic literature review. Int. J. Disaster Risk Reduc. 78, 103123 https://doi.org/10.1016/j.ijdrr.2022.103123.
Rosén, L., Lindhe, A., Bergstedt, O., Norberg, T., Pettersson, T.J.R., 2010. Comparing risk-reduction measures to reach water safety targets using an integrated fault tree model. Water Sci. Technol. Water Supply 10, 428–436. https://doi.org/10.2166/WS.2010.089.
Sedlak, D.L., 2014. Water 4.0 : the Past, Present, and Future of the World's Most Vital Resource.
Seger, C., Bogelein, S., Meleady, R., Lede, E., Sexton, N., Brown, A., Castelvecchi, S., Davies, W., Barnett, P., 2019. Turn off the Tap: behavioural messages increase water efficiency during toothbrushing - UEA Digital Repository. Inst. Water J. 3, 42–47.
Shove, E., 2010. Beyond the ABC: Climate Change Policy and Theories of Social Change. https://doi.org/10.1068/A42282.
Sun, Y., Garrido-Baserba, M., Molinos-Senante, M., Donikian, N.A., Poch, M., Rosso, D., 2020. A composite indicator approach to assess the sustainability and resilience of wastewater management alternatives. Sci. Total Environ. 725, 138286 https://doi.org/10.1016/J.SCITOTENV.2020.138286.
Sweetapple, C., Astaraie-Imani, M., Butler, D., 2018. Design and operation of urban wastewater systems considering reliability, risk and resilience. Water Res. 147, 1–12. https://doi.org/10.1016/J.WATRES.2018.09.032.
Thaler, R.H., Sunstein, C., 2009. Nudge. Penguin Books, New York.
Tortajada, C., 2020. Contributions of recycled wastewater to clean water and sanitation Sustainable Development Goals. npj Clean Water 2020 31 3, 1–6. https://doi.org/10.1038/s41545-020-0069-3.
Tortajada, C., González-Gómez, F., Biswas, A.K., Buurman, J., 2019. Water demand management strategies for water-scarce cities: the case of Spain. Sustain. Cities Soc. 45, 649–656. https://doi.org/10.1016/J.SCS.2018.11.044.
United Nations, 2014. Human Right to Water and Sanitation | International Decade for Action "Water for Life" 2005-2015 [WWW Document]. URL. https://www.un.org/waterforlifedecade/human_right_to_water.shtml. accessed 5.5.22.
United Nations, 2021. Goal 6: Clean water and sanitation - The Global Goals [WWW Document]. URL. https://www.globalgoals.org/goals/6-clean-water-and-sanitation/. accessed 5.5.22.
Vázquez-Rowe, I., Kahhat, R., Lorenzo-Toja, Y., 2017. Natural disasters and climate change call for the urgent decentralization of urban water systems. Sci. Total Environ. 605–606, 246–250. https://doi.org/10.1016/J.SCITOTENV.2017.06.222.
Vega, A.S., Lizama, K., Pastén, P.A., 2018. Water quality: trends and challenges. Glob. Issues Water Policy 21, 25–51. https://doi.org/10.1007/978-3-319-76702-4_3.
Velez, M.A., Moros, L., 2021. Have behavioral sciences delivered on their promise to influence environmental policy and conservation practice? Curr. Opin. Behav. Sci. 42, 132–138. https://doi.org/10.1016/J.COBEHA.2021.06.008.
Visser, M., Booysen, M.J., Brühl, J.M., Berger, K.J., 2021. Saving water at Cape Town schools by using smart metering and behavioral change. Water Resour. Econ 34, 100175. https://doi.org/10.1016/J.WRE.2020.100175.
Weber, E.U., 2017. Breaking cognitive barriers to a sustainable future. Nat. Human Behav. 1 (1) https://doi.org/10.1038/s41562-016-0013, 0013.
White, M.D., 2013. The manipulation of choice: ethics and libertarian paternalism. Manip. Choice Ethics Libert. Paternalism 1–185. https://doi.org/10.1057/9781137313577.
World Economic Forum, 2022. The Global Risks Report 2022, seventeenth ed.
Wostl, Pahl, 2015. Water Governance in the Face of Global Change. From Understanding to Transformation. Springer, Switzerland.
Xu, W., Cong, J., Proverbs, D., Zhang, L., 2021. An evaluation of urban resilience to flooding. Water (Switzerland) 13 (15), 2022. https://doi.org/10.3390/w13152022.
Yoon, S., Naderpajouh, N., Hastak, M., 2019. Decision model to integrate community preferences and nudges into the selection of alternatives in infrastructure development. J. Clean. Prod. 228, 1413–1424. https://doi.org/10.1016/J.JCLEPRO.2019.04.243.
Zhang, C., Oh, J., Park, K., 2022. Evaluation of sewer network resilience index under the perspective of ground collapse prevention. Water Sci. Technol. 85 (1), 188–205. https://doi.org/10.2166/wst.2021.503.