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DOI:
10.3389/frsus.2023.1177574

Frontiers in Sustainability
TYPE Hypothesis and Theory
PUBLISHED 02 June 2023
DOI 10.3389/frsus.2023.1177574

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OPEN ACCESS

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RECEIVED 01 March 2023
ACCEPTED 16 May 2023
PUBLISHED 02 June 2023

CITATION
Bowman BM, Abbott-Donnelly I, Barsoum J-F, Williams P, Hunt DVL and Rogers CDF (2023) The water pivot: transforming unsustainable consumption to valuing water as a resource for life. *Front. Sustain.* 4:1177574.
doi: 10.3389/frsus.2023.1177574

The water pivot: transforming unsustainable consumption to valuing water as a resource for life

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Water is a resource essential for all life and on which society depends but undervalues. This paper presents theories on methods to pivot from linear, extractive uses of water to considering water as a high value, circular resource. Analysis of the literature, which is primarily focused at the abstractor scale, has highlighted the prioritization of human water rights over environmental needs without incorporating the ramifications of environmental degradation and the complexities of applying a market-driven approach to a heterogeneous resource particularly at the domestic consumer level. A discussion of the relationship between society and water, in particular mechanisms that have been used to reduce water consumption, highlights the complexity of this issue and the need to consider fairness and equity at the global and local scales. A comparison of global, urban water supply and sanitation costs shows the extensive variation in the amounts of water consumed and the prices paid at the domestic consumer scale. Finally, a series of hypotheses are presented that, with local development, testing and refinement, are posited to bring about change in the value society places on water.

KEYWORDS

fairness, justice, price, resource management, value, water resources, ecological economics

1. Introduction

Water is an essential component for life across all of nature and has been recognized as a human right in the UN Sustainable Development Goals, SDG6 (United Nations, 2015). However, human activity, industry, agriculture and urbanization all disrupt the natural water cycle, both through direct impacts (Naden et al., 2016; Bell et al., 2021) and through the consequences of climate change altering the frequency, severity and location of rainfall (IPCC, 2021). This is not wholly a new phenomenon with increasing levels of nutrients, accompanied by decreasing populations of fish and other aquatic species, seen across the UK since the industrial revolution (Bell et al., 2021). Indeed, the convergence of increasing development and reducing environmental quality, particularly water quality, has been observed around the world with examples including China (Rasiah et al., 2013; Xu and Berck, 2013; Han et al., 2017; Li et al., 2019), USA (Lozano et al., 2021) and France (Thiebault et al., 2021). In the UK improvements have been observed since the start of the 1900s with the introduction of wastewater treatment requirements and, more recently, regulations on the use of phosphorus in detergents (Naden et al., 2016) and the introduction of the Urban Wastewater Treatment Directive (Directive 91/271/EEC, 1991) and Water

Framework Directive (Directive 2000/60/EC, 2000). However, it remains the case that most rivers across the UK and the rest of Europe do not meet the required standard for good chemical or ecological status (Marcal et al., 2021).

In addition, the majority of the world's water basins are classed as water scarce (Reddy et al., 2015), with impacts on consumptive and non-consumptive users (for explanation of key terms see Table 1). This is a situation that is rapidly deteriorating: in 2015 it was reported that 2% of USA watersheds had withdrawals, through municipal and industrial users alone, that are greater than the renewable supply (Reddy et al., 2015). By 2019 predictions across the contiguous states within the USA estimate that 83 out of the 204 freshwater basins will experience some degree of monthly shortage by 2045, with this increasing to nearly half by 2070 (Brown et al., 2019). Globally 70% of consumptive water use is for agricultural irrigation (Wada et al., 2011; Zhao et al., 2020) and within the USA ∼82% of all water use is for agriculture and thermoelectric power generation (Luby et al., 2018). Competition and prioritization of water resources between different users is therefore a complex issue within which there is a wealth of research—see for example Gurluk and Ward (2009), Piniewski et al. (2014), Kumar et al. (2016), Wada et al. (2017), Ahmadi et al. (2020), Tomlinson et al. (2020)—including the consideration of separate water sources for different uses (United Kingdom Water Partnership, 2015; Oteng-Peprah et al., 2018; Arden et al., 2021). The basis for rights to water are frequently, particularly across the global north, related to either a riparian doctrine or doctrine of prior appropriation, both of which prioritize human use over ecological benefit (Praskievicz, 2019). However, degradation of the environment has impacts in terms of ecosystems services and therefore ramifications for society and the economy (Costanza et al., 2017; Dasgupta, 2021). Incorporation of environmental impacts in water prioritization assessments has been incorporated into some assessments for example Hatamkhani et al. (2023) and others by these authors.

Regulations such as the EU Water Framework Directive (Directive 2000/60/EC, 2000) and US Environmental Protection Agency Effluent Guidelines (United States Environmental Protection Agency, 2022) along with policies promoting cleaner production and sustainable development in China (Song et al., 2018; Li et al., 2019) aim to provide protection through legal obligation, although there are concerns that this is neither sufficient, nor quick enough, to improve the water quality in our lakes, rivers and seas (Lozano et al., 2021; Environment Agency, 2022). Additionally water protection and availability is not universal: around the world 2.2 billion people do not have access to clean drinking water and 4.2 billion people do not have access to safely managed sanitation (United Nations, 2015). Therefore globally there is currently disparity in the distribution, use and protection of water, which without intervention will continue to grow in the near and far future.

There are, therefore, a multitude of pressures on water quality and quantity exacerbated by human activity. Our collective

TABLE 1 Glossary of key terms.

	Term	Definition
General terms	Pivot projects	A global collaboration that seeks to use diverse viewpoints and holistic approaches to help solve the world's ecological challenges.
	Pivot	An abrupt change compared to current trends.
	Watercourse	Surface water system, including tributaries, rivers, streams and lakes.
	Watershed	Entire catchment that drains into one body of water, including land area. Also, river basin or water basin.
	Water resource	Above or below ground body of water that acts as a water resource for people or nature. Includes rivers, lakes and aquifers.
Water use	Consumptive water use	Use of water such that it is not returned to the original water resource for immediate re-use as it has evaporated, transpired, been incorporated into goods or products, or been consumed by humans or livestock.
	Non-consumptive water use	In-stream use of water, or diversion of water where that water does not change in quantity or quality and is returned to the same point.
	Embedded (virtual) water	The water required to generate products.
Justice	Environmental justice	Movement to address inequity in environmental hazards and benefits; to prioritize intergenerational environmental and social equity.
	Water justice	The ability for all peoples to access clean water for consumption and recreational purposes as a human right.
Economic terms	Marginal price	The difference between the cost of production and the price at which a product can be sold.
	Price elasticity	The price difference needed to elicit a change in consumption. For example, if price elasticity is high then small changes result in changing consumption patterns; if price elasticity is low then even large price differences do not lead to changing consumption.
	Rising block price/Rising block tariffs	Charges attributed to a unit of water changes with cumulative consumption during a given time period. For example: £0.8 per m^3 up to 25 m^3/month and £1.40 per m^3 thereafter.
	Shadow price	Monetary value assigned to provide an estimated economic cost for a characteristic with a cost that cannot be easily determined and in the absence of correct market prices.

relationship with the water environment needs to change for our mutual benefit. Whereas much of the existing literature is positioned at the abstractor scale, this research focuses on domestic consumption and influencing mechanisms applying a systems approach. The objective of this paper is to explore the environmental and justice impacts of water use, in particular the impacts of domestic water pricing mechanisms and propose a series of approaches to transform unsustainable consumption to society valuing water as a resource for life This paper firstly discusses societies' relationship with water at a domestic user scale, including mechanisms that have been used to drive behavior change to reduce water consumption. Secondly, it provides a brief exploration of global approaches to water pricing. Finally, a series of hypotheses are proposed to stimulate testing and development at a local scale with the aim of driving a shift from unsustainable water use to society valuing water as a resource for life.

2. Method

Pivot Projects (https://www.pivotproject.org/) is a global collaboration that seeks to use diverse viewpoints and holistic approaches to help solve the world's ecological challenges through identification of a pivot: a means to bring about an abrupt change as opposed to a transition. Collaborators participate in topic-focused groups ranging from education to energy, sustainable infrastructure and 15-minute cities. The authors of this paper form a group within Pivot Projects that ispecificallyy focused on the area of water; they have backgrounds in water and wastewater treatment, smart water, smart cities, innovation, disaster relief and environmental stewardship. A process of collective knowledge-sharing within this group and exploration of ideas and connections was used to discuss potential methods to enable a pivot to sustainable water use in which water is valued by society as a resource for life (Figure 1). The approaches used to facilitate these discussions were based on soft systems methodologies (Checkland and Scholes, 1999), and participatory systems dynamics modeling (Pluchinotta et al., 2021). Additionally, visualizations were generated to explore interconnected points of influence within the complex, adaptive system of domestic water consumption using systems mapping techniques (van Rooyen et al., 2020; Gittins et al., 2021). A number of tools were used to facilitate this process including Spark Beyond (research.sparkbeyond.com/), an artificial intelligence (AI) research tool that uses natural language processing (NLP) to mine information from the internet, and Kumu relationship mapping software (https://kumu.io/) as a method of visualization and evidencing connections in a collaborative forum. Kumu has been utilized as a visualization tool due to the range of features offered and the benefits of generating an interactive open-access model (Arena and Li, 2018; McCullough, 2019; Pedersen Zari and Hecht, 2019). Through this process a key area of potential influence was identified as 'price of water as a mechanism for reducing consumption'. While this is superficially unsurprising, it was important that it emerged from the systems analysis, not least because it also leads directly to consideration of the value of water.

A search of academic literature was undertaken focused on the value of water and pricing mechanisms using Web of Science, Google Scholar and including articles identified by Spark Beyond. Search terms of "water", "price" and "value" were used to identify relevant research within literature databases. This was used to understand the current knowledge in this area and identify how this could be used to increase the value attributed to water. A comparison of global domestic water prices and rates of consumption has been conducted to explore the variation of price and consumption globally (Section 3). Countries and cities were selected to provide a range of climates, socio-economic systems and water payment regimes. The selection was limited to those areas where water and sanitation is provided to a large proportion of the urban population (>80% with water supply and 40% sanitation provision based on data from World Bank, 2022) and where data could be sourced with reliability. Therefore this analysis seeks to provide an indication of the relationship between consumption and water price across the globe, however does not reflect the variation caused by non-centralized water services which may have substantial price differences, supply restrictions and inequitable access impacts (Ntengwe, 2004; Opryszko et al., 2009; Plappally and Lienhard, 2012; Ahmad, 2017; Murwirapachena, 2021).

A collaborative process was used to build from this body of knowledge to identify crux issues and from these generate a series of hypotheses, facilitated by the use of Kumu. These hypotheses postulate how pricing mechanisms and structuring of the distribution of water could be used to facilitate a pivot to sustainable, and valued, water consumption. It is considered unlikely that there is a single approach that could act as a worldwide panacea, however common themes and thought processes are relevant globally to drive discussions at a country, region or catchment scale. Five hypotheses are presented (Section 4) which are complementary and act as a starting point for specific discussions that can take account of local cultural, climate and economic requirements.

3. Results: our relationship with water

3.1. The value of water

The issue of the value of water can be traced back to Adam Smith's The Wealth of Nations (1776). Smith noted the diamond-water paradox in which greater value is ascribed to the non-essential diamond rather to life-preserving water (Investopedia, 2021). Since then, economists and others have theorized over different approaches to considering value and the influence this has on consumption. Numerous approaches could be used to influence the consumption of water at both industrial and domestic user scales. These range from raising awareness through education and public campaigns, to fitting water saving devices such as in Australia during the Millennium Drought (Rogers et al., 2020) and South Africa in Cape Town's Day Zero (Booysen et al., 2019; Gittins et al., 2021). Alternatively, more overt methods can be used to directly influence consumption either through assigned quotas (Shi et al., 2014) or markets and pricing mechanisms (Brookshire et al., 2004; Olmstead and Stavins, 2009; El-Khattabi et al., 2021). It is in these latter areas on which this paper will focus.

At a local scale, overexploitation has been observed to increase public perception of value (Roobavannan et al., 2020). Additionally,

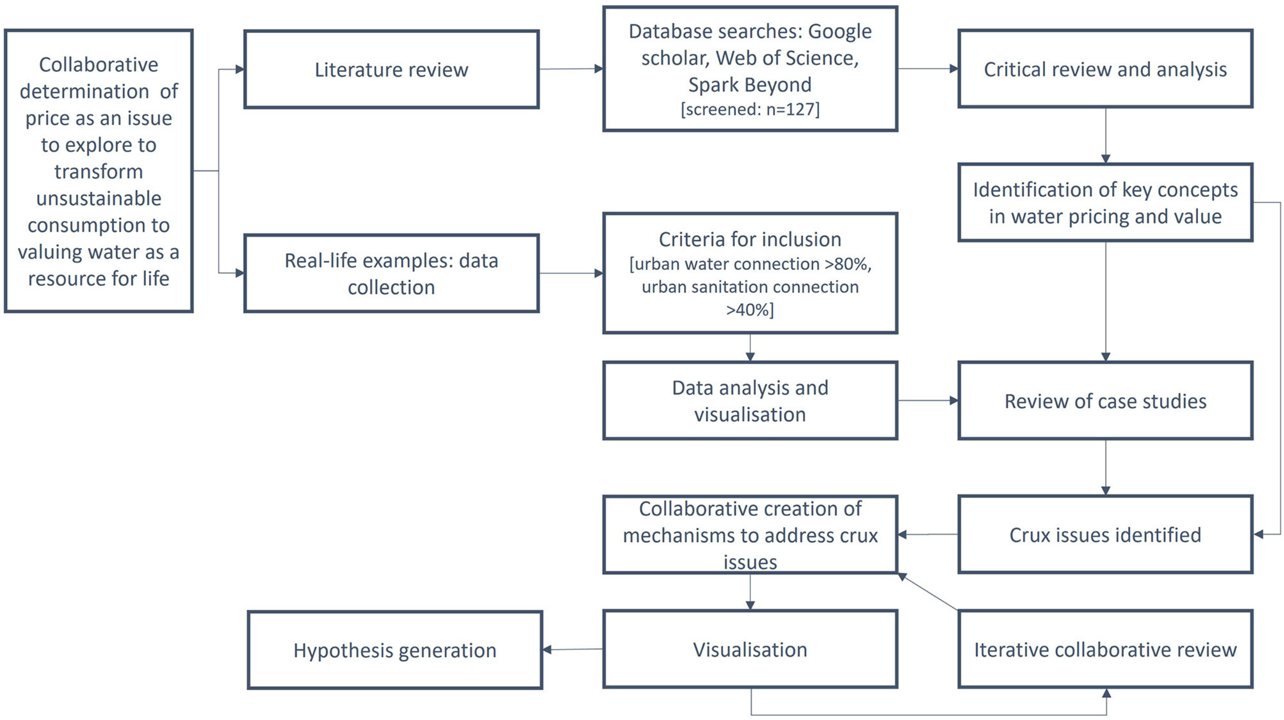


FIGURE 1
Visualization of method.

given that water is traded between nations in an embedded form (Roson and Damania, 2017; Wang et al., 2018; Serrano and Valbuena, 2021) and through transboundary watercourses (Plappally and Lienhard, 2012; Yu and Lu, 2018), the global interaction of water policy becomes an area of potential sensitivity. Therefore different cultural contexts, and desired goals, are likely to influence the success of the approaches considered in previous studies. How these fit in a global context is also important.

Assigning quotas, or command and control methods, can be used to facilitate efficient, predictable sharing of resources (Shi et al., 2014). They are considered to be quicker and easier to implement compared to exploring the use of alternative water resources (Hunt and Shahab, 2021), including recycling (Blackmore et al., 2020) or allowing market forces to influence multiple users of the resource (Munasinghe, 2010). However, studies have also found command and control methods to result in greater economic losses and therefore to be more expensive to society (Olmstead and Stavins, 2009; Luby et al., 2018).

Restrictions in water consumption have the potential to impact crop selection and agricultural irrigation practices (Castellano et al., 2007; Shi et al., 2014), which could have economic effects (Shi et al., 2014; Yan et al., 2020), or promote a transition from domestic production to imported goods (Luckmann et al., 2016) with subsequent equity and green-house gas emission implications at the local and global scales. Water efficiency measures are frequently reliant on the adoption of technological changes. This has inherent risks in leading to technological lock-in (Markolf et al., 2018), has the potential to limit innovation (Olmstead and Stavins, 2009) and not lead to the expected savings due to behavioral changes (Olmstead and Stavins, 2009; Hunt and Rogers, 2014; Hunt and Shahab, 2021). It also has the potential to increase inequity due to a requirement for new technology to meet the restriction. It has been suggested that a palatable approach would be the combination of technology with behavioral approaches (Hunt and Shahab, 2021; Murwirapachena, 2021), which could align with market-based policies akin to other environmental initiatives (Gugler et al., 2021).

A market-driven and liberal policy has been shown to increase welfare (Luckmann et al., 2016); indeed there are many studies based on a market- and price-driven approach (United States Environmental Protection Agency, 2002; Brown, 2006; Castellano et al., 2007; Bjornlund and Shanahan, 2015; Reddy et al., 2015; Luckmann et al., 2016; Luby et al., 2018; Bierkens et al., 2019). However, a difficulty arises in that water is a provider of both private and public goods and services, and as such markets are considered to be poor providers of information on either the value of water or optimal allocation (Reddy et al., 2015). Options to use payment for ecosystem services have been discussed (Pissarra et al., 2021) in which downstream users of water systems compensate headwater farmers to adopt agroforestry and sustainable forestry practices. The conversion of environmental impacts into a monetary variable for inclusion in economic analysis (Hatamkhani et al., 2023) risks the commodification of nature (Farley and Costanza, 2010) and excludes from the assessment further impacts to the community. Alternatively, a multi-capitals approach to assessing value is gaining traction (Fenech et al., 2003; Kanakoudis et al., 2011; Acosta et al., 2020; Dasgupta, 2021; Mellander and Jordan, 2021; British Water, 2022), which allows a complete understanding of value to be considered alongside fiscal measures.

The price elasticity, namely the price difference needed to elicit change in consumption, is variable based on the timescale under consideration for impact (Scheierling et al., 2006) and the sector, along with the ability to pay increased prices (Olmstead and Stavins, 2009; Berbel and Expósito, 2020), or cope with interruptions in supply (Brown et al., 2019). Therefore the success of price measures is mixed and highly dependent on the price elasticity of water use (Shi et al., 2014; Kertous et al., 2022). At the domestic scale, water use is generally considered to be inelastic (Olmstead et al., 2003; Luby et al., 2018), and therefore to effectively influence water consumption different factors become significant for different users and cultural contexts.

Water price elasticity is linked to the shadow price, which in turn is influenced by the marginal product value (Shi et al., 2014; Bierkens et al., 2019). As such it has been suggested that increasing block pricing, i.e. increasing the unit rate for water based on consumption, can be ineffective as it changes the marginal cost of water (Olmstead and Stavins, 2009). A difficulty arises when considering the value of water when we contemplate the diversity of source water quality (Piper, 2003; Brown, 2006), varied uses of water within society including agriculture, industry and municipal use (Brown, 2006; Castellano et al., 2007; Bjornlund and Shanahan, 2015; Blackmore et al., 2020), and the cultural significance of waterbodies (Shriver and Peaden, 2009; Auerbach et al., 2014; López Moreira M et al., 2018) and users within nature. This heterogeneity means that the water market does not lead to a single price for water (Brown, 2006); indeed when water is considered a public good it typically has a lower price associated with it (Shi et al., 2014). However, much of the discussion (Brown, 2006; Scheierling et al., 2006; Bjornlund and Shanahan, 2015; Bierkens et al., 2019) is focussed on the shadow price of water and the use of markets at abstractor, or organizational, level and not how this translates to the domestic consumer. This reflects a view of water as an economic good rather than a public good and human right. Although in many ways analogies may be sought between water pricing and carbon pricing, in that markets in both cases could be used as mechanisms to change environmental impacts, it is in this area that the two diverge. Whereas a unit of greenhouse gas, for example a kilogram of carbon dioxide equivalent, has a similar climate change impact anywhere in the world, water has an almost infinite number of possible prices depending on local conditions, availability and requirements.

There are justice considerations (for discussion of justice principles see: Neal et al., 2014, 2016; Sultana, 2018; Menton et al., 2020; Shrimpton et al., 2021) when setting water prices to reduce consumption. If the difference in shadow price compared to the current price is too great this can have inequitable and unjust economic and societal impacts. There is a risk of inter-sectoral inequity when applied at the organization level (Shi et al., 2014) and community level inequity (Ntengwe, 2004; Olmstead and Stavins, 2009; Heino and Takala, 2015; Luby et al., 2018; Kertous et al., 2022) if the pricing structure is established without justice principles at the forefront. Furthermore there are additional restrictions in the implementation of changes to water pricing due to institutional rigidity within the political economy and governance systems (Mumssen et al., 2018).

Price measures to discourage consumption inevitably lead to increased revenue in the short-term (Olmstead and Stavins, 2009); which body becomes responsible for these sums is uncertain and there are justice considerations to this. There are options to reduce poverty through the redistribution of wealth and provision of additional societal benefits (Olmstead and Stavins, 2009; Luckmann et al., 2016). Therefore, although pricing and market mechanisms are frequently viewed as the most effective method of reducing consumption, they are not methods without implications for fair and equitable use of water. The hypotheses presented in Section 4 discuss how price could be an aspect in a wider framework that considers the specific cultural, economic, climate and environmental influences within a region.

3.2. Pricing structures and availability

At a local level, reliability of supply is a key factor in consumer willingness to pay for water alongside awareness of water quality and knowledge of water service. However this willingness to pay is tempered by the ability to pay (Ntengwe, 2004; Adeoti and Fati, 2022; Ahmed et al., 2022). Where infrastructure and regulation are sufficiently developed, such that access to clean water and sanitation is locally universal, understanding of the volume of water consumed, the price of this water and subsequently the value it provides can be seen to be lacking. This is observed throughout the population, including amongst an environmentally aware sample group, where there is frequently little recognition of either the amount of water used, or the cost of that water (Heino and Takala, 2015; Lucio et al., 2018; Hunt and Shahab, 2021).

A comparison of domestic water use, the price of water and the amount of rainfall in various countries around the world highlights that there are various approaches to assigning a monetary value to water. To enable comparisons, data has been collected from a sub-set of urban areas in countries with extensive access to safely-managed drinking water and sanitation services, as documented by the World Bank (2022). The collection of data based on established, centralized distribution excludes the prices paid by populations where this is not the case. Therefore it does not take account of the substantial price increases when private water vendors are utilized in place of, or to supplement, centralized infrastructure (Opryszko et al., 2009; Plappally and Lienhard, 2012; Ahmad, 2017), or the impact of intermittent or restricted supply caused by the lack of, or inequity of access to, centralized services (Ntengwe, 2004; Murwirapachena, 2021). Consequently, this analysis provides an indication of the relative value ascribed to water services, but does not seek to demonstrate the full range of prices paid for water globally, or the value placed upon water in all circumstances.

As can be seen from Figures 2, 3, and Table 2, the data collected focuses on the global north, reflecting availability of extensive piped supply of water and sanitation services in these areas. A comparison of average rainfall in each country and the rate of consumption (Figure 2) highlights that in the United Arab Emirates and Singapore the amount of surface water and groundwater renewed by rainfall is less than the amount required for domestic consumption alone, not including the amount required for industrial, energy and agricultural sectors. For current levels of consumption to remain viable, the use of desalination and wastewater effluent reuse are required in these regions. A

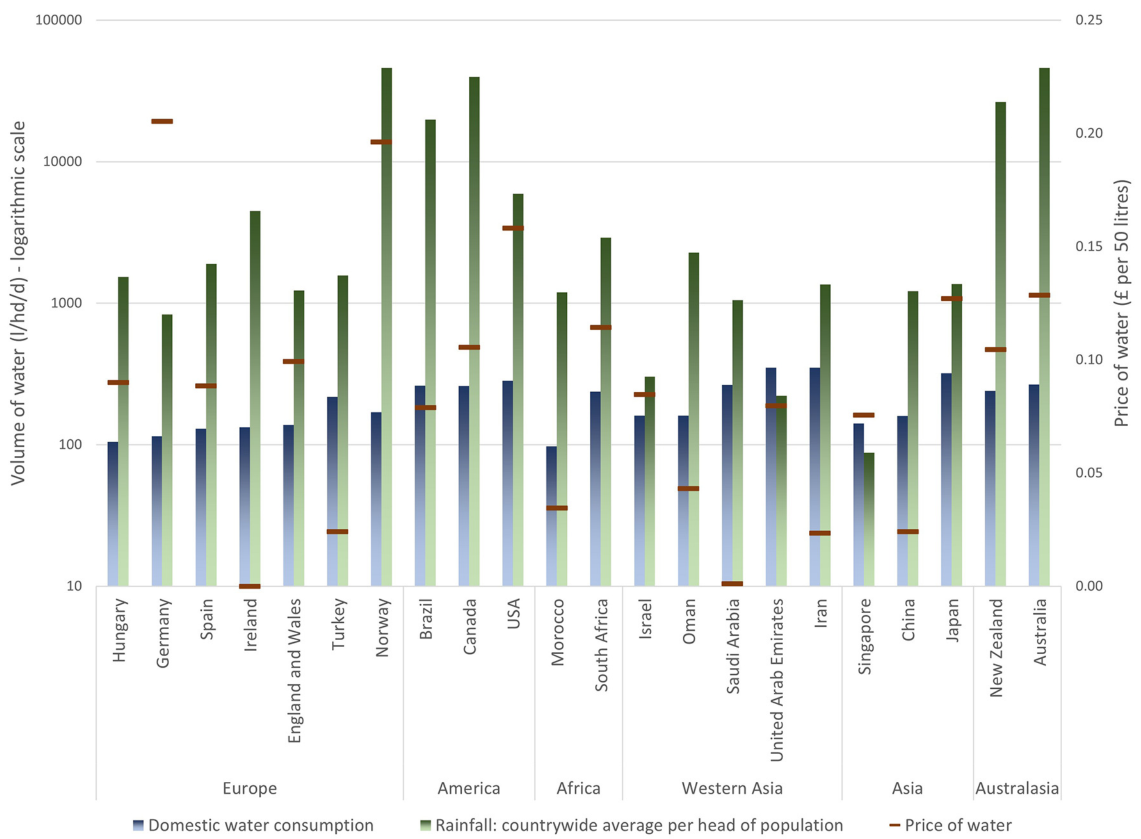


FIGURE 2
Chart showing domestic water use and rainfall per head of population compared against the price of water.

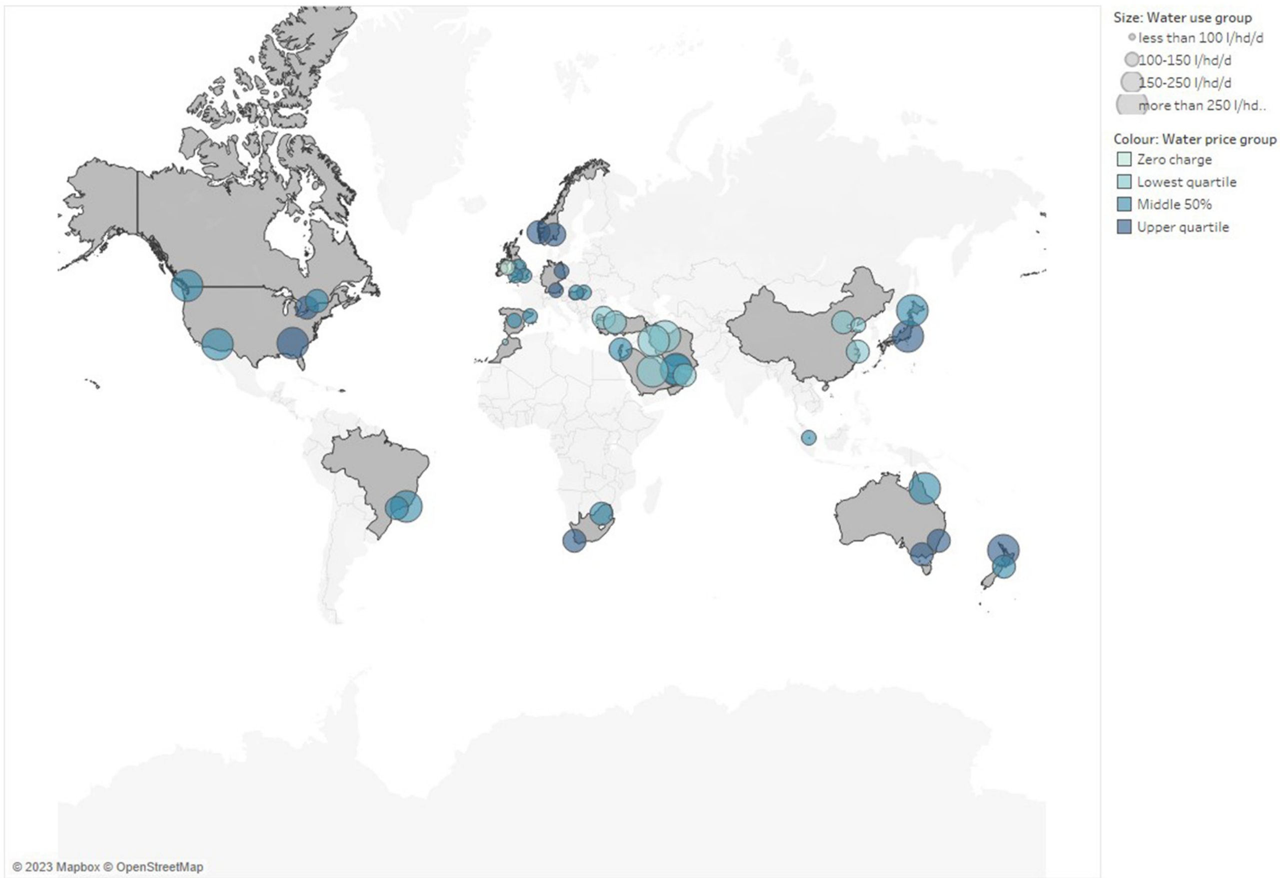
comparison of rainfall by country is a crude measure and may be misleading, particularly in countries with a large surface area and those with dense populations in small pockets of land for which average rainfall may not equate to available water supplies, or in areas with extensive evapotranspiration or sporadic rainfall. Additionally, the impact of temperature on water consumption has not been explored here. These factors may explain why there is no universal relationship between rainfall, consumption or water price. Finally, it is noted that per capita consumption ranges between 97 liters/person/day (Morocco) and 350 l/person/day (United Arab Emirates). This illustrates that the relationship of water availability and water price is complex—being influenced by population density, surface area, level of economic development and geography, among other factors.

Prices of water are stated per 50 liters (Table 2, Figures 2, 3) as this is the minimum volume of water considered required (Kanakoudis et al., 2011; Hunt and Rogers, 2014; 50L Home Arcadis, 2021) with prices calculated to incorporate actual rates of consumption. Prices range from free at the point of use (Ireland) or £0.001/50 liters (Saudi Arabia) to £0.21/50 liters (Germany). Comparatively low water prices are observed across Western Asia despite water stress in this region (Wada et al., 2011), and substantial heterogeneity of water price is observed within countries such as the USA, Australia and Japan. Low prices may imply that the cost of providing water services is subsidized, thereby creating a hidden cost that is not directly charged, and therefore not visible, to consumers. A discussion of a small number of specific examples of pricing structures follows.

3.2.1. Centralized funding: example from Ireland

Water supply in Ireland has undergone some recent changes; previously delivered through local government and funded via central taxation, water services are now delivered across the country through Irish Water. Originally planned to be funded through direct billing of the 80% of the population that is provided with centralized services, public outcry (Rodriguez-Sanchez et al., 2018) led to an agreement that government subvention would provide baseline funding, equivalent to 74% of revenue needs (2019–2024) (UISCE Eireann Irish Water, 2018). Excess water use (over 213 m^3 per year for a 4-person household, equivalent to 146 l/person/day) is charged, under a 'polluter pays' principle, with a cap on the total charge per year (UISCE Eireann Irish Water, 2021). These events demonstrate the difficulty in changing water pricing structures due to rigidity in the political economy and in public acceptance of changes.

Due to the lack of direct billing of water there is an argument that the cost of water becomes hidden and there is a disconnection between domestic water use and the costs associated with water use, including environmental impact and thereby the value of water.



Map based on Longitude (generated) and Latitude (generated) and Latitude (generated). For pane Latitude (generated): Details are shown for Country. For pane Latitude (generated) (2): Color shows details about Colour: Water price group. Size shows details about Size: Water use group. Details are shown for City.

FIGURE 3
Visualization of domestic water price and domestic water consumption in a selection of countries around the world.

Figure 2 shows that the per capita consumption of water in Ireland is comparable to the rest of northern Europe. It remains to be seen whether domestic consumption remains constant in Ireland at a time when there are widespread campaigns to reduce consumption in comparable countries, or if this disconnection leads to levels of demand from domestic users in Ireland remaining constant.

3.2.2. Direct billing: example from England and Wales

In contrast to Ireland, the water industry in England and Wales was privatized in 1989, in line with the political trend of the time, to stimulate investment from private sources for the continued provision of water and to drive improvements in wastewater treatment (Byatt, 2013; Bayliss, 2014). The primary function of the UK water industry, and specifically licensed water companies, is to perform their statutory duty to provide potable water and sanitation services to the population; this is overseen by several regulators and advisory bodies. Ofwat, as the economic regulator, has a focus on the ongoing financial viability of privatization as well as ensuring value for money for customers (Bayliss, 2014; Department For Food and Rural Affairs, 2022). Recent investigations by the Consumer Council for Water (CCW) have indicated that 10% of households regularly struggle to pay bills (Consumer Council For Water, 2021), therefore fairness of bills is a concerning issue. CCW defines water poverty as water bills totalling more than 5% of household income after housing costs have been paid; this is comparable to the UN recommendation of water services costing <3–5% of household income, although noting that this is an imperfect metric (United Nations Childrens Fund (UNICEF) and The World Health Organisation, 2021).

Currently bills in England and Wales average at £394/household/year which is 1.4% of the median income level across the UK; however for the more vulnerable in society, i.e., those on minimum wage, the national living wage, or Universal Credit the picture changes. For those households, water bills rise to between 3% and 12% of income depending on age, the number of people in the household and the income level. It is estimated (Consumer Council For Water, 2021) that 6% of households in England and Wales spend more than 5% of income on their water bill. Contrast this with the 10% that views bills as unaffordable and it appears that there is a discrepancy between the threshold for water poverty and the value which the public ascribes to water. This could be related to the perceived abundance of water in the country (Praskievicz, 2019), or that water was delivered as a public service within living memory of the majority of the population.

TABLE 2 Summary of domestic water consumption and cost of water in selected countries and cities.

Country/city	Domestic water consumption (l/person/day)	Water price per 50 liters (£/50 l)**	References
Australia, Cairns	400	0.09	Cairns Local News, 2021
Australia, Moonee Valley	200	0.16	Rogers et al., 2020
Australia, Sydney	200	0.13	Sydney Water, 2022
Brazil, Rio de Janeiro	301.3	0.10	Economist Intelligence, Unit, 2010; p. 91
Brazil, São Paulo	155	0.05	Economist Intelligence, Unit, 2010; p. 99
Canada, Ottawa	179	0.10	Ottawa Insights, 2017
Canada, Toronto	210	0.13	City of Toronto, 2022
Canada, Vancouver	390	0.09	Sustainable Vancouver, 2020
China, Beijing	154	0.03	CEIC Data, 2021a
China, Dalian	120	0.02	Huang et al., 2015
China, Shanghai	204	0.02	CEIC Data, 2021b
Germany, Berlin	115*	0.22	Environment Agency, 2008
Germany, Munich	115*	0.19	
Hungary, Budapest	105*	0.10	United Nations Economic Commission For Europe, 2010
Hungary, Debrecen	105*	0.08	
Iran, Kermanshah	350*	0.02	Tehran Times, 2020
Iran, Tehran	350*	0.03	
Ireland	133	N/A	UISCE Eireann Irish Water, 2019
Israel, Jerusalem	160	0.08	Vanham et al., 2016
Japan, Sapporo	320*	0.11	United Nations Educational Scientific Cultural Organization, 2006
Japan, Tokyo	320*	0.14	
Morocco, Rabal-Sale	97.1	0.03	Bourekkadi et al., 2021
New Zealand, Auckland	253	0.14	Auckland Council, 2022
New Zealand, Wellington	227	0.07	Learnz, 2022
Norway, Bergen	180*	0.14	Statistics Norway, 2022
Norway, Oslo	160	0.22	OECD, 2016
Oman, Muscat	160	0.04	Albawaba, 2019
Saudi Arabia, Riyadh	265	0.001	Arab News, 2014
Singapore	141	0.08	Singapore's National Water Agency, 2022
South Africa, Cape Town	237*	0.16	Murwirapachena, 2021
South Africa, Pretoria	237*	0.07	
Spain, Barcelona	132	0.10	Tello and Ostos, 2011
Spain, Madrid	127.1	0.07	Carranza and Bueno, 2018
Turkey, Ankara	246	0.02	Turkish Statistical Institute, 2021
Turkey, Istanbul	190	0.03	Turkish Statistical Institute, 2021
United Arab Emirates, Ajman	350*	0.07	The National News, 2012
United Arab Emirates, Dubai	350*	0.09	
United Kingdom	130.4	0.10	OFWAT, 2020
USA, Atlanta	283*	0.27	Luby et al., 2018
USA, Phoenix	283*	0.05	

*Average consumption across the country has been used. **Derived from International Benchmarking Network For Water And Sanitation Utilities (2022).

Nevertheless, it is evident that at a national scale, current water bills are inequitable in the degree of impact they have. In addition, the mechanism of customer-driven adoption of water metering is increasing the financial burden to those less able to pay, and bill payment support is geographically varied (Bayliss, 2014; Consumer Council For Water, 2021) thereby increasing inequity across the country.

3.2.3. Rising block tariffs and seasonal charging: example from USA

Rising block tariffs are seen in various forms around the world, including within 14 of the 22 countries compared previously in Section 3.2. There is variation both within and between countries as different urban areas adopt varying charging regimes. The data presented here is not sufficiently detailed to draw conclusions on the impact of pricing strategies; however existing literature has postulated that price measures may be ineffective due to inelasticity of use with respect to price at current levels (Olmstead et al., 2003; Luby et al., 2018), heavy users not identifying that they pay higher prices (El-Khattabi et al., 2021), or specific local and cultural conditions (Reddy et al., 2015).

Examining water prices in the USA, it becomes apparent that there are vast differences in pricing strategies. Luby et al. (2018) found a negative relationship between water price and water scarcity that persisted when accounting for variation in the cost of living. Despite water charges in Phoenix being lower than across much of the USA, the policy of enabling affordable water for essential inside use with increased charges for higher water users, including seasonal variation of rates, has gained support as a method of reducing consumption. However, this is coupled with indirect unjust impacts as higher water charges have a greater influence over behaviors of less affluent parts of the community. In this case this is exhibited as converting lawns to desert landscaping whilst more affluent areas maintain existing behaviors and high water demanding lawns and plants. This exacerbates the urban heat island effect and inequitably impacts the community (Sorensen, 2019).

3.3. There is no silver bullet

This analysis demonstrates that there is extensive global variation in the amount of water consumed, the price and price structures, even within those areas where access to piped, clean water and sanitation is near universal. The implementation of payment for water services is linked to the political ideology of that time and place, this has implications for the value society places on water and justice implications due to the potential for variable impacts across society.

Whilst the value of water is commonly defined by the economic value it generates, this fails to recognize the wider values that water provides unless a multi-capitals, or payment for ecosystem services policy, is adopted. Value is also frequently biased toward human prioritization over ecological benefits. How the price of water impacts different communities and sub-populations means that a justice approach is needed to enable intergenerational equity and environmental, or water, justice.

4. Discussion: five hypotheses for change

Multiple influences and impacts result from the interconnections between people and water consumption. These have been explored using system mapping and influence diagrams in an iterative process to generate a series of interconnected concepts (Figure 4) that are posited to drive a transformation toward sustainable water consumption at the domestic scale. This section details five hypotheses (available at https://kumu.io/BryonyB/water-pivot-hypotheses) that have been developed to promote the value of water (see Sections 4.1 to 4.5). These hypotheses set out a framework for discussion and are proposed to be tested and developed at a local scale to incorporate specific cultural, economic, climate and environmental influences.

4.1. Hypothesis 1: catchment-scale management

Viewing water at the scale of the catchment and employing a systems thinking approach provides the ability to consider multiple users of water within a catchment and ensure that this resource is managed, across existing boundaries (utility, commercial or regulatory), for the protection of the ecosystem as well as ensuring long-term supply of water now and for future generations. In turn, this enables the incorporation of justice themes through both environmental and water justice. Importantly this must incorporate the whole water cycle within a catchment, including the usage cycle.

Figure 5 depicts the premise for catchment-scale management that is proposed. This diagram depicts water use cycles alongside the inputs and outputs to catchment water resources. It also proposes a governance mechanism that incorporates legal personhood, water use recovery and a full water accounting framework. Within this diagram the blue arrows summarize the flow of resources through the natural and human usage cycles within a catchment. The red arrows portray protections provided through governance systems, including regulation-based management of water resources. The first of these to consider is the generation of a statutory framework to (1) define the catchment, and (2) specify the agencies and governments that are required to collaborate, their responsibilities and the means of collaboration. Within the statutory framework it is proposed that legal personhood for the catchment is sought. This enables the catchment, and the ecosystems held within the catchment, to be directly represented in court and enable inclusive institutions (Smith, 2017; Clark et al., 2018; Willems et al., 2021; Global Alliance For The Rights Of Nature, 2022).

Within the statutory framework there is an additional need to define a legal entity, acting as agent for the environment that is able to bill users for consumption and impairment. In such a way this governance structure enables the true value of water to the environment and society to be represented in the usage cycle. It

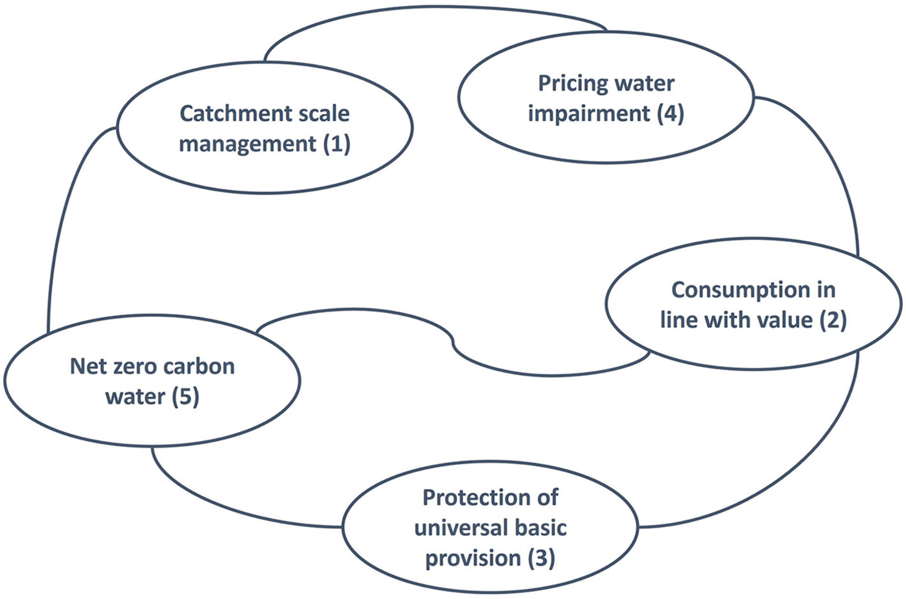


FIGURE 4
Interconnection between concepts that form the five hypotheses for the transformation toward sustainable domestic water consumption.

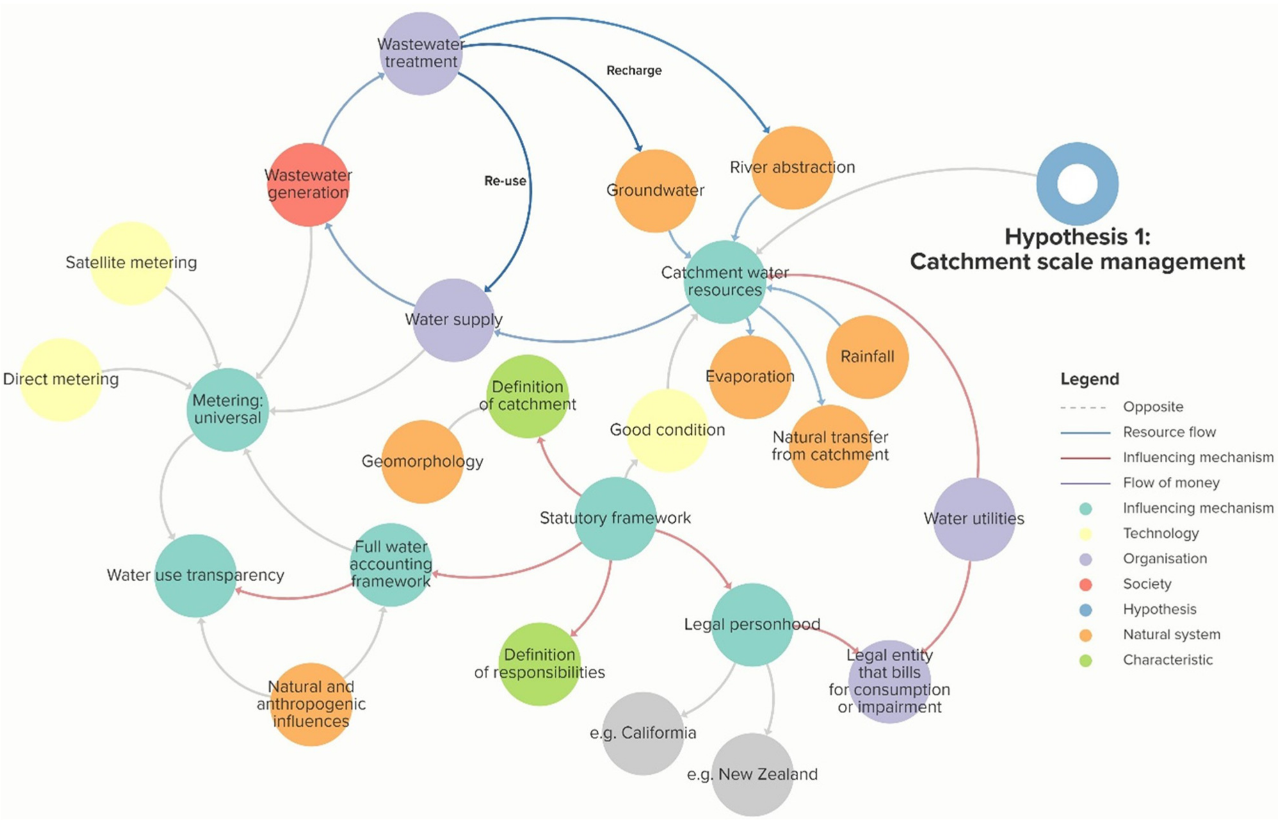


FIGURE 5
Hypothesis 1: catchment scale management. Kumu map depicting relationships between factors with resource and money flows, and influencing mechanisms highlighted.

also enables the price of water to be set as high up the value chain as possible, echoing the structure of many carbon pricing mechanisms which have been found to be effective (Gugler et al., 2021).

In order to facilitate catchment scale management, data is required on water within the catchment and the use of that water in terms of both quantity and quality. This should form a complete water accounting framework to provide transparency over water use and impairment, encompassing both natural and anthropogenic influences. Water accounting frameworks are under development; for example, Water Accounting (Water Accounting Team At Ihe Delft, 2023), Water Sensitive Cities (Rogers et al., 2020) and others (Statistics Canada, 2003, 2019; Castellano et al., 2007; Abolafia-Rosenzweig et al., 2021; Belmans et al., 2021; Fridman et al., 2021) including a patent for Water Accounting (Abbot Donnelly et al., 2013). These are data-dependent frameworks and as such, particularly when attributing water use at the domestic household level, there is a requirement for universal metering. Although there is opposition to metering, primarily focused on its ability to elicit change and potential to lead to regressive outcomes (Dresner and Ekins, 2004), a combination of universal, accurate, granular use data with pricing mechanisms based on justice principles is suggested to overcome these concerns.

4.2. Hypothesis 2: consumption in line with value

This concept centers on two key aspects; firstly, the water guardian an entity which acts as a hub between the catchment legal entity and the water abstractor. This relationship relays the value attributed to various types of water use based on the catchment value. Secondly, it includes the variable cost of consumption as a mechanism for wealth redistribution in the form of a social dividend.

If we are to value water as a resource and reflect the complete value that water provides to nature and humans, both directly and through ecosystem services, then it is a logical consequence that consumption of water is prioritized in line with the value this consumption provides. This requires the ability to define and measure the value of the catchment across the realms of environmental, societal and economic value (for example via ecosystem services (Costanza et al., 2017; Pissarra et al., 2021) or a multi-capitals approach (Dasgupta, 2021; British Water, 2022) as part of a total cost recovery model (Rogers et al., 2002; Kanakoudis et al., 2011; Mumssen et al., 2018; Berbel and Expósito, 2020).

The next stage is to prioritize water use for the highest value activity within the catchment, including use by nature. Prioritization for infrastructure decisions has been assessed including environmental impacts converted to an economic value (Gurluk and Ward, 2009; Kumar et al., 2016; Costanza et al., 2017; Pissarra et al., 2021; Hatamkhani et al., 2023). This concept is here taken further to apply prioritization across domestic consumption and propose methods of influence in the form of water pricing. However, variable domestic water pricing has been applied, for example through pricing structures to reduce consumption in Phoenix, USA. In this case justice issues have arisen where the impact is disproportionately felt by a subsection of the community (Sorensen, 2019). The final part of the concept presented here, a social dividend, provides a method of wealth redistribution to counter this effect.

It is proposed that prioritization is provided through pricing mechanisms. The price should, in this case, include a number of aspects: (1) cost to enable basic provision (see Hypothesis 3) (2) cost of high consumption (see Hypothesis 3) 3) cost of impairment (see Hypothesis 4) and (4) cost of embedded water and achieving net zero water (see Hypothesis 5). Each of these aspects will be explored further in Sections 4.3 to 4.5. Somewhat controversially for a catchment pricing structure to represent value, all users would have a charge attributed to them including private water well users.

Figure 6 highlights influence mechanisms to incorporate the value of water into prioritization of water resources within a catchment (shown as red arrows in the diagram). In this depiction the prioritization of water use, driven by the cost these activities have on the value of water, alongside the inherent value of the catchment, is presented to the water guardian. The water guardian acts as an agent for the catchment forming the link between the catchment legal entity and the organization responsible for the extraction of water and its return, vis-à-vis the water utility, industrial user or private water supplier. This organization is charged based on the amount of water that is used and on the potential for damage via impairment of the watercourse.

Funds that are generated are used to pay operating expenses and a social dividend, which is paid to the whole of society impacted by that catchment based on the damage caused to the water resource (Bayliss, 2014; Luckmann et al., 2016). This is envisioned as a price discovery mechanism to influence the water utility, industrial user or private water supplier to act to protect the watercourse. In the case of water utilities and industry, although the price will be passed on to the customer, the cost of impairment will be returned to society in the form of a social dividend, and price protection at consumer level is provided (Hypothesis 3). As will be discussed in Section 4.3, pricing water at consumer level based on consumption will also allow wealth redistribution when large water users are also in a higher income bracket and their behavior less impacted by price rises. There is an opportunity for the organization responsible for the extraction of water, and its return, to invest in both their conveyance and treatment facilities, and in the wider catchment in order to mitigate the potential for damage and improve catchment resilience to future water use (Lee et al., 2018; Du Plessis, 2022). This is an opportunity for positive feedback as it would in turn increase the value held within the catchment and improve the resilience of the water system to external shocks.

4.3. Hypothesis 3: protection of universal access to basic provision

UN SDG 6 (United Nations, 2015) states that the provision of water and sanitation is a human right. It is therefore necessary that access to a basic provision of water is provided universally. Figure 7 proposes a mechanism to ensure a basic provision of water across the population regardless of affluence, this aims to counter the justice implications observed in the UK and Phoenix (Section 3.2.2

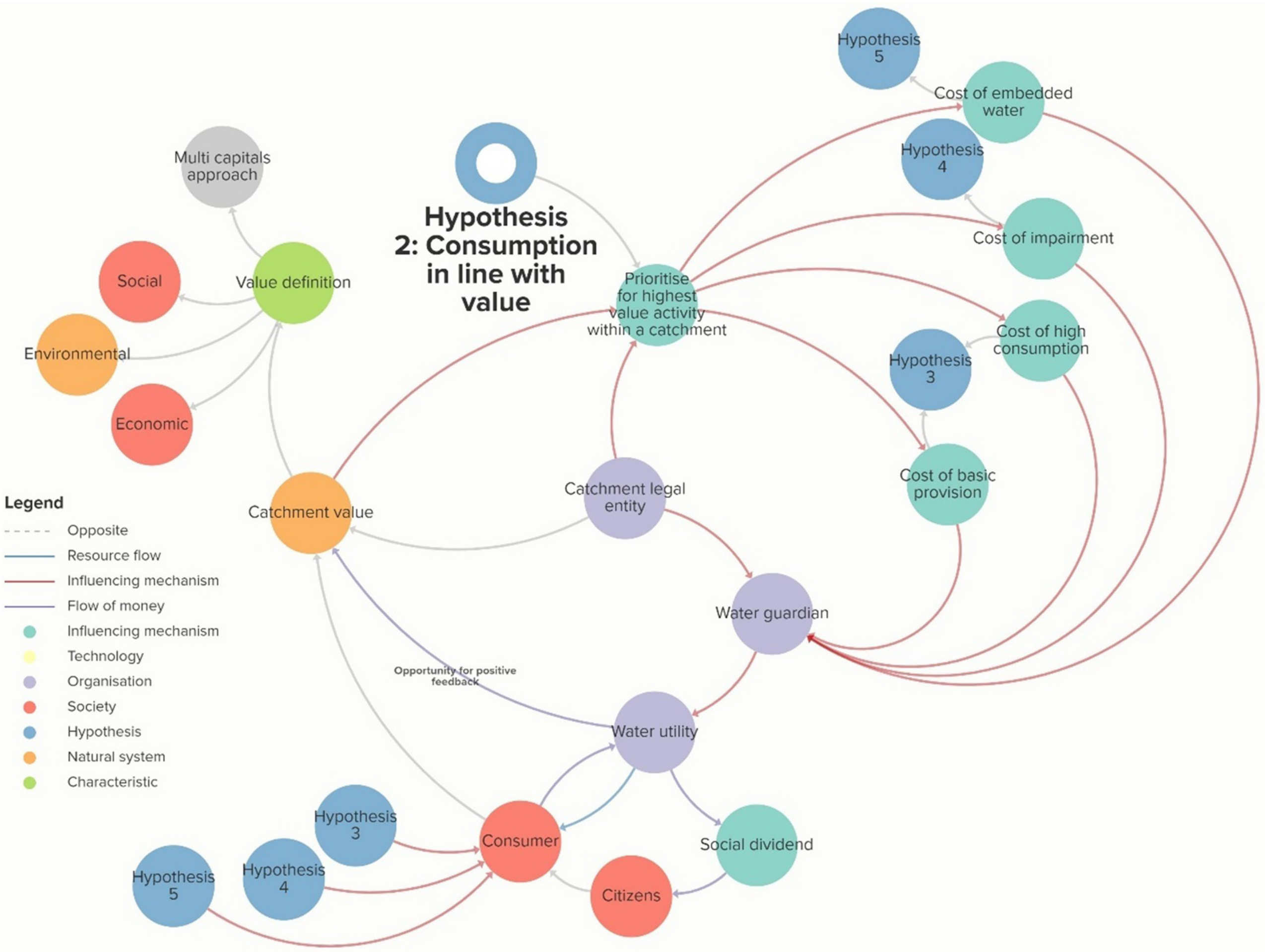


FIGURE 6
Hypothesis 2: consumption in line with value. Kumu map depicting relationships between factors with resource and money flows, and influencing mechanisms highlighted.

and 3.2.3). The volume of water that constitutes a basic provision is dependent on a number of factors including climate, cultural norms and access to technology that supports low water use. A number of studies have explored the topic of a basic provision, indicating that this could vary between 50 and 125 liters/person/day (Hunt and Rogers, 2014; 50L Home Arcadis, 2021). Comparing this to the average consumption currently ranging between 97 and 350 liters/capita/day in the analysis in Section 3, it is apparent that globally consumption is far greater than the basic provision. However, basic provision at a domestic level is not the only consideration; subsistence farming carries additional water needs, and additional value. Therefore, the volume deemed necessary as a basic provision for subsistence farming would be greater than for domestic use and subject to climate considerations.

Depending on the location, culture and historic relationship with water, there may be a need to provide payment protection through a variety of means in order to preserve the value of water within society (Figure 7). Indeed the impacts of an inability to pay for water increase mental and physical health burdens (Winkler et al., 2023). Therefore to ensure equity of access to a basic level of provision payment protection is required, this could be through zero tariffs, payment relief or by setting the price of basic provision relative to a proportion of income. Some regions have payment protection in place for example zero rate tariffs in Japan, Brazil and South Africa (International Benchmarking Network For Water And Sanitation Utilities, 2022) and bill payment support in the UK, although this has received criticism for geographical inconsistency (Consumer Council For Water, 2021).

Conversely, the price of water use in excess of the basic provision would be set according to Hypothesis 2. This offsets the risk to maintaining conveyance and treatment infrastructure through reduced revenue, whilst ensuring that the value of water throughout the catchment, and the potential harm caused by excess water use, is translated into water pricing. This mechanism balances the viewpoints of water as a public good and as an economic good by applying different pricing mechanisms across varying consumption levels to reflect these use-types. Linking this to the mechanism proposed in Hypotheses 2 and 5 provide methods of embedding just approaches into pricing to ensure public goods are provided with equity both within and between communities.

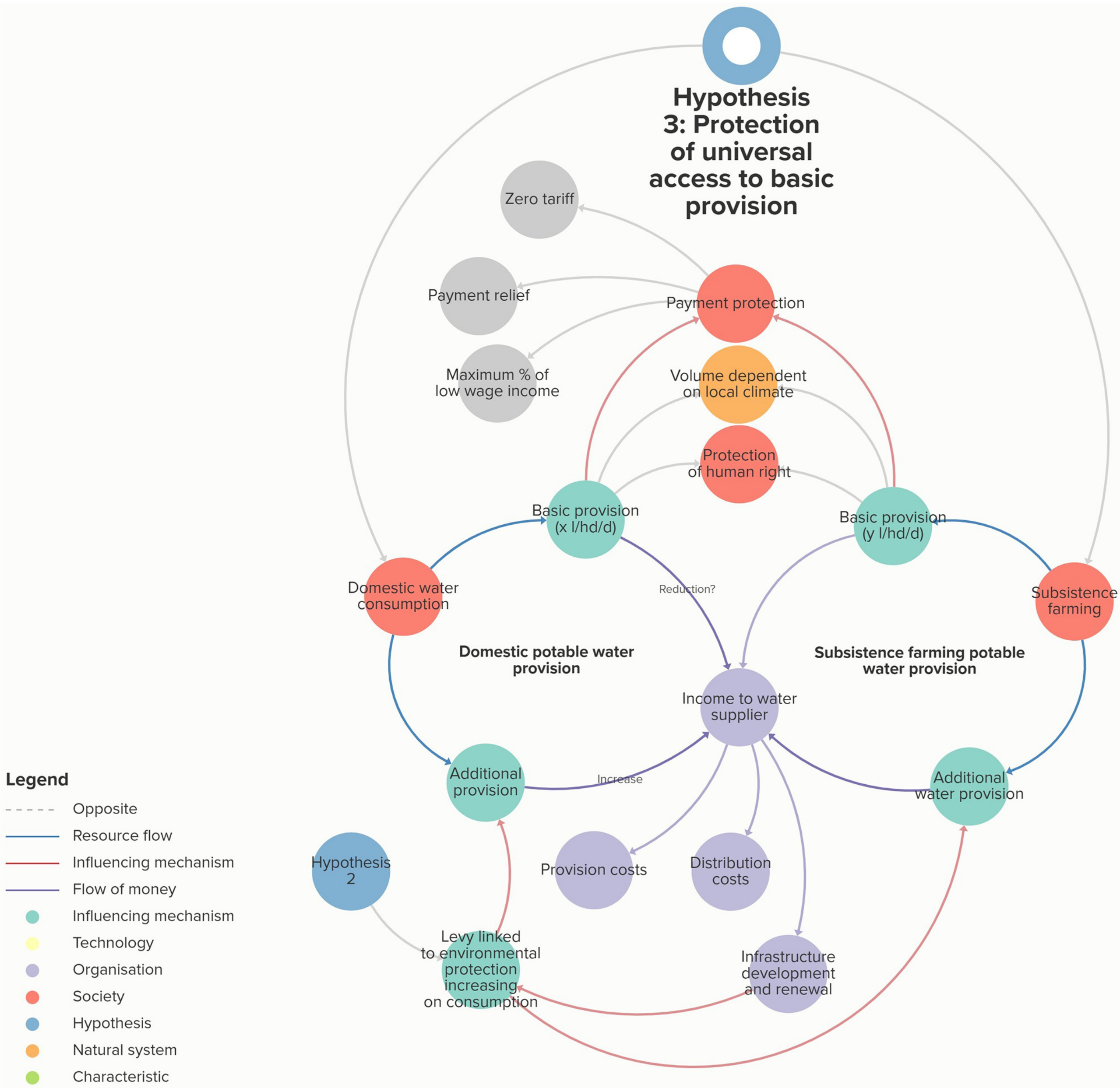


FIGURE 7
Hypothesis 3: protection of universal access to basic provision. Kumu map depicting relationships between factors with resource and money flows, and influencing mechanisms highlighted.

4.4. Hypothesis 4: pricing water impairment

Pricing water based on the quantity that is used is a relatively straightforward mechanism, albeit one that requires measurement of consumption. However, this addresses part of the potential for harm to the catchment. There is substantial risk of water use, and subsequent return to the watercourse resulting in impairment due to changes in the characteristics of water (Rasiah et al., 2013; Xu and Berck, 2013; Naden et al., 2016; Han et al., 2017; Li et al., 2019; Bell et al., 2021; Lozano et al., 2021; Marcal et al., 2021; Thiebault et al., 2021).

Figure 8 depicts the flow of water through a series of mechanisms and descriptors that demonstrate the potential environmental harm due to human influence on the quality of water entering the waterbody. The impairment can include quantity and quality aspects such as modification of the chemical and biological content, pH and temperature. The actual harm these changes can elicit is mitigated by the capacity of the catchment to self-repair. Changes over this threshold have the ability to cause harm, and this harm may limit the ability of the catchment to self-repair into the future, thereby reducing resilience (Adams et al., 2020; Canning and Death, 2021). The inclusion of payments for ecosystem services into economic

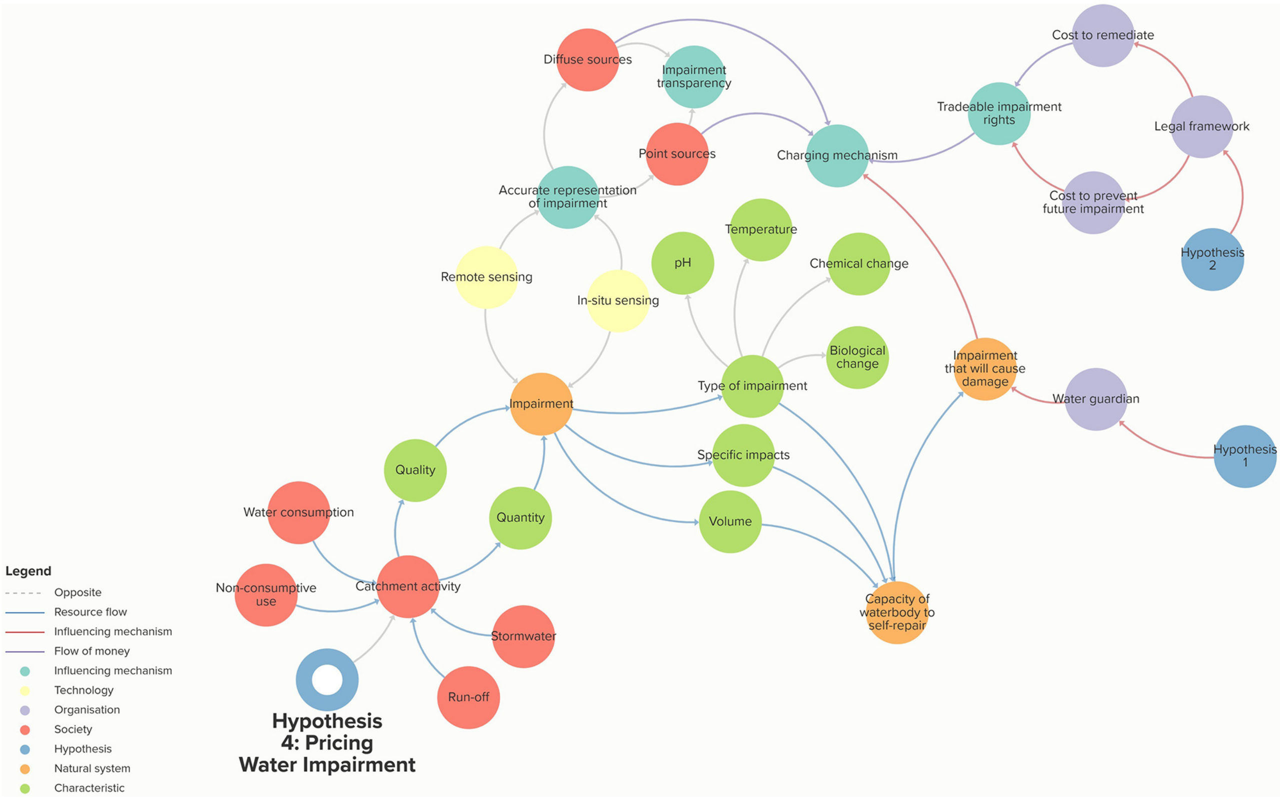


FIGURE 8
Hypothesis 4: pricing water impairment. Kumu map depicting relationships between factors with resource and money flows, and influencing mechanisms highlighted.

analysis has predominantly been applied at the abstractor level (Costanza et al., 2017; Hamann et al., 2020; Gomes et al., 2021; Pissarra et al., 2021; Hatamkhani et al., 2023), and has the potential to commodify nature (Farley and Costanza, 2010). Through interaction with the proposal in Hypothesis 1 the water guardian determines the value which should be accrued through the pricing mechanism relating to impairment. As in Hypothesis 1, transparency is required over the sources and scale of impairment in order for the charging mechanism to be applied appropriately. This would be achieved through a combination of remote and *in situ* sensing that would be formulated into a representation of impairment.

Finally, there is the representation of tradeable impairment rights that could be implemented through a market mechanism such as EnTrade (Gosal et al., 2020; Rodgers and Kendall, 2023). This would utilize transferable impairment rights with a strike price established following the pricing strategy set out through these hypotheses.

4.5. Hypothesis 5: net zero carbon water

The drive to net zero carbon is incorporated in Hypothesis 5. The water sector is a contributor to greenhouse gas emissions through energy use and process emissions (Aboobakar et al., 2013; Brotto et al., 2015; Water UK, 2020); however, this increases substantially once domestic heating of water is included (Water UK, 2020; 50L Home Arcadis, 2021). As such commitments have been made to reach net zero within the water industry (Water UK, 2020; Global Water Intelligence, 2022), at the organizational level with commitments such as the UNFCC Race to Zero and international commitments (United Nations, 2023).

The water industry has the potential to mitigate the carbon impact of water through organizational, societal and technological solutions, including the use of nature-based solutions (Haddaway et al., 2018; Delre et al., 2019; Ritson et al., 2021; Tao et al., 2021; Thomassen et al., 2021). However, to address the impact of water consumption and impairment at a global scale, the influence of embedded, or virtual, water also needs to be considered (Reimer, 2012; Roson and Sartori, 2014; Wang et al., 2018; Serrano and Valbuena, 2021; Novoa et al., 2023). It is postulated that this could be achieved through an international water trading mechanism that links Hypotheses 3 and 4 with a climate impairment pricing structure (van den Bergh et al., 2020; Hu et al., 2021; Kornek et al., 2021).

In Figure 9 the red arrows represent the influence of commitments at global, national and local scales. This feeds into an agent for the climate, which could be the same or separate to the water guardian. The object of this entity would be to influence water users through a climate impairment pricing structure. This pricing structure is proposed to be developed in line with existing carbon accounting frameworks that may be in place, or in line

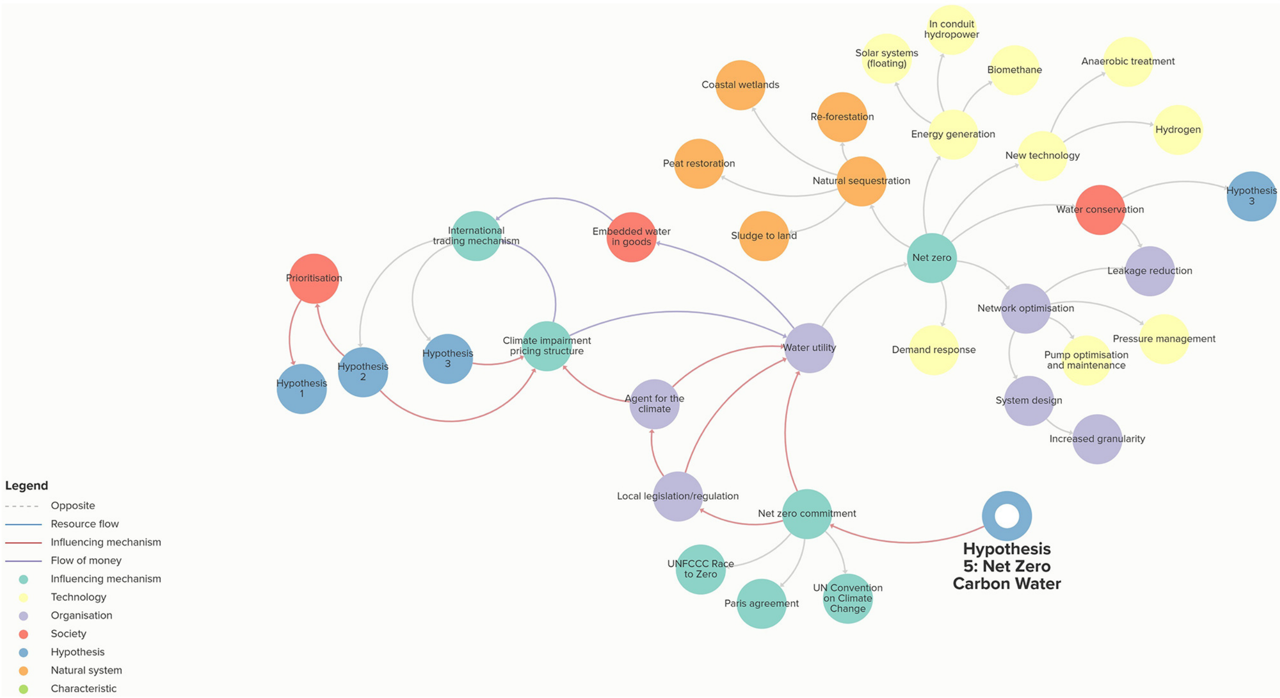


FIGURE 9
Hypothesis 5: net zero carbon water. Kumu map depicting relationships between factors with resource and money flows, and influencing mechanisms highlighted.

with the water pricing structure proposed in Hypotheses 1–4 and have justice principles embedded within it. The pricing structure is able to influence water users in a catchment directly, and feed into international trading mechanisms to ensure the climate impact of embedded water is reflected in the systematic assessment of water consumption.

5. Conclusions

Current water use can be seen to be unsustainable and inequitable, both globally and within communities, demonstrating the low value that society places on water, particularly where that water is, or is perceived to be, readily available. This paper presents the current situation with regard to water consumption and pricing at the domestic user scale, alongside a summary of the theory and practice regarding pricing mechanisms to influence how water is valued by society.

Water rights, particularly in the global north, prioritize human use over environmental needs, however degradation of the water environment has impacts not only on water availability but also ecosystem services and therefore it has societal and economic ramifications. A market-driven approach has been applied in some localities, however there is a difficulty in the effectiveness of this approach in that water is a provider of both public and private goods and services. As such, markets are considered poor informers of value or optimal allocation and have variable impacts across user groups, therefore justice implications become paramount. Further complexity arises from the heterogeneity of water due to availability, quality, uses and cultural significance resulting in an almost infinite number of possible prices. The global interaction of water, particular within traded goods, and impacts on equity within and between societies' need to be considered when developing mechanisms to improve the sustainability of water use. The research presented here aims to combine pricing mechanisms with a systems thinking and justice-led approach to promote the value of water across society in order to improve the sustainability of consumption.

The comparison of domestic water consumption, availability and price presented here provides a system level view of the situation. A more thorough investigation to include regional water availability analysis and local views, and incorporating areas in which piped water and sanitation is not universal, would be beneficial to highlight the variation in availability, cost and value placed on water. It is recommended that future work incorporates an analysis of consumption, availability and price across the global south as well as the global north.

Examining a small number of examples of water price across a sub-set of countries highlights the potential for pricing mechanisms to have deleterious impacts of equity both within and between communities. The five hypotheses presented here postulate how combining responsible agents, legal representation, pricing mechanisms and justice principles could be used to formulate a pricing structure that instills the value of water within society nationally and globally whilst ensuring that communities, or sub-sets of communities, are not disproportionately impacted. The transformation posited here is reliant on a number of aspects: (1) legal representation of the ecosystem, including indigenous communities, to enable inclusive institutions; (2) universal metering to provide consumption transparency; (3) water prices to reflect harm to the environment; (4) social dividend so that high water use or impairment leads to benefits across society; and (5) recognition of the value of water embedded in globally exported goods.

In recognition of the influences of climate and culture on these mechanisms, this paper does not claim to present a worldwide panacea or to stipulate how this should be achieved in all cases. The local context is a vital part of effective water management, especially as this context is changing with the impacts of climate change, and as such needs to be incorporated and reflected in the development of influencing mechanisms. Instead, it posits a series of important system-scale ideas to be explored and tested with the aim of pivoting from a simplistic, linear extractive use of water, to begin working with water as a high value, circular, resource for all of life within a catchment.

Data availability statement

The original contributions presented in the study are included in the article. In addition, kumu diagrams are openly available at the following link: https://kumu.io/BryonyB/water-pivot-hypotheses.

Author contributions

BB, IA-D, J-FB, and PW collaboratively designed the method and conceptualization of the hypotheses presented herein. BB conducted the detailed analysis and investigation as part of her doctoral studies under supervision of DH and CR and wrote the first draft of the manuscript. All authors contributed to manuscript revision, have read, and approved the submitted version.

Acknowledgments

The authors gratefully acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC) under grants EP/R017727 (UK Collaboratorium for Research on Infrastructure and Cities Coordination Node) and EP/S016813 (Pervasive Sensing of Buried Pipes), and both EPSRC, under grant EP/R513167/1, and United Utilities for supporting the doctoral research study of BB, of which this article is part of.

Conflict of interest

J-FB is employed by IBM. Pivot Projects is a voluntary collaboration of which BB, IA-D, J-FB, and PW are associated.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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