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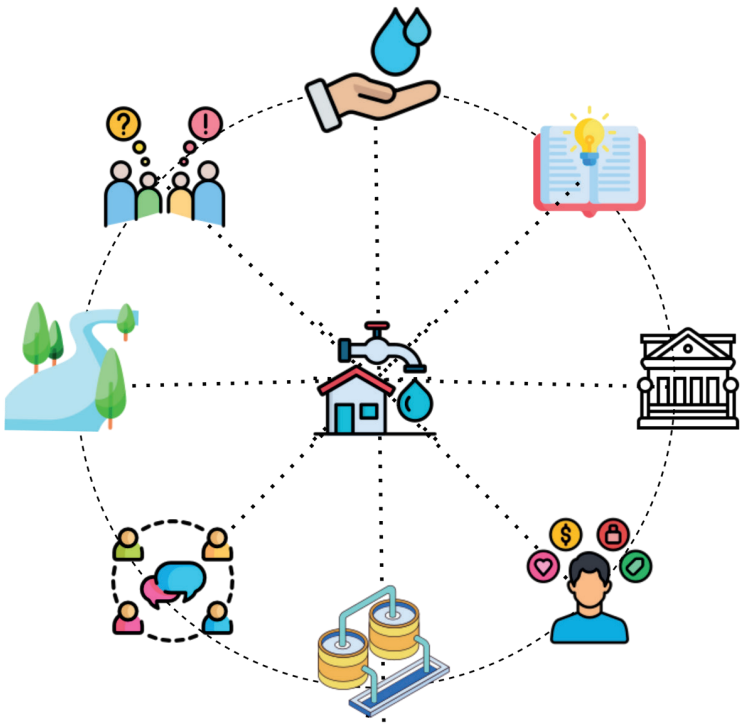
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CONTEXTUAL AND PSYCHOLOGICAL FACTORS ASSOCIATED WITH WATER USE EFFICIENCY IN PERI-URBAN AND RURAL WATER SUPPLY SYSTEMS



Diana Carolina
Callejas Moncaleano

TU Delft

PROPOSITIONS

pertaining to the thesis
Incresing water use efficiency
By Diana Carolina Callejas Moncaleano

1. Water use efficiency and sustainability should be aligned with pressure on water sources, not just in producing more goods and services with less water (This Thesis).

2. Technology can solve numerous drinking water availability challenges, but we also need curtailment behaviour to accomplish sustainable use of water (This Thesis).

3. Socioeconomic context factors and social norms, attitudes regarding the evaluation of costs and benefits, and environmental values are mainly responsible for decisions of water users and suppliers on sustainable water use (This Thesis).

4. Decision makers should consider that the implementation of water use reduction measures can be balanced out by the so-called rebound effect (This Thesis).

5. Water scarcity and overuse challenges should primarily be seen in the perspective of the well-being of human beings and environmental sustainability, and in the second place, on economic indicators "This proposition pertains to this dissertation".

6. Predictive models are useful to study water use trends, but we first need to understand how water users behave "This proposition pertains to this dissertation".

7. The information about water use coming from either water meters or water users, is equally important, since the actions of water use are executed by humans "This proposition pertains to this dissertation".

8. In the socio-hydrology field, to close the gap between engineering and social sciences, we need to align the scale and time steps of the data set from both hydrology and social information" This proposition pertains to this dissertation".

9. Pursuing a PhD is an endurance track rather than being the fastest "This proposition pertains to this dissertation".

10. Knowledge is constructed through individual curiosity and effort, and it can grow and expand if there is a supportive teamwork, and respectful and constructive dialogue "This proposition pertains to this dissertation".

These propositions are regarded as opposable and defendable and have been approved as such by the promotor Prof.dr.ir.L.C.Rietveld and copromotor Dr.S.Pande.

Contextual and psychological factors associated with water use efficiency in Peri-urban and rural water supply systems

Diana Carolina CALLEJAS MONCALEANO

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Contextual and psychological factors associated with water use efficiency in Peri-urban and rural water supply systems

Dissertation

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by the authority of the Rector Magnificus, prof. dr. ir. T.H.J.J. van der Hagen,
chair of the Board for Doctorates
to be defended publicly on
Wednesday 12th November 2025 at 17:30 o'clock

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Dedicated to
My parents Zoraida y Jorge
My grandmother Hilda
My brother Nicolás
My lovely pets Balti and Zazir
Other people who supported and believed in me

Patience, failure, resilience, strength and the love of loved ones are the factors that enable us to achieve our goals.

La paciencia, el fracaso, la resiliencia, la fortaleza y el amor de nuestros seres queridos son los factores que nos permiten alcanzar nuestras metas.

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Summary

Water scarcity is a classic problem in the water management field. Water scarcity occurs when water is not renewed and cleaned at the same rate as it is used. Scholarship has indicated that water scarcity at a global level is increasing caused by climate change, and growing water demand. This growing water demand is primarily caused by increasing populations, domestic use, and economic activities. Additionally, the growing water demand is also caused by overuse, inefficiency in water use, weakness in the management of water use, and unsustainable water use behaviour.

Reducing water demand and enhancing water sustainability have emerged as priority measures on decision-makers' agendas. An example is the indicator 6.4.1, "Increasing water-use efficiency (WUE)", one of the Sustainable Development Goals formulated by the United Nations. These measures are on the water management programmes at a global level and also at regional and local levels. Currently, in urban and rural areas of countries such as Colombia, water scarcity is problematic due to extreme weather events such as the El Niño phenomena and urbanization. Under these circumstances, decision makers such as water managers and suppliers must simultaneously deal with guaranteed water supply and promote reduced water demand.

Decision makers typically focus on supply-side solutions, such as new water sources and construction of the reservoirs, and demand-side solutions, such as educational programs to raise awareness, the adoption of water-saving devices, economic incentives, and encouragement for the reduction in water use. To reduce water demand, these measures can mitigate drought conditions that occur more regularly and that do not necessarily translate into mid- to long-term water reductions. Besides conventional strategies, human decisions and actions are essential in reducing water use.

Behavioural factors such as attitudes and perceptions to assess relationships between human beings and water use are not usually integrated into supply

and demand side solutions. For example, awareness initiatives often overlook why individuals do or do not adopt cost-effective water saving devices or why people take shorter showers or recycle greywater. Little progress has been made in understanding what drives the behaviour that can support policy to target and achieve urgent water savings.

Knowledge about water use behaviour in rural and peri-urban areas is still limited. Previous studies have identified a variety of contextual and psychological factors underlying water use behaviour at the household level. Most studies in this field have only been conducted in urban areas.

The research to date has focused on studying specific behavioural factors rather than integrated ones. Yet, few studies consider an integrated view of behavioural factors in shaping water use behaviour. We propose a systematic understanding of how contextual and psychological factors contribute to (in) efficient water use of water based on existing psychological approaches. This thesis aims to develop an integrated, systematic approach for identifying contextual and psychological factors underlying the (un) sustainable domestic use of water for applications in rural and peri-urban water supply systems.

We proposed a conceptual model which connects contextual and psychological factors to water use and represents relationships as supported by various environmental psychology approaches and theories, specifically the RANASt (risk, attitudes, norms, abilities, self-regulation and trust) approach and theory of values, beliefs and norms (VBN). The conceptual model has been applied to assess the relationship between contextual and psychological factors and to identify which factors underline the (un) sustainable domestic use of water. This conceptual model was then applied in a case study which included eight water supply systems, four in a peri-urban area of Cali and four in a rural area of Restrepo in the Valle del Cauca Department, situated in the western part of Colombia.

We collected self-reported data on water use activities through a cross-sectional survey, with a focus on domestic use from April to December 2021. A face-to-face survey was conducted with a random sample of 926 households which belong to eight water supply systems in rural villages and peri-urban zones in the Valle del Cauca Department in the western part of Colombia. We estimated water use efficiency based on survey data targeting the adoption of water saving devices (*SP*) and curtailment behaviour (*SD*), represented by shower duration. In this study we employed a quantitative methodology. Descriptive data were generated for all variables, and a multiple regression model was used to examine the relationship between water use and the contextual and psychological variables proposed by the RANASt and VBN theory.

Statistical analysis was used to identify various contextual and psychological factors underlying water use behaviour. A conceptual model integrating contextual and psychological factors, based on existing models and theories was proposed.

We found that the water supply was higher in rural areas than in peri-urban areas, even though the perceived water use was higher in peri-urban areas. Socioeconomic factors and proximity to capital cities can shed light on these results. Here, we show that the *SP* and *SD* variables exhibit relationships with contextual factors such as education level and location. The RANASt approach revealed that *SD* was related to attitudes, capabilities, and self-regulation. Meanwhile, *SP* was associated with risk, attitudes, social norms, and abilities. The relationship between environmental values, beliefs and norms, and *SP*, and *SD* was tested using VBN theory. The results of relationship analysis indicated that *SP* was connected to altruistic and egoistic values, as well as personal norms. Conversely, *SD* was linked to biospheric values and the moral duty to save water, which was recognized as a personal norm.

This study confirms that education level is associated with water use behaviour. However, the relationship between *SD*, *SP,* and location has not been previously described. The findings presented in this study suggest that policymakers often overlook the differences in organization and management between water supply systems far from urban areas and those nearer to urban areas when making decisions regarding water use reductions.

These results further support the idea that risk perception, attitudes about cost-benefit, abilities, altruistic, egoistic values, and social norms are connected with environmental behaviours. Consistent with the literature, which indicates that biospheric values might connect to environmental behaviours, this research found that these values connect with *SD*. This approach will be helpful in expanding our understanding of how the RANASt approach and VBN theory work help to examine water use behaviours.

Applying behavioural science to water use connects water management and the social sciences. This study's methodology includes innovative and interdisciplinary methods, such as integrating engineering with the social sciences. To integrate both fields is essential to shift from unsustainable to sustainable water supply systems and to promote sustainable water practices. The findings will be of interest mainly to decision makers, such as water managers and academics, who want to include human behaviour components into water supply and demand side solutions.

Various areas around the globe that are facing overuse and highwater demand could also gain insights from this study by including human behaviour when examining water usage. The systematic approach used to examine contextual and psychological factors, and the conceptual model proposed in this study might be applied to other water supply systems elsewhere in the world.

Resumen

La escasez de agua es un problema clásico en el campo de la gestión del agua. La escasez de agua ocurre cuando el agua no se renueva y depura a la misma tasa que es usada. Los investigadores han indicado que la escasez de agua a nivel global se está incrementado debido al cambio climático y al crecimiento de la demanda de agua. Este crecimiento de la demanda se debe principalmente al crecimiento de la población, del uso doméstico del agua y de las actividades económicas. Adicionalmente, el crecimiento de la demanda es también causado por el exceso en el uso del agua, el uso ineficiente del agua, debilidades en la gestión del agua y un uso insostenible del agua por parte de las personas.

Reducir la demanda del agua y mejorar la sostenibilidad del agua han emergido como medidas prioritarias en las agendas de los tomadores de decisiones. Un ejemplo de esto es el indicador 6.4.1. "Incrementar el uso eficiente del agua", el cual es uno de los indicadores de los Objetivos de Desarrollo Sostenible, formulado por las Naciones Unidas. Estas medidas están en los programas de la gestión del agua a nivel global, pero también a nivel regional y local. Actualmente en las zonas urbanas y rurales de países como Colombia, la escasez de agua es problemática debido a los eventos extremos como el fenómeno del Niño y la urbanización. Bajo estas circunstancias, los tomadores de decisiones como los gestores del agua, tienen que enfrentar, simultáneamente, el garantizar el agua para el suministro y promover la reducción en la demanda del agua.

Los tomadores de decisiones tradicionalmente se enfocan en soluciones basadas en el suministro, como buscar nuevas fuentes de agua y la construcción de reservorios, y en soluciones basadas en la demanda, como programas de educación para generar concientización, la adopción de sistemas o equipos ahorradores, incentivos económicos y motivar la reducción del uso del agua. Estas medidas pueden mitigar condiciones de

sequía que ocurren regularmente pero no necesariamente se traducen en reducciones del uso del agua en el mediano y largo plazo. Además de las decisiones tradicionales, las medidas que tengan en cuenta las decisiones y acciones humanas son esenciales para reducir el uso del agua.

Los factores de comportamiento como las actitudes y las percepciones para analizar las relaciones entre los seres humanos y el uso del agua usualmente no están integradas en las soluciones en el suministro y en la demanda de agua. Por ejemplo, iniciativas de concientización, aveces omiten analizar el por qué los individuos deciden o no adoptar sistemas o equipos de ahorro del agua, porque las personas toman duchas cortas o no, porque las personas deciden reciclar el agua gris o no. Pocos avances en el conocimiento hay en el entender cuales son los motivos que conllevan a una persona a adoptar un comportamiento u otro, lo cual podría contribuir a políticas enfocadas en objetivos específicos y lograr ahorros del agua en un corto plazo, por ejemplo, ante una emergencia de escasez.El conocimiento acerca del uso del agua como comportamiento ambiental, es decir el uso del agua por parte de los usuarios en zonas rurales y peri-urbanas es limitado. Estudios anteriores han identificado varios factores de contexto y psicológicos que influyen en las decisiones y acciones de los usuarios domésticos, para usar el agua. Sin embargo, la mayoría de estos estudios se han realizado en las zonas urbanas.

Hasta la fecha, los estudios realizados se han enfocado en estudiar factores específicos más que integrar varios factores. Hasta ahora, solo algunos estudios incluyen una visión integral para entender cuales son los factores que influyen en el uso del agua. En este estudio proponemos entender de forma sistemática como los factores de contexto y psicológico contribuyen al uso eficiente o ineficiente del agua basados en modelos y teorías propuestas desde la psicología. Esta tesis tiene como objetivo desarrollar una aproximación sistemática e integrada para identificar los factores de contexto y psicológico que influyen en el uso sostenible o no sostenible del agua para uso doméstico aplicado para sistemas de acueducto en zonas peri-urbanas y rurales.

Se propone un modelo conceptual que conecta los factores contextuales con los psicológicos y el uso del agua y que representa las relaciones entre estos. Las variables y sus conexiones se basan en teorías y modelos de la psicología ambiental, específicamente el modelo RANASt (Riesgo, Actitudes, Nomas, Habilidades, Auto-regulación y Confianza) (VBN) y la teoría de valores, creencias y normas. El modelo conceptual ha sido aplicado en un caso de estudio que incluye ocho sistemas de acueductos. Cuatro localizados en zonas peri-urbanas de Cali y cuatro localizados en zonas rurales de Restrepo, en el departamento del Valle del Cauca, situados en la parte occidental de Colombia.

La recolección de información se realizó utilizando encuestas a los hogares, las respuestas a las encuestas corresponden a un reporte propio y la percepción de la persona entrevistada. Estas entrevistas se enfocaron en uso doméstico y se realizaron entre abril y diciembre de 2021. Las entrevistas se realizaron en persona, utilizando una muestra aleatoria de 926 hogares que incluyó los ocho acueductos seleccionados. La estimación del uso eficiente del agua se basó en la información recolectada de las encuestas, una de las preguntas incluyó indicar el número y el tipo de dispositivos ahorradores y por otra parte se utilizó información secundaria de consumo de estos dispositivos (*SP*). El tiempo de duración en la ducha (*SD*) se utilizó como variable para medir la reducción en el uso del agua. En este estudio se utilizó una metodología cuantitativa. El análisis descriptivo de la información se realizó para todas las variables, y el modelo de regresión múltiple se utilizó para analizar las relaciones entre el uso del agua y los factores de contexto y psicológico propuestas por el modelo RANASt y la teoría VBN.

El análisis estadístico fue usado para identificar los factores de contexto y psicológicos que influyen en el uso del agua. Se propuso un modelo que integra los factores de contexto y de comportamiento basado en un modelo y una teoría de la psicología ambiental.

Se encontró que el suministro de agua es mayor en zonas rurales que en zonas peri-urbanas, sin embargo, la percepción acerca de la cantidad de agua usada

es mayor en zonas peri-urbanas que en zonas rurales. Los factores socioeconómicos y la cercanía a la ciudad capital, Cali pueden dar una luz acerca de estos resultados. En este estudio, las variables *SP* y *SD* se relacionan con los factores de contexto, como son educación y localización, es decir zona urbana o peri-urbana. El modelo RANASt reveló que *SD* está relacionado con actitudes, capacidades y auto-regulación. Mientras tanto, SP estuvo asociado con riesgos, actitudes, normas sociales y habilidades. La relación entre los valores ambientales, creencias y normas, y *SP* y *SD* analizadas utilizando la teoría de VBN. Los resultados indican que, por un lado, *SP* está conectado con valores altruistas y egoístas y también con normas personales. Por otro lado, *SD*, está conectado con los valores biosfericos y el deber moral de ahorrar agua, lo cual corresponde con una norma personal.

Este estudio confirma que el nivel de educación este asociado con el uso del agua. Sin embargo, la relación entre SD, SP y la localización no se había analizado previamente. Los resultados presentados en este estudio sugieren que los responsables de las políticas públicas cuando tomas decisiones para reducir el uso del agua algunas veces no tienen en cuenta que las organizaciones encargadas de gestionar y suministrar el agua en zonas rurales y en las zonas peri-urbanas tienen contextos socioeconómicos diferentes y por lo tanto su nivel de organización también es diferente. Estos resultados respaldan la idea que la percepción relacionada con el riesgo al desabastecimiento, las actitudes relacionadas con el costo-beneficio, las habilidades, los valores altruistas y egoístas y las normas sociales están conectados con el comportamiento ambiental. Estos resultados son consistentes con la literatura, que indica que los valores biosfericos pueden conectarse con el comportamiento ambiental, en este estudio se encontró que estos valores conectan con *SD*. La aproximación sistemática propuesta en este estudio y los resultados obtenidos pueden ser de utilidad para ampliar el conocimiento de como el modelo RANASt y la teoría de valores contribuyen a analizar el uso del agua. La aplicación de las ciencias del comportamiento al uso del agua permite conectar la gestión del agua y las ciencias sociales. La metodología utilizada en este estudio incluye métodos innovadores e

interdisciplinarios, que integran la ingeniería con las ciencias sociales. La integración de estos dos campos es esencial para movernos de un uso no sostenible a un uso sostenible del agua en los sistemas de suministro de agua para promover mejores prácticas del uso del agua. Estos resultados pueden ser de interés, principalmente para tomadores de decisiones, como gestores del agua y académicos que estén interesados en incluir el comportamiento humano en las soluciones de suministro y demanda de agua. Varias regiones alrededor del mundo que enfrentan problemas de abastecimiento y disponibilidad por el exceso en el uso del agua y la alta demanda de agua, pueden tomar como referencia este estudio para incluir el factor humano cuando analicen el uso del agua. La metodología propuesta permite examinar los factores de contexto y de comportamiento, y el modelo conceptual propuesto en este estudio puede ser aplicados por otros sistemas de suministro en otras partes dentro y fuera de Colombia.

Esta tesis contribuye a la solución del foco reto país "*Bioeconomía, gestión integral de la biodiversidad y sus servicios ecosistémicos*" al proponer un modelo orientado a identificar los factores de contexto y de comportamiento que influyen en el uso eficiente del agua en acueductos rurales y peri-urbanos en el Valle del Cauca, desarrollado en el marco del programa Colombia Científica. En esta investigación se abordó un enfoque interdisciplinar que incluye la ingeniería ambiental y las ciencias sociales para estudiar y entender el uso no sostenible del agua en sistemas de suministro de agua. Se utilizaron métodos de hidrología y de investigación social para identificar los factores de contexto y de comportamiento que influyen en el uso eficiente del agua. La aplicación del modelo conceptual y los resultados obtenidos contribuyen y fortalecen el conocimiento requerido para diseñar intervenciones más efectivas para promover la reducción de la demanda de agua lo cual contribuye a disminuir la presión sobre las fuentes hídricas, favoreciendo su conservación y sostenibilidad ambiental y alineadas con las prioridades del foco reto país. Adicionalmente, esta investigación suministra información y recomendaciones que se pueden utilizar para orientar decisiones enfocadas a enfrentar el foco-reto-país.

Chapter 1

1. Introduction

1.1. General introduction and scope

Discrepancies between water availability and demand have been studied for several decades, mainly using hydrological models (Falkenmark, 1979). In 1976 the United Nations reported that the daily domestic water use per person worldwide ranges from 20 liters in rural areas to 300 liters for urban areas with multiple taps (Falkenmark, 1979). She concluded that "some world regions should be considered as truly water-scarce at least during the next generation". The so-called "water gap" can occur because water is not renewed and cleaned at the same rate as it is used. This conclusion remains valid four decades later.

Hydrological models have yielded insights about water availability and the drivers of water scarcity, such as growing water demand, overuse, and weather conditions. On the other hand, socio-economic models have expanded knowledge about water demanded by users and economic sectors. Based on that information, decision-makers have designed programs, made policies, and proposed incentives to reduce water demand and promote sustainable water management. Increasing water-use efficiency, for example, corresponds to indicator 6.4.1 of the Sustainable Development Goals, formulated by the United Nations, which has been considered a water management-side strategy to reduce water use (Hellegers & Halsema, 2021). However, accomplishing this goal is challenging because inefficiency in water use roots in various components, such as population and economic growth, unplanned urbanization, climate change, water governance, operation and management of water systems, socio-economic context, and unsustainable water use behaviour (Abu-Bakar et al., 2021; Cominola et al., 2023; Conway, 2024; Hoekstra, 2014). Regarding the causes of high-water demand in water supply systems, Liemberger & Wyatt (2019), for example, have stated that "Reducing global non-revenue water by one-third is essential and could create enough savings to provide clean drinking water for 800 million people, based on a daily consumption of 150 liters per person".

The water scarcity crisis presents an imminent threat, evident in declining water levels, and increasing droughts. Moreover, the World Meteorological Organization highlighted in 2021 that climate change severely impacts water supply, with extreme weather events contributing to scarcity. This situation has repercussions for water quality, availability, and dependability for people (UN, 2021). Furthermore, reduced environmental flows and water levels harm ecological water availability, food security, and other water-related uses. Globally, the projected volume of the demand for domestic water is expected to increase by 50% to 250% by 2050, and around 40% of the worldwide population might face water stress (AbuEltayef, 2023; Mukherji et al., 2022; Wada et al., 2016). The UN report on "the advancement of Integrated Water Resources Management" states that if the present circumstances continue, the world will not reach sustainable water management until at least 2049. The outlook is worsening, as by 2030, around 40% of the worldwide population may lack effective governance structures to manage conflicting water needs and to address rising pressures from climate change (UN, 2024).

Reducing water demand and making progress in sustainable water management to lower the water gap are thus urgent in the mid- and long-term. Demand can be reduced by enhancing water use efficiency such as installing water-saving devices and promoting changes in water use behaviour. Water users may adjust their habits to ensure that communities and ecosystems can be sustained amidst the challenges posed by extreme weather events. Decision-makers, such as water managers, should explore and understand the driving forces behind unsustainable water use in order to design interventions that modify water use habits such as, for example beliefs regarding water abundance.

As cities and municipalities confront limited water resources, decision-makers explore options to meet demand and typically search for supply-side solutions, such as new water sources, and the construction of reservoirs. Meanwhile, demand-side solutions include educational programs to raise awareness, the installation of water-saving devices, economic incentives, and encouragement for the reduction in water use. Installing and adopting technologies and constructing infrastructure is an essential aspect of strategies to maintain water supply and decrease excessive water use OECD, (2016). However, frequently there is a lack of monitoring of the impact of these measures on water use reduction, after they are implemented frequently lacks. In addition, these measures can mitigate punctual situations such as drought conditions, and do not necessarily translate into mid- to long-term water reductions. Finally, conventional technical, economic, and awareness initiatives often overlook the reasons why individuals do not adopt cost-effective water-saving technologies or why they do not respond to water policies aiming at reducing use (Koop et al., 2019). Insufficient attention is thus paid to human actions being crucial in reducing water use. Alongside conventional strategies, the human factor should also be included in water measures to reduce water use. Insights into the connection between water use management and society have been developed since the late 1960s; Starr (1969) has pointed out that conservation and management of water is the result of a decision-making process; and is, therefore, society's responsibility. A decade later, Widstrand (1978), stated that the strong connection between humans and water indicates that the social sciences need to play a more prominent role in water management. This has been supported by Weems (2023), who has stated that facing a water crisis requires facilitating transdisciplinary research. Thus, including human behaviour in water management strategies contributes to the study and prediction of how existing water-reduction measures could be implemented by target actors.

Overuse and the high demand for water are, amongst others, the result of user behaviour. However, we frequently do not know how the relationship between water users and demand is playing out in communities and what the root causes of high water use. Connecting hydrology models and human models can be effective in understanding high water use, contributing to identifying factors that affect unsustainable water use. An understanding of how people behave could be based on evidence from mixed methods from social sciences which include the analysis of qualitative and quantitative data (Geller, et al., 2019; Koop et al., 2019; Pande & Sivapalan, 2017).

Domestic, agricultural, and industrial uses occupy the top places in terms of water demand and are essential for human well-being (Singh & Turkiya, 2013). Domestic water use averages around 9% of the total water use. The other 91% of the water is used in agriculture and industry and for energy generation (Millock & Nauges, 2010; UN, 2021). While all sectors demand high volumes of water, domestic water use is crucial as it covers the basic needs of the population, such as hygiene and sanitation. Moreover, domestic water use is the highest water use compared to other uses in urban areas (Lee et al., 2011). Water demand is increasing due to a growing population and rising services and production. To ensure water security, maintain water balance, and cover needs in the mid and long term, improving water use efficiency is essential (Hasan et al., 2021). To address the increasing water demand and guarantee water supply, the first and most common solution is, typically, the expansion of water supply sources; however, a demand side management (DSM) framework is also necessary to conserve water and increase water availability. DSM aims to enhance water use efficiency and reduce per capita water use (Abu-Bakar et al., 2021). Reducing water demand through improved efficiency and behavioural changes requires an understanding of how water is used at the household level and how DSM strategies and interventions can lead to savings and reductions. Household water use impacts basic needs, particularly in urban areas where the majority of the population is concentrated (Fielding et al., 2012; Jorgensen et al., 2009; Lee et al., 2011).

Ensuring sufficient water supply for domestic use remains a challenge in low- and middle-income countries (Russell & Knoeri, 2020*).* Water suppliers are still grappling with the challenge of encouraging households to conserve water and to effectively influence the behaviour of water users. Understanding what drives this gap can support policy targeting and achieving urgent water savings. In this context, urban water use is better understood than rural and peri-urban water use. There is limited knowledge on how people in rural and peri-urban communities use water, what are the water conservation practices they employ, and the challenges they face to adopt water saving measures, therefore, hampering the implementation of effective water demand reduction strategies.

Behavioural science involves a research-based comprehension of how individuals act, make choices, and react to various programs, policies, and incentives (United Nations, n.d.). Leveraging behavioural science across programmatic areas, such as understanding how users and sectors adapt their water use practices and set milestones for reduction, can support policies on sustainable water supply and demand. Research shows that a lack of awareness about water scarcity can slow down the progress toward sustainable practices (Clark & Finley, 2007; Rodriguez-Sanchez & Sarabia-Sanchez, 2020). To encourage sustainable water use, we thus need to identify and address the factors that shape individual behaviour.

Various studies have identified a variety of contextual and psychological factors underlying water use behaviour at the household level (Abu-Bakar et al., 2021; Addo et al., 2018; Cahill et al., 2024; Cominola et al., 2023). The contextual factors typically include socioeconomic, technical, institutional, and environmental factors, and the behavioural factors include those associated with

the perception of risk, attitudes, and norms among others. Yet, few studies consider an integrated view of these factors in shaping water use behaviour.

Therefore, the objective of the presented thesis is to develop an integrated, systematic approach for identifying contextual and behavioural factors underlying the (un)sustainable domestic use of water in rural and peri-urban water supply systems. To achieve this objective, a conceptual model was proposed which connects contextual and behavioural factors to water use and represents relationships as supported by various socio-psychology approaches and theories, specifically the RANAS (risk, attitudes, norms, abilities, and self-regulation) approach and the theory of values, beliefs and norms (VBN). In the presented study, water use efficiency was estimated based on survey data targeting the adoption of water-saving devices and curtailment behaviour represented by shower duration. The conceptual model was then applied in a case study which included eight water supply systems, four in peri-urban area of Cali and four in rural area of Restrepo in the Valle del Cauca Department, situated in the western part of Colombia.

To achieve the research objective, the following questions were posed:

1. What are the current approaches used and knowledge gaps in water use behaviour underlying water use efficiency?
2. What are the contextual factors that influence water use considering household and water supply levels?
3. From the perspective of the RANAS approach, what contextual and psychological factors are associated with the adoption of water-saving devices and curtailment behaviour at the household level and how are these relationships related to the so-called rebound effect[1]?
4. From the perspective of the VBN theory, what are the contextual and psychological factors that explain the efficient use of water and curtailment behaviour at the household level?

Based on the answers to these research questions the determinants shaping individuals´ behaviour could be identified, allowing decision-makers and scientists to 1) understand the reasons for adopting water-saving devices or taking shorter showers, 2) facilitate the awareness promotion on the impacts of water overuse and high demand, and 3) set goals and pledges to carry out sustainable behaviour. In addition, the outcome of the thesis could help policymakers to determine when a behavioural approach might successfully tackle a policy challenge and can contribute to identifying the preliminary steps before designing behavioural interventions. This consists of a good understanding of the driving forces of the negative environmental behaviour and identification of target actors whose behaviour change can shift the environmental trajectory.

Targeted and carefully designed behavioural interventions will lead to more immediate impacts and behavioural changes, also requiring understanding of specific contexts, including factors such as age and education.

1.2. Outline of the thesis

Chapter 2 discusses the current approaches to water use efficiency and factors underlying water use behaviour. In addition, in this chapter challenges in understanding water use behaviour are identified, while considering various contextual and behavioural factors based on previous research. Additionally, in this chapter the gaps in our understanding of human behaviour are outlined. This chapter also highlights the need to comprehensively assess and consistently measure such factors and their relationships. The result of Chapter 2 is a conceptual model that connects contextual and behavioural factors to water use and represents a potential relationship as supported by the RANAS model and VBN Theory. We extended the RANAS approach by adding trust, an essential factor which potentially connects water associations and water users.

Chapter 3 discusses what is currently unavailable to assess water demand reduction related to both water use at household and water supply system levels. This chapter proposes an interdisciplinary approach to develop an integrative understanding of water use at household and water supply system levels. As a result, Chapter 3 presents the factors underlying (in)efficient water use in water supply systems and households.

In Chapter 4 and 5, conceptual relationships of the model developed in Chapter 2 are quantified in practical applications. In Chapter 4, an existing approach, the RANAS model is adapted and implemented, to systematically examine the contextual and psychological factors associated with household water use. In addition, it discusses the current unavailability of integrated assessing of strategies to reduce water use by users from water supply systems, such as the adoption of water-saving devices and curtailment behaviour. The result of Chapter 4 consists of determining the contextual and psychological factors that affect the adoption of water-saving devices and curtailment behaviour with an understanding of the relevance of assessing both behaviours to reduce water use.

In Chapter 5 the importance of the relationship between current reduction measures and human behaviour is assessed to contribute to bridging the gap between technical and social factors influencing the reduction of water use. Chapter 5 uses the VBN theory to study water use behaviour at the household level. The result of Chapter 5 is identifying the factors affecting water use behaviour at the household level by applying the VBN theory.

Chapter 6 discusses the final achievements of the thesis in terms of the objective and research questions, as well as the outlook to future research and implementation.

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Chapter 2

2. Water use efficiency: a review of contextual and behavioural factors

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Abstract

Water withdrawals around the world have increased almost twice as fast as the population during the last century. Higher than expected water demand is leading to water scarcity and causing rapid depletion of water tables around the world. One reason behind the higher than expected demand is the inefficient use of water. Inefficient use of water affects the well-being of society, the economic stability of countries, and environmental health. Indeed, water use efficiency (WUE) is one of the pillars of sustainable development goals (SDG 6.4.1). However, progress toward achieving WUE is slow, especially for many developing countries where the degradation of natural resources is critical, economic growth is slow, and there are few strong institutions to coordinate actions. One reason behind inefficient water use is human behavior. A variety of contextual and psychological factors underline the behavior. The contextual factors include socioeconomic, technical, institutional, and environmental factors and the behavioral factors include factors associated with the perception of risk, attitudes, norms, etc. Yet, few studies consider an integrated view of these factors in shaping water use behavior. This paper consolidates contextual and behavioral factors which influence water use, studies the gaps in our understanding of human water behavior underlying WUE and highlights the need to comprehensive assess and consistently measure such factors and their relationships. Based on the gaps identified, it proposes a conceptual model that connects contextual and behavioral factors and represents potential cause-effect relationships as supported by various environmental behavior approaches and psychological theories. Based on the literature review of water use, and conservation behavior, environmental psychology, and water use models, this model proposes an institutional factor to assess the relationship between institutions and stakeholders, and study contextual factors linked not only for individual water users but also studying these factors for individuals of water supply organizations.

Keywords: water use efficiency, human behavior, contextual factors, psychological factors, behavioral factors.

2.1. Introduction

Every day large amounts of water are extracted from inland surface water bodies (e.g., rivers, lakes, wetlands, and reservoirs) and aquifers for diverse uses such as for agriculture, domestic, electricity, and industrial purposes. Water withdrawal around the world has increased almost twice as fast as the world population (FAO, n.d.). Agriculture is the largest water-using sector, accounting for approximately 69% of global water withdrawals, whereas municipal withdrawals contribute to 12% of total withdrawals (FAO, 2018b). Withdrawing water faster than it is recharged has led to water scarcity in countries such as Qatar, Saudi Arabia, and Pakistan, which are suffering from extremely high water stress conditions (Hofste et al., 2019). This, when

combined with weak control of water permissions and concession rights, has exasperated water scarcity.

The difference between global water withdrawals and real water demand is significant and is steadily increasing. One of the reasons behind this difference is the inefficient use of water, leading to consumption that can otherwise be lower (Wang et al., 2015; Nazari et al., 2018; Ding et al., 2019; Ghanim, 2019). The resulting over-extraction poses considerable risks to water sustainability as rivers and groundwater resources around the world are running dry (Jorgensen et al., 2009; Graymore and Wallis, 2010; Arto et al., 2016; Bhaduri et al., 2016; Mekonnen and Hoekstra, 2016; Lund et al., 2018).

Driven by unconstrained consumption, water scarcity could occur even under average climate conditions. Inefficient use of water also affects the provision of environmental flows and contributes to environmental degradation and economic instability (Mekonnen and Hoekstra, 2016; Vieira et al., 2017; Piedra-Muñoz et al., 2018). Efficient use of water has therefore often been proposed as a measure by policymakers and water managers to reduce the inflated gap between water extractions and water demand.

Efficient use of water conserves water and reduces pressure over natural sources. By reducing water consumption, water flows in water treatment plants and irrigation systems diminish (Tang et al., 2013; Jorgensen and Martin, 2015), leading subsequently to reductions in effluent discharges (Hoekstra, 2014). It thus also contributes to environmental and economic benefits (Rad et al., 2019) such as water protection, and reduction in operational costs (See, 2015; Jabari, 2017).

Therefore, water users and institutions have taken actions toward improving water use efficiency (WUE) (Bruneau et al., 2013). Global and local policies, aiming at reducing water demand, have focused mainly on two sectors with a relatively high number of users and relevant for water security: households (Attari, 2014; Manouseli et al., 2019), and farmers (Bruneau et al., 2013; Tang et al., 2013; Chang et al., 2016; Roobavannan et al., 2017; Benito et al., 2019; Ghanim, 2019; Xiao et al., 2019), farmers being the biggest water user. Actions include installation of water-saving devices, leakage control, water re-use, water harvesting, implementation of indicators like non-revenue water (NRW), and the extension of economic incentives to users, such as increasing water price, and subsidies to water savers (Wang et al., 2015; Chang et al., 2016).

Increasing WUE is also one of the pillars of those global and local policies, such as the SDGs of the United Nations (Cole et al., 2018; Ortigara et al., 2018). In addition, the strategy of the European Commission (EU, 2014) is to move from a linear economy to a sustainable, circular economy by 2050. Moreover, the national water initiative of Australia (Department of Agriculture, 2019) is pursuing WUE to conserve rivers and groundwater systems, Colombia's Government has established plans to improve WUE in their policy plan (Minambiente, 2010), and the United States Environmental Protection Agency (USEPA) is implementing WUE strategies to mitigate water stress and prevent water conflicts (GAO-14-430, 2014; EPA, 2018).

Despite such efforts, the slow progress of the application of WUE principles remains a matter of concern for many developing countries where natural resources are being critically degraded, and the economic growth is slow compared to developed countries (Sánchez et al., 2004; Carrus et al., 2010; Russell and Fielding, 2010; Bruneau et al., 2013; Jorge et al., 2015; Mekonnen and Hoekstra, 2016; Rad et al., 2019). Often WUE is only associated with technical factors that affect the performance of water utilities, e.g., water leakages in water distribution systems, poor management, and maintenance of irrigation systems (European Environment Agency, EEA, 2007). Other factors such as those linked to the psychology of water use, influencing behavior, and decisions of relevant water users, are frequently ignored by policymakers. Mosler (2012) defines behavior as the result of the psychological processing of factors within the individual. Therefore, a comprehensive assessment of these factors and their relationships is needed to provide insights into the causes of over-extraction, the interdependence between stakeholders, and the effects on WUE.

A holistic view of how various such factors influence WUE behavior is currently not available. Therefore, this contribution aims to identify challenges in understanding water use behavior, especially underlying WUE, while considering various contextual and behavioral factors. Based on gaps that are identified, a conceptual model is proposed to capture the relationship between institutions and stakeholders, and studies contextual factors linked not only of individual water users but also studying these factors for individuals of water supply organizations to understand (in)efficient water use.

2.2. Water Use Efficiency Concept

2.2.1 Definition of Water Use Efficiency

The WUE concept has been extended to environmental sustainability, sustainable development, and water management frameworks. As summarized in Table 2.1., WUE is interpreted differently in different uses of water (e.g., agriculture, industry, and service sectors). Activities linked to water use, therefore, pursue different WUE targets. However, only few frameworks have focused on WUE as an alternative to water protection and conservation.

Table 2.1. Diverse interpretations of WUE.

Domain	Interpretation	Reference
Agronomy	Crop production per unit volume used	Howell, 2005; Stanhill, 1986
	The water efficiency is the ratio between water used and water withdrawals.	FAO, 2018; UN, 2015

	WUE in any activity is related to using the resource in a better way, doing more or the same with less quantity.	Sánchez, T., Luis D., Sánchez, T., 2004
Sustainability	Resource efficiency refers to water consumption per unit of process or product.	Hoekstra et al., 2017
	Actions focus on reducing water consumption, and leakages, or optimizing water usage. These actions include water reuse, recycling, rain usage, controlling leakages, and moving to saving technologies.	Minambiente, 2018
	Using the Earth's limited resources sustainably while minimizing the impacts on the environment.	EC, 2020
Water management	It is a term used to measure the productivity of water used for specific purposes.	Brooks, 2006
Technical	Innovation based, moving to water saving systems, e.g., moving from flood irrigation to sprinkler systems, and from high to low-pressure systems.	Bruneau et al., 2013

2.2.2 Approaches to Achieve WUE

Since the concept of WUE involves various definitions, approaches, and indicators, it has implications on water literacy (Dean et al., 2016), specifically WUE knowledge. It means how WUE is interpreted and implemented by various water users.

There are numerous approaches available to achieve WUE (Gleick et al., 2011). Each approach depends on specific objectives, Table 2.2. summarizes the most important approaches that refer to WUE. For example, water conservation and mitigation of scarcity can motivate efficient water use practices to meet specific environmental goals. Expanding existing production, profit maximization, and costs minimization efforts prompt producers to use water more efficiently (Bruneau et al., 2013). It may also be motivated by consumer or regulators demands for cleaner production, lower water footprint (Mekonnen et al., 2015), and circular economy (Winans et al., 2017; Varbanov and Walmsley, 2019).

Table 2.2. Approaches toward improving WUE.

Domain	Principles guiding water use	Definition of/approach towards WUE	Motivation	Reference
	Economic, Sustainability	Development that meets the needs of the present without compromising the	*Economic viability *Protection of the environment	Hens et al., 2018

Sustainable development goals (SDG)		ability of future generations to meet their own needs.	*Social and ethical acceptance	
		Goal 6.4.: increasing water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater. Improving water efficiency means water-saving and making water available for other purposes.	*Addressing water scarcity. *Increasing water availability for people and the economy.	Ortigara et al., 2018; UN, 2015
Cleaner production (CP)	Economic	Integrate preventive environmental strategies to processes, products, and services to increase efficiency and reduce the risk to humans and the environment.	*Environmental sustainability *Maximization of water reduction *Recycling *Reuse	Hens et al., 2018
		Resource use minimization, Improved eco-efficiency, Environmental protection.	Doing more with less	Glavič & Lukman, 2007
Circular economy (CE)	Economic	Minimizing the intake of fresh raw materials.	*3rs (reduce, reuse, recycle) *Closing the loop of use of resources	Varbanov & Walmsley, 2019; Winans et al., 2017
Sustainable water management (SWM) efficiency	Social, Environmental, Economic, Technical	Balancing water resources supply with demands from society, economy, and the environment.	Sustainable water management (SWM)	Zhang & Xu, 2019
Water footprint	Sustainability, Economic	Analysing water usage along supply chains, and assessing the sustainability, efficiency, and fairness of its water use.	Reduction of water consumption.	Hoekstra, 2014
Blue water footprint	Sustainability, Economic	Measuring the consumption of	The assessment of freshwater use and its relation to	Hoekstra et al., 2017

		groundwater or surface water.	consumption, production, and trade.

Reduction of water footprint implicitly measures the effect of reducing water usage on water scarcity (Hoekstra, 2014). In the context of sustainable water management, efficient water use aims at finding a balance between water resources availability and demands from society, the economy, and the environment (Zhang and Xu, 2019). The circular economy, on the other hand, involves the reduction of water use, water reuse, and recycling schemes and implies closing the loop of resource usage (Winans et al., 2017).

Therefore, calculating WUE for a particular use depends on how WUE is interpreted, how specific variables are used, availability of reliable data, and if data tally with the variables. Experts who have developed a methodology to compute indicator 6.4.1. of SDGs, related to water-use efficiency, mention that "different sectors require their definition of water-use efficiency" (FAO, 2018a).

The indicators used to estimate WUE vary with temporal and spatial scales of water use and users, depending on the variables and methodology used for its estimation, and the target stakeholders (FAO, 2018a). Table 2.3. presents various indicators that have been used to analyze water usage related to WUE.

Table 2.3 Indicators related to WUE.

Indicator/index	Description	Reference
WUE 6.4.1. (SDG)	Change in water-use efficiency over time. It is an economic component of SDG target 6.4. and evaluates to what extent a country's economic growth is dependent on the use of water resources. It can be calculated at national and basin scales.	FAO, 2018; UN, 2015
Bluewater footprint	It is an indicator of direct and indirect freshwater use by a consumer or producer. It gives information about how much water is being consumed by a particular country at river or catchment scale. It can be calculated for a particular process, product, and company. It is computed as the volume of water abstracted from natural sources minus the water returned to the system.	Hoekstra, 2014; Water footprint network, 2020
Water exploitation index (WEI)	Measuring the ratio between the mean annual total freshwater abstraction and the long-term average of available freshwater resources. The unit of measure is a percentage.	EC, 2020

Water productivity index (WPI)	Measuring the amount of economic output produced (EUR) in terms of gross domestic product (GDP) per unit of water abstracted (m^3). The WEI and WPI indices aim at monitoring WUE at national scale through sustainable water usage and reduced pressure over natural water sources.	EC, 2020
WUE Evaluation index system	It is a method used in sustainable water management efficiency (SWM) evaluation, and it aims to evaluate regional sustainable water utilization. The index considers the experts' psychological factors in the decision-making processes, and uses six indicators	Zhang & Xu, 2019

Hoekstra et al. (2017) state that "looking at efficiency from the production perspective is limited because most of the reduction of water consumption can be achieved by changing consumption patterns." In the assessment of WUE indicator 6.4.1. of SDGs, institutions play an essential role in coordinating various stakeholders who are involved in monitoring the indicator (FAO, 2018a).

Details on how various variables are measured and their effects estimated are often not clear. Bhaduri et al. (2016) state that "the level of allowable withdrawal rates from freshwater bodies is not well established scientifically", Hák et al. (2016) and Miola and Schiltz (2019) show there is no clear link between methods and indicators used to measure the performance of SDGs. Zhang and Xu (2019) claim that "the absence of an effective, scientific evaluation method may lead to a lack of awareness of sustainable water usage."

Approaches to assess and achieve WUE influence knowledge and capacity of water users to adopt best practices. These, in turn, affect behavioral factors such as attitudes and perceptions of individuals and influence their decisions about water use.

2.3. Factors Underlying Water Use Behavior

In the context of water use, water use behavior is defined as environmental behavior. Steg and de Groot (2018) define environmental behavior as "any behavior that has a good or bad impact on the environment" (p. 164). This behavior is influenced by contextual and behavioral factors (Carrus et al., 2010; Graymore et al., 2010; Russell and Fielding, 2010).

Contextual factors refer to the background characteristics of individuals and their physical environment (Dreibelbis et al., 2013). These influence behavioral factors in different ways (Contzen and Mosler, 2012) and may facilitate or constrain behaviors. The contextual factors encompass social, economic, technical, environmental, and institutional backgrounds, acquired skills, immediate personal conditions, economic resources, capabilities, regulations, etc. The first three factors have been shown to be important in predicting water use (Russell et al., 2020). Here, the environmental factors refer to geographical experiences which are connected with associative

learning (Dean et al., 2016), and institutional factors involve institutional relationships (Kapetas et al., 2019) between water users and the water supply systems and regulations (Khair et al., 2019).

Behavioral factors are referred to as determinants (Jager and Joachim Mosler, 2007; Dreibelbis et al., 2013) that may immediately influence individual behavior. These are also actions and habits that can be observed directly and factors that influence the mindset of individuals.

2.3.1 Contextual Factors

Several studies have examined the domain large number of contextual factors (Russell and Fielding, 2010). Stern (2000) finds contextual factors as the second major type of causal variables of environmentally significant behavior after attitude related factors. Contzen and Mosler (2012) state that contextual factors can affect behavior by influencing behavioral factors. In fact, various contextual factors influence behavior and individual motivations (Steg and Vlek, 2009; Dietz, 2014) (see Table 2.4.).

Table 2.4 Examples of contextual factors that influence environmental behavior.

Approach	Factors	Reference
Theory of environmentally significant behaviour	interpersonal influences; community expectations; advertising; government regulations; legal and institutional factors; monetary incentives and costs; the physical difficulty of specific actions; capabilities and constraints provided by technology and the built environment; the availability of public policies to support behaviour; social, economic, and political context.	Stern, 2000
Environmental psychology	physical infrastructure, technical facilities, the availability of products, and product characteristics	Steg & Vlek, 2009
Water, sanitation, and hygiene behaviour (WASH)	Social, physical and personal	Contzen & Mosler, 2012

In the context of WUE, the contextual factors that have been studied are social, economic, environmental, technical (Jorgensen et al., 2009; Millock and Nauges, 2010; Russell and Fielding, 2010; Lee et al., 2011; Willis et al., 2013; Scott et al., 2014; Jorge et al., 2015; Wang et al., 2015; Hussien and Memon, 2016; Vieira et al., 2017; Kneebone et al., 2018; Nazari et al., 2018; Benedict and Hussein, 2019; Kapetas et al., 2019; Koh, 2020) and, in some cases institutional factors.

Socioeconomic Factors

Factors such as age (Beal et al., 2013; Tang et al., 2013; Attari, 2014; Chang et al., 2016; Dean et al., 2016; Piedra-Muñoz et al., 2018; Khair et al., 2019), gender (Beal et al., 2013; Attari, 2014; Piedra-Muñoz et al., 2018), education level (Beal et al., 2013; Chang et al., 2016; Dean et al., 2016; Piedra-Muñoz et al., 2018; Khair et al., 2019), information (Dean et al., 2016), networking (Tang et al., 2013; Dean et al., 2016), household characteristics (Russell and Fielding, 2010; Dreibelbis et al., 2013), and population density (Benito et al., 2019; Zhang and Xu, 2019) are the key socio-demographic factors that contextualize water use.

Age, education level, information, and networking are strongly associated with knowledge (Dean et al., 2016) about water use, which is a core component of solving water-related problems. Some authors have shown that men and women differ in terms of environmental awareness (Piedra-Muñoz et al., 2018), and risk perception (Attari, 2014). Meanwhile, cultural factors involve beliefs and traditions that influence water use practices. For instance, Kadibadiba et al. (2018) observed that high levels of domestic consumption are associated with the daily desire for cleanness,

comfort, and convenience in certain cultures. Household size and composition are linked with economic capability to make investments, e.g., on water saving devices; while population density influences the operation and performance of water utilities due to economies of scale, resulting from consequent size of utilities (Benito et al., 2019).

Financial incentives include subsidies that may have positive or negative effects on WUE. There are subsidies to conserve water, investments in technology and infrastructure; others such as subsidized energy mainly have promoted groundwater overuse (Nazari et al., 2018; Khair et al., 2019). This incentive has thus had the opposite effect, known as the rebound effect (Freire-González, 2019).

Water pricing is a relevant determinant since it affects perceptions (Tang et al., 2013), willingness (Bruneau et al., 2013), awareness, and attitudes (Nazari et al., 2018) of water users such as farmers and households. This, together with other factors signals people to use water efficiently. The regional economy also influences technical factors, such as training, investment in infrastructure or ability to acquire water savings devices (Bruneau et al., 2013). Several economic activities, such as agriculture, depend on water to produce goods, and its productivity is often associated with average income of the producers (Graymore et al., 2010; Khair et al., 2019; Xiao et al., 2019), and diversification of the economy. For instance, if irrigated agriculture is the only source of livelihood (i.e., lack of diversification), water users will focus solely on increasing production to increase profits (Roobavannan et al., 2017; Khair et al., 2019), leading to a higher water demand (Ghanim, 2019; Xiao et al., 2019). In such cases, users may not adopt techniques to increase WUE if water is not appropriately priced or may adopt low flow high-efficiency faucets like drip irrigation but still consume more water (so called efficiency paradox), since their perception of well-being is driven by profit maximization.

Technical Factors

Frequently examined technical factors include training, data availability, elaboration of WUE plans, infrastructure and technology readiness, and the performance of utilities in terms of financial and NRW indicators, and capacity to supply water demand. Training facilitates a better understanding of water usage and knowledge of good water management practices (Dean et al., 2016; Nazari et al., 2018) and better informed decisions. The metering and monitoring of water use are often overlooked. Also, flawed estimations of water requirements, water balance, and allocation (Manouseli et al., 2019), and management of water systems (Benito et al., 2019) can lead to water use inefficiency. Timely and accurate information is therefore required to plan and implement efficient use of water (Manouseli et al., 2019).

The infrastructure of a water system also impacts WUE. Proper pricing and financial sustainability can lead to more capacity for investments (Ding et al., 2019; Manouseli et al., 2019), and proper operation (Nazari et al., 2018), and maintenance. In some water systems, the operations have to be stopped because of reasons such as water scarcity, and water contamination. As a result, there are water restrictions, e.g., shortages and intermittent supply. Such circumstances can motivate users

to adopt water savings measures (Graymore et al., 2010) but can also have serious implications for efficient operations and water use (Charalambous and Laspidou, 2017).

Institutional and Environmental Factors

There are three groups of functions that water related institutions are generally responsible for. First concerns the goals to guide, enable, and constrain the actions of individuals (Greif, as cited in Vitola and Senfelde, 2015), firms, households, and other decision-making units (Lynne et al., 1991), and shaping human interactions around water use (North as cited in Vitola and Senfelde, 2015). These may activate values and shape beliefs of individuals and can change the behavior of many toward water use (Stern, 2000). The second group of functions focuses on coordinating activities (Geels, 2004), and designing, and implementing policies systematically (Kapetas et al., 2019). The third group of functions facilitates information and promotes incentives to encourage people to use water appropriately (Ostrom, 1990; Aligica, 2006; Koehler et al., 2018).

Individual staff members are crucial stakeholders along the chain of water use decisions and actions (Meglino and Ravlin, 1998). The structure of institutions itself (Ortigara et al., 2018) determines the progress and implementation of regulations. For example, populist agendas rarely prioritize WUE. At the same time, unstable water governance (Ortigara et al., 2018) interrupts planning activities, and lack of environmental awareness policies becomes a hurdle to implement WUE measures promptly.

The influence of institutions on behavior has been often highlighted (Markey-towler, 2018). Jorgensen et al. (2009). Graymore et al. (2010) argue that trust in institutions is linked to water-saving by water users. If water users do not trust the institutions, they are less likely to use water efficiently. Additionally, weak institutions produce ineffective regulations and subsequently do not encourage users to use water efficiently (Khair et al., 2019).

Regulations often lag behind the understanding of current and future water challenges (Nazari et al., 2018) with little participation of stakeholders (Chang et al., 2016). The involvement of communities is important, but often ignored, in the design and application of rules and regulations (Horinkova and Abdullaev, 2003), because it influences their attitudes toward the implemented regulations, awareness of beneficial consequences, and willingness to obey (Chang et al., 2016).

2.3.2 Behavioral Factors

Behavioral factors consist of perceptions, thoughts, feelings, and beliefs that affect the practice of behavior. These factors as a whole characterize the mindset of an individual linked to behavior (Contzen and Mosler, 2012).

Several theories and models have been used to analyze environmental behavior such as the norm activation model (NAM) (Steg and de Groot, 2018); the new environmental paradigm (NEP) (Dunlap et al., 2000); the theory of planned behavior (TPB) (Ajzen, 1991); the theory of values (Steg and de Groot, 2018); the values, beliefs, and norms theory (VBN) (Stern, 2000; Yildirim and Semiz, 2019); the theory of environmentally significant behavior (Stern, 2000); and the risk,

attitude, norms, abilities, and self-regulation (RANAS) model (Contzen and Mosler, 2012) (see Table 2.5.).

Table 2.5 Models and theories and factors to understand environmental behavior.

Model or theory	Approach	Factors
The norm activation model (NAM) (Schwartz 1977; Schwartz and Howard 1981) [1]	The pro-environmental actions follow from the activation of personal norms, reflecting feelings of moral obligation to perform actions. Experimental studies have showed that NAM variables are causally related.	Personal norms are activated by: problem awareness; ascription of responsibility; outcome efficacy; self - efficacy
The new environmental paradigm (NEP) (Dunlap and Kent 1978), [2,3]	The NEP focused on beliefs about humanity's ability to upset the balance of nature, the existence of limits to growth for human societies, and humanity's right to rule over the rest of nature.	beliefs
Theory of planned behaviour (TPB) (Ajzen 1985) [1]	Behaviour results from the intention to engage in specific behaviour. The TPB assumes that socio - demographics and values influence behaviour indirectly via attitudes, subjective norms, and perceived behavioural. Attitudes express a positive or negative stance toward a behaviour; subjective norms, normative factors represent convictions about the incidence of a behaviour and how the social network thinks about the behaviour; perceived behavioural control ability factors represent the aptitudes and individual beliefs.	attitudes, subjective norms, and perceived behavioural
Theory of values (Schwartz 1992) [1]	Values include beliefs about desirability or undesirability of certain end-states that transcend specific situations. Values serve as guideline principles for the evaluation of people and for behaviours.	Key values for pro-environmental behaviour. These are separated in two dimensions: Self - transcendence: altruistic; biospheric. Self - enhancement; egoistic and hedonic.
The theory of environmentally significant behaviour Stern (2000) [4]	This theory assesses the definitions, classifies the precursors of environmental behaviour, evaluates the links between environmental concern and behaviour and identifies the factors that	Causal variables: attitudinal; personal capabilities; contextual

	determinate environmentally significant behaviour.	factors; habit and routine.
The value - belief - norm theory (VBN) Stern, et al. (2000) [1,3,4,5,6]	This theory is an extension of the NAM and links the values theory, the norm activation theory (NAM) and new environmental paradigm (NEP). A causal chain of values (biospheric, altruistic and egoistic), beliefs and personal norms triggers the behaviour. Beliefs consist of personal worldview of concerns or perceptions about the consequences of human actions that may harm the environment; norms relate to moral obligations to engage in an environmental behaviour; values are central to any decision-making process, and guide behaviour and attitudes.	Values; beliefs on relationships between humans and the natural environment reflected by ecological worldview; norms
Risk, Attitude, Norm, Abilities, Self - Regulation (Ranas) Mosler (2012) [1,5,7]	This model systematically identifies, measures and integrates behavioural and contextual factors to assess behaviour at an individual scale. The RANAS model derives the factors on the basis of quantitative data. Behavioural outcomes: behaviour; intention and habit. Risk: perceived vulnerability. Attitude: instrumental beliefs, affective beliefs. Normative: descriptive, injunctive and personal norms. Ability: action knowledge, self-efficacy, maintenance efficacy, recovery efficacy. Self - regulation: action control/planning, coping planning, remembering, commitment.	Risk; attitude; ability; self-regulation.

[1] (Steg and de Groot, 2018); [2] (Dunlap and Van Liere, 2010); [3] (Russell and Fielding, 2010); [4] (Stern, 2000); [5] (Contzen and Mosler, 2012); [6] (Dietz, 2014).

The RANAS model combines the most important behavioral theories to explain and change behavior (Contzen and Mosler, 2012). It has two main advantages, firstly, it can be adapted to a range of behaviors in a variety of settings and populations, and it provides a standard template of questions to quantify behavioral factors and analyze the behavior. This further allows the comparison of multiple sites or scenarios (Dreibelbis et al., 2013). Risk, attitude, norms, abilities, and self-regulation has been used to evaluate behaviors linked to water, sanitation, and hygiene (WASH) practices, such as handwashing and adoption of household water treatment technology (Contzen and Mosler, 2012; Mosler, 2012; Dreibelbis et al., 2013; Lilje and Mosler, 2018; Daniel et al., 2019; Nunbogu et al., 2019). In the context of water use, RANAS factors such as knowledge, beliefs, and emotions are linked to an individual's psychology of water use and influence the

practice of a behavior (Mosler and Contzen, 2016). Indeed, this model includes behavioral factors such as risk, and self-regulation that are crucial to regulate and understand different behaviors.

One of the theories that has been integrated in the RANAS is the TPB, which has also been widely used to investigate and understand environmental behaviors, including water use and its associated factors (Harland et al., 1999; Stern, 2000; Steg and Vlek, 2009; Russell and Fielding, 2010; Mosler, 2012; Fu and Wu, 2014; Yuriev et al., 2020).

Values are defined as "concepts or beliefs about desirable end states or behaviors that transcend specific situations and guide the evaluation of behavior and are ordered by relative importance" (Dietz et al., 2005, p. 345–346). Values may directly affect beliefs, norms and behavior. Beliefs have a direct effect on norms and norms influence behavior (Roobavannan et al., 2018). In the domain of environmental behavior, values are factors that are linked with concern about the environment and may affect individual decisions. These are altruism, biospheric, egoistic, and hedonistic values (Stern, 2000; Dietz et al., 2005; Steg and de Groot, 2018). Personal norms are a solid base for predispositions of individuals to pro-environmental action (Stern, 2000).

Stern (2000) integrated the values theory, NEP and NAM to develop the VBN theory of environmentalism. It is represented by a causal chain that includes values, beliefs and norms and its variables (Stern, 2000; Dietz et al., 2005) (see Figure 2.1.).

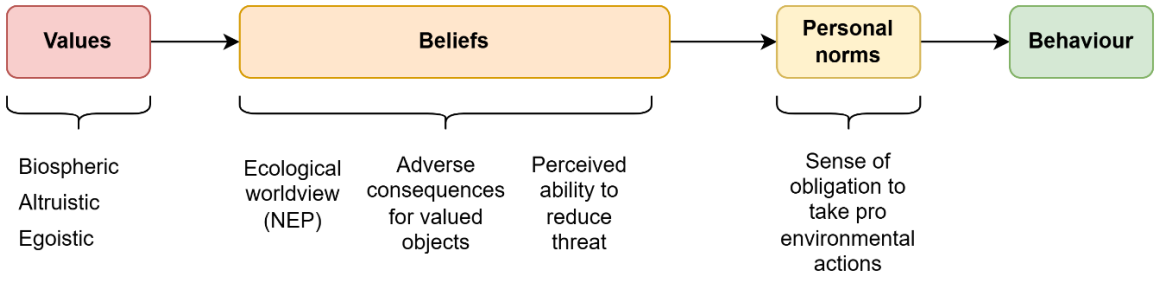


Figure 2.1. Representation of the VBN theory of environmentalism. Arrows represent direct effects. Adapted from Dietz et al. (2005) and Stern (2000).

Since individual behavior is essential to analyse the psychology of why people use water efficiently or not, behavioral studies have mainly focused on individual users, e.g., how consumers react to WUE measures and regulations (Graymore and Wallis, 2010; Lee et al., 2011; Scott et al., 2014; Jorge et al., 2015; Wang et al., 2015; Vieira et al., 2017; Kneebone et al., 2018; Nazari et al., 2018; Benedict and Hussein, 2019; Kapetas et al., 2019; Koh, 2020). Several stakeholders, including farmers and households from rural communities have been considered.

2.4. Knowledge Gaps in Understanding WUE

Limited number of studies (Cortner et al., 1998; Chai and Schoon, 2016; Nazari et al., 2018; Kapetas et al., 2019) have considered stakeholders such as the institutions and their staff in assessing WUE. The determinants of individual behavior within organizations are different from those of household behaviors and the behavior of organizations has a huge environmental impact. All stakeholders may ignore it. But the disregard for environmental criteria by institutions can have more adverse consequences. For example, institutions may ignore environmental criteria or make decisions regarding the use of water that lead to unknown adverse environmental impacts (Stern, 2000). Such decisions may drive individual behavior (Stern, 2000) within organizations (Meglino and Ravlin, 1998). Moreover, environmental behavior of individuals may be influenced by the actions of organization to which they belong (Stern, 2000).

Few studies have highlighted and incorporated the role of users' trust in institutions and their influence on environmental behavior. The specific role that trust plays in determining water efficiency behavior remains unclear (Jorgensen et al., 2009). The actions taken by institutions are a result of a chain of decisions taken by relevant individuals. Subsequently, the psychology and consequent actions of such individuals also alter water use related decisions and measures those institutions take up as a whole.

Assessment of individual perceptions (Meglino and Ravlin, 1998) and the relationships between engaged stakeholders can unravel the influence of institutions over users, and how institutions can work toward WUE targets. This is illustrated in Figure 2.2. Note that the users can also be influenced by the individuals of institutions given that they frequently interact with each other.

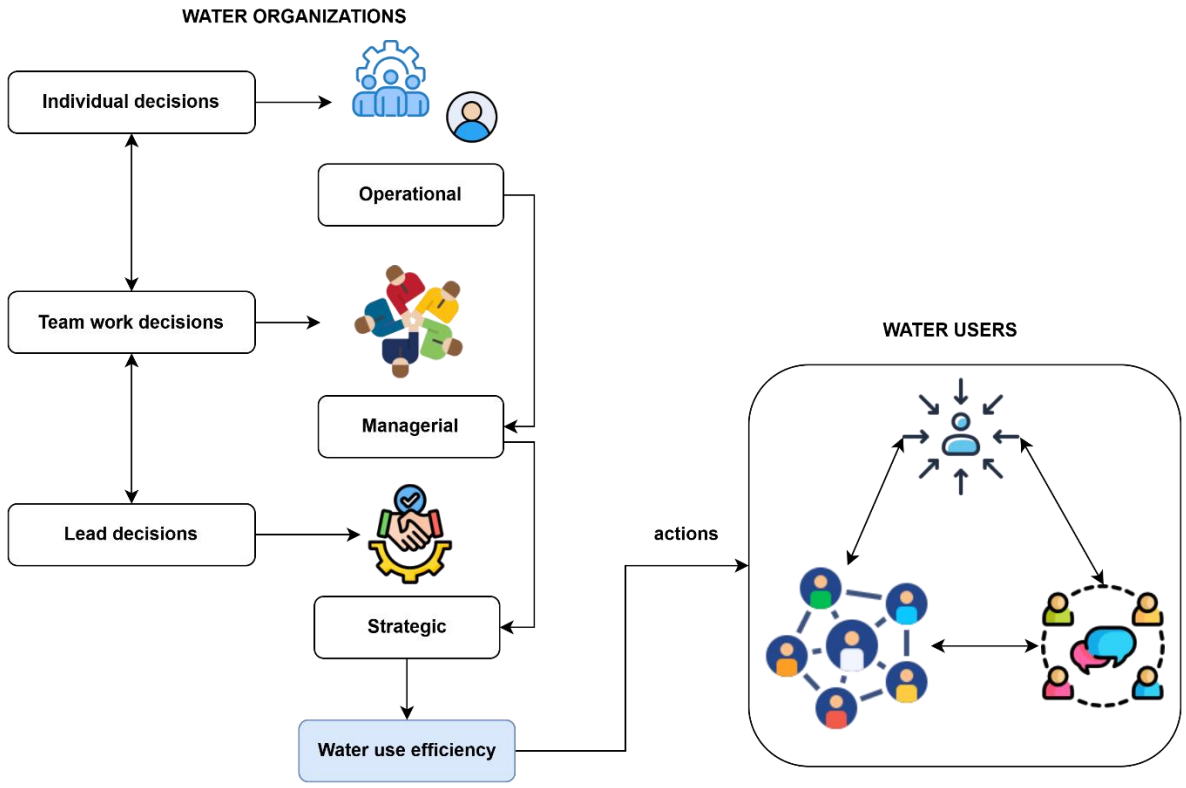


Figure 2.2. Factors involved in using water (in)efficiently for domestic purposes.

The variables that influence sustainable water use have been widely studied, such as age and incentives (Brown and Keath, 2008; González-Gómez et al., 2011; Wang et al., 2015; Khair et al., 2019). Most of the variables are assumed to independently influence the behavior of water use. Yet many studies have highlighted the need for an integrated view of WUE, indicating its links with the underlying human behavior and institutions (Graymore and Wallis, 2010; Lee et al., 2011; Scott et al., 2014; Jorge et al., 2015; Wang et al., 2015; Vieira et al., 2017; Kneebone et al., 2018; Nazari et al., 2018; Benedict and Hussein, 2019; Kapetas et al., 2019; Koh, 2020).

Therefore, there are three main gaps in our understanding of WUE concerning to human behavior. First, an integrated assessment of behavioral and contextual factors and its relationships in relation to WUE is lacking. Second, the influence of institutions on WUE has not been evaluated completely. Only end users such as households and farmers are acknowledged for their roles in using water (in)efficiently. All other stakeholders in the supply chain of water use are mostly ignored. The influence of institutional stakeholders is neither fully known nor documented. Consumers' trust in institutions is however important to implement WUE measures (Graymore et al., 2010; 2009; Beal et al., 2013; Fu and Wu, 2014; Caspers, 2020). Further, decisions within an institution involve actions of multiple staff members and, therefore, staff dynamics within institutions also play a role in proposing regulations about WUE, of which little is known about its effect on WUE. Finally, a standardized method to understand WUE practices in terms of contextual and behavioral factors is missing.

An integrated approach of stakeholders is therefore needed to move from the current assessment that focuses solely on the behavior of individuals and households as water users to include other stakeholders, especially institutions and how they behave (Stern and Dietz, 2020).

To do that we propose an extension of the RANAS model and integrate it with the VBN theory. The extension consists of including institutions (the organization responsible for water supply system) as an additional contextual factor, and trust as an additional behavioral factor.

2.5. A Conceptual Model to Understand WUE Behavior

Existing approaches for measuring and understanding environmental behavior are used as guide and source of inspiration. These include the model of behavior change (Contzen and Mosler, 2012) that has been used for the water and sanitation sector in developing countries (Mosler, 2012); the framework of Steg and Vlek (2009) for understanding and promoting pro-environmental behavior; the research of Carrus et al. (2010) for studying the socio-psychological and contextual predictors to assess sustainable water consumption and the causal chain of factors across the environmental significant behavior (Stern, 2000).

A causal hierarchy of contextual and behavioral factors is assumed, in order to suggest that context affect the psychology and the behavioral factors, which in turn influence the environmental behavior of individuals. All factors together determine the behavioral outcome with respect to efficient use of water. The model has three main components: contextual factors, behavioral (or psychological) factors, and water users, including institutions who are the stakeholders (see Figure 2.3.).

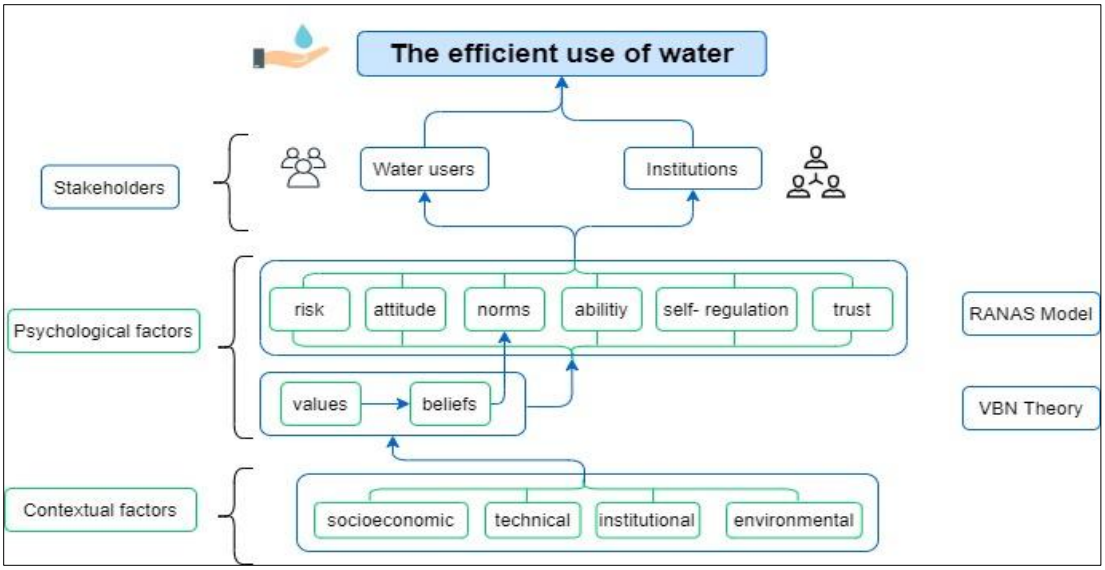


Figure 2.3. Elaboration of contextual and psychological factors within the conceptual model.

The target behavior is the efficient use of water (WUE). It is a result of psychological processing of factors intrinsic to an individual (Steg and Vlek, 2009; Mosler, 2012) and involves the execution

of responsible pro-environmental actions (Hines et al., 1987; Steg and de Groot, 2018). WUE behavior involves curtailment actions that are associated to resource conservation and efficiency actions that are related with the installation of water efficiency technology (Russell and Fielding, 2010; Beal et al., 2013). These actions can be shorter showers or harvest water by using rain barrels, both having positive impacts on water use due to less water consumption and withdrawals.

The conceptual model provides a structure to construct a quantitative model to measure factors that are based on social science experiments (Voinov and Bousquet, 2010) or are informed by local observations such as social surveys (Argent et al., 2016).

This conceptual model offers to fill the identified gaps in several ways. Based on existing psychological models and theories, such as RANAS and VBN, the model interprets behavior underlying WUE with an extension of the RANAS model to include factors linked to institutions. The model concept also offers a "flexible" method that can be used, modified, or expanded to other water use contexts, e.g., drinking water treatment by rural communities, reuse of water, or harvesting of rainwater. Finally, the inclusion of institutional factor also allows the interpretation of water use behavior of individuals of water supply organizations and the relationships between water users and water supply organizations.

To explain and identify the relationships within the conceptual model between factors and their influence on (in)efficient water use, the factors and WUE need to be quantified. For this a group of variables are identified for each factor, e.g., socio-demographic variables, attitude, and perception variables, and water use and availability. These variables can then be quantified using RANAS inspired questionnaires (Daniel et al., 2019), interviews, and field measurements of water use and supply (e.g., rainfall) fluxes.

Discussion

Numerous studies have identified various models and crucial factors, such as the Behaviour Change Wheel, COM-B, the Theory of Planned Behaviour (TPB), and Social Norms, to analyse and understand water user behaviour (Addo et al., 2018; Cominola et al., 2023; Koop et al., 2019; Tamason et al., 2016). However, a key problem with much of the existing literature on water use is that the models often focus on specific factors rather than incorporating common elements considered essential for studying the contextual and psychological aspects related to water use. Moreover, studies emphasise understanding intentions, motivations, or habits; they do not focus on understanding and measuring behaviour. Additionally, previous research has emphasised the need for standardised methodologies to evaluate and understand water use under various conditions and to facilitate comparisons between studies. Other studies have emphasised the importance of adopting a holistic approach to understand water user behaviour (Tamason et al., 2016).

This study proposes a model that builds upon the existing RANAS model and the VBN theory (Karakaş, 2023; Lilje & Mosler, 2018). Both approaches have previously demonstrated their effectiveness in understanding water hygiene, sanitation, and environmental behaviours. Our

proposal provides systematic, and integrated approach for understanding water use. Moreover, this model can be modified by including or excluding one or more factors. For instance, we extended the RANAS model by adding the trust factor, which is essential for effectively studying water use (Jorgensen et al., 2009).

The RANAS framework combines existing theories of behaviour change along with insights from environmental and health psychology. It identifies risk factors through three theories: the Health Belief Model (HBM), Protection Motivation Theory (PMT), and the Health Action Process Approach (HAPA). Attitudes, norms and abilities factors draw from the TPB, while self-efficacy factors relate to the ongoing practice and sustainability of the behaviours (Mosler, 2012). The TPB theory is grounded in rational choices, and referent behaviours are directed by self-interest to gain rewards and avoid punishment. Thus, the TPB theory refers to the idea that a person's behaviour can be anticipated by their intention to perform those behaviours. This intention is further shaped by their attitudes, subjective norms, and beliefs (Price & Leviston, 2014; Seymour et al., 2010).

The VBN theory, like the RANAS approach, incorporates three established theories: value theory, the new environmental paradigm (NEP), and the norm activation model (NAM). The NEP focuses on assessing environmental beliefs, which, in the context of VBN, illustrate the connection between worldviews and behaviours. Meanwhile, the NAM emphasizes the importance of individual norms that influence environmental actions (Price & Leviston, 2014; Seymour et al., 2010; Steg et al., 2005). Unlike the RANAS framework, the VBN theory focuses on moral dimensions, and its premise is that behaviours connect to altruism guided by norms and environmental values. Furthermore, this theory is used to explain the motivation of individuals which trigger environmental behaviour. The VBN theory is based on a sequence of factors which begin with stable environmental values, followed by beliefs about human-environment links, which, in turn, affect personal norms (Price & Leviston, 2014; Seymour et al., 2010; Steg et al., 2005).

As RANAS is based on the TPB, one of the primary models used to study human decision-making for over three decades. It is widely utilised in social research to explain pro-environmental behaviour; however, it does not incorporate a values component (Seymour et al., 2010). As attitudes, norms and abilities of RANAS model are grounded in the TPB model, previous studies indicate that TPB has been applied in numerous environmental contexts and is helpful to explain specific practices such as household recycling, water conservation, farmers' use of weather and climate forecasts and riparian management by landholders (Price & Leviston, 2014; Seymour et al., 2010).

Unlike the RANAS model, the VBN theory effectively explains general environmental behaviours rather than focusing on specific practices like the TPB. This model has been applied to various areas and has proved effective in explaining different behaviours, including consumer behaviour, environmental citizenship, and the willingness to reduce car usage (Seymour et al., 2010; Steg et al., 2005).

The RANAS and VBN approaches have been used in several studies (Mosler, H.-J., & Contzen, 2016; Price & Leviston, 2014). However, these approaches have not yet been integrated and tested

to examine behaviours related to water use. Both the RANAS approach and the VBN theory approach share similar factors; however, these factors do not always focus on the same aspects of behaviour assessment. In the RANAS model, the factor risk refers to the individual's understanding of environmental knowledge, and its consequences (Seymour et al., 2010) Attitudes are related to a positive or negative stance toward a behaviour and include instrumental beliefs, such as those about cost in terms of money, time, and effort (Mosler, 2012). Moreover, the TPB theory identifies three kinds of beliefs: behavioural beliefs, perceived social pressure, and control beliefs (Seymour et al., 2010).

In the RANAS approach, three types of norms are included: descriptive norms refer to perceptions of what behaviours are typically performed by others. Injunctive norms represent perceptions of which behaviours are typically approved or disapproved of by relatives or friends; injunctive norms also include institutional norms. Personal norms address what an individual personally believes others should do. Ability factors represent the confidence of a person in their ability to perform a behaviour. Self-regulation factors refer to personal responsibility for the continuance and maintenance of behaviour. (Mosler, 2012).

The values in the VBN theory represent desirable goals and reflect on the negative impacts on the natural environment, themselves, and others. In this context, beliefs refer to people's environmental concerns, their awareness of environmental threats, and the consequences of these threats on the biosphere, other individuals, and themselves. Within the VBN theory, personal norms emerge because people have a desire to be morally responsible (Price & Leviston, 2014).

The RANAS approach links to the VBN theory through factors such as risk, beliefs, attitudes, and personal norms. The connection between risk and beliefs is established through understanding and awareness. Risk involves the comprehension of environmental knowledge related to potential consequences, while the VBN theory encompasses environmental beliefs that address the effects of environmental threats.

In the context of the TPB, norms refer to the socially accepted standards set by colleagues, relatives, friends, or the community at large (Mosler, 2012; Price & Leviston, 2014). Specifically, personal norms are the beliefs that an individual holds about what they should do. In contrast, within the VBN theory, personal norms reflect a sense of self-responsibility and individual and moral obligation to engage in pro-environmental behaviours. Personal norms are followed by an individual's beliefs regarding environmental risk awareness and their perception of their ability to address those threats. This activation of norms subsequently leads to specific behaviours (Steg, 2023).

Moreover, the ability of the RANAS approach refers to an individual's beliefs in their self-ability to perform specific behaviour. This ability factor links to the VBN theory, which suggests that environmental beliefs are tied to a person's perceived ability to tackle environmental threats. The attitudes of the RANAS model align with the personal norms of the VBN theory, as the norms activation model effectively explain low-cost environmental behaviour, while the attitudes of the RANAS model evaluate the perceived consequences of behaviour. Particularly, this evaluation

consists of evaluating the costs and benefits of perceived behaviour in terms of effort, time and money (Mosler, H.-J., & Contzen, 2016; Steg et al., 2005).

2.6. Conclusions

The success of various efforts at implementing WUE measures has been limited by several related reasons. One cause behind higher than expected demand and inefficient use of water is human behavior and therefore related to the lack of an integrated assessment of behavioral and contextual factors that influence water use behavior.

Based on an extensive review, the paper identified a variety of contextual and psychological factors underlying the behavior. A conceptual model, based on existing models and theories, was proposed that integrates both groups of factors and proposes relationships between water users and institutions to understand (in)efficient water use. Involving water managers facilitates the assessment of institutional relationships between water users and water managers. This will unravel the influence of institutions or organizations on the behavior of water users, and vice versa.

Local observations and social surveys should provide the data that are needed to populate the model and test factors influencing the behavior.

Both the RANAS approach and the VBN theory are valuable for exploring water use, as they shed light on the practices and motivations behind individuals' environmental behaviour. These frameworks complement each other in various ways; for instance, while RANAS focuses on risk and abilities, it does not address values. Additionally, the frameworks differ in their treatment of personal norms.

The paper further highlighted that water users and institutions involved in the water use chain have an important role to play in making decisions and taking actions that affect WUE. Often the focus on end users such as households means that other stakeholders in the supply chain of water use are mostly ignored, such as institutional stakeholders (organizations/water managers). Linking the knowledge of WUE with stakeholder's perceptions, would, as a result, contribute to a more comprehensive assessment of WUE.

Author Contributions

DC drafted, revised, and finalized the paper. SP and LR edited the paper. All authors contributed to the ideas in the paper and agreed to the submitted form.

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Conflict of Interest

The 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.

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2.7. References

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Chapter 3

3. Inefficiencies in water supply and perceptions of water use in peri-urban and rural water supply systems: case study in Cali and Restrepo, Colombia

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This chapter is based on: Callejas M., D., C, Pande, S., Haeffner, M., Rodríguez, J., P., Rietveld, L. (2024): Inefficiencies in water supply and perceptions of water use in peri-urban and rural water supply systems: A case study of Cali, Colombia. Journal Frontiers in Water. Frontiers in Water. (6) Sec. Water and Human Systems. DOI: 10.3389/frwa.2024.1389648.

Abstract

Water scarcity is a significant global challenge that frequently manifests as an inadequate water supply for domestic purposes. However, domestic water insecurity can occur even in regions where water is naturally abundant. Despite Colombia's plentiful surface water resources, rural and peri-urban communities often experience limited access to water. Existing water supply systems are frequently susceptible to poor maintenance, particularly in remote areas where much of the infrastructure remains outdated. Consequently, water is often lost through leaks or unintentional non-domestic use. Although a regulatory framework for water usage exists, it does not consistently translate into effective implementation.

Based on an extensive survey of approximately 1000 households in four rural and four peri-urban communities in the Valle del Cauca Department, Colombia, we identified the factors underlying inefficient water supply and use. Perceived water use at the household level, based on self-reported time spent on various use types, such as bathing, and water supplied at the system level, was estimated.

Our findings indicate that household size, education level, age and occupation are critical factors influencing end water use and water supply. These results not only elucidate why water is supplied and used inefficiently in rural systems (e.g., due to non-domestic use) but also accounts for the variability of perceived water use within peri-urban systems. The water use perceived by households in the rural systems was statistically similar across the rural systems studied and was significantly lower than that in the peri-urban systems. Most rural systems exhibited very low ratios of perceived water use to water supplied, indicating that either water is lost in conveyance or that water is used for non-domestic purposes. Peri-urban users, who were perceived to use more water than users in rural areas, were associated with younger and more educated households. Higher education levels were also associated with better financial capacity and technical ability to manage water systems; therefore, peri-urban systems were better managed.

Keywords: water use behavior, contextual factors, distance, household water use, water users' associations.

3.1. Introduction

It is widely known that most people use more water than is strictly necessary for health and well-being (Chukwuma, 2017; Crouch et al., 2021; Hou et al., 2019). Excessive water use puts pressure on natural water sources, water supply systems (WSSs), and wastewater systems (Keshavarzi et al., 2006; Srinivasan et al., 2012), which could result in rural water suppliers being unable to fully meet everyones basic water needs. In many countries, particularly those experiencing exacerbated water stress due to extreme weather conditions and persistent socio-economic inequalities, challenges abound (Gonzales & Ajami, 2017; Koop et al., 2019; Rahayu & Rini, 2019; Sant'Ana

& Mazzega, 2018). These challenges, notably prevalent in low and middle-income countries, limit access to essential resources, such water for domestic purposes and food security.

Water demand and overuse have posed significant challenges to water conservation for decades, owing to population growth and increased welfare which in turn increases the demand for goods and services. Climate change exacerbates these challenges, the Intergovernmental Panel on Climate Change (IPCC) emphasizes the importance of demand management to address the increasing vulnerability of freshwater resources (Russell & Fielding, 2010). Climate change, combined with factors such as population growth and shifts in land use, exerts immense pressure on existing water sources worldwide, raising doubts about their capacity to meet the growing water demand. Water authorities are confronted with the daunting task of ensuring adequate water availability amid droughts, population surges, and anticipated reductions in water supply due to climate change. Consequently, reducing water usage and enhancing water use efficiency have become pressing concerns in numerous regions (Fu & Wu, 2014; Jorgensen et al., 2009).

Ensuring sustainable water management is imperative, with a central focus on reducing water losses from supply systems. Sustainable water management becomes increasingly critical as water scarcity intensifies annually, and water utilities can no longer afford inefficiencies in their supply systems. Addressing water losses poses a myriad of challenges, encompassing various options with their inherent complexities, diverse evaluation criteria, uncertainties, and conflicting objectives and interests among stakeholders from different sectors (Zyoud et al., 2016). For example, in many low- and middle-income countries, most water utilities must deal with leakage and losses (Chawira et al., 2022; Liemberger &Wyatt, 2019), resulting in high levels of so-called Non-Revenue Water (NRW), which is "the difference between the system input volume and billed authorized consumption" (Lambert and Hirner, 2000). Therefore, NRW is often used as an indicator for efficiency within WSSs (Charalambous and Laspidou, 2017; Chawira et al., 2022; Makaya and Hensel, 2014). The NRW in urban areas can reach levels of up to 50%, whereas information on this topic is not available for rural areas (Chawira et al., 2022; Liemberger & Wyatt, 2019; Makaya & Hensel, 2014). The NRW indicator for both urban and rural Latin America ranges from 18 to 62%, whereas in urban Colombia, the NRW ranges from 40 to 48% (Liemberger & Wyatt, 2019; SSPD); however, this information is not available for rural areas (Chawira et al., 2022; Liemberger & Wyatt, 2019; Makaya and Hensel, 2014). These percentages may be rooted in various factors, such as the location of the WSSs and organizational issues that influence financial sustainability, operation, and maintenance.

The peri-urban zone is a transitional area where rural and urban zones converge. Characterized by a growing population, expansion in size, and a predominantly non-agricultural labour force (Mittal, 2019), this region represents a dynamic interface between rural and urban zones. In the peri-urban and rural zones of low- and middle-income countries, water suppliers are frequently organized as

water users' associations (WUA) (Delgado-Serrano et al., 2017), which are mainly volunteer-led community management organizations, including hired staff who may be professional or non-professional. However, WUAs are often unable to afford regular maintenance of the WSSs to ensure efficient performance (Muniz et al., 2020). Sometimes, there is even an insufficient number of professional, operational, and executive personnel serving the WSSs. This situation is marked by weak knowledge and the capacity to apply this knowledge to decisions, which has been defined as water literacy (Dean et al., 2016a; Dean et al., 2016b; McCarroll & Hamann, 2020). This situation is also exacerbated by the fact that most employees of WSSs receive low wages or work without salaries. The distance from urban areas is another challenge which impacts communities and the functionality of the system by WUAs (Muniz et al., 2020), because it hinders providers from operating and maintaining systems. Low-income residents cannot afford the high costs of maintaining the quality services and logistics needed to support the system (Muniz et al., 2020). It is possible that the proximity to the city provides the urban managers with better access to information and technical support from institutions compared to rural managers (Barde, 2017; Muniz et al., 2020).

Water system inefficiencies occur not only due to poor infrastructure (leakages and losses), but also because of how efficiently individuals use the water. Socio economic factors, such as income, household size, age, gender, education and occupation are known as contextual factors that influence the behavior of individuals (Mosler & Contzen, 2016; Singha et al., 2022; Steg & Vlek, 2009; Stern, 2000), and, thus, water use within households (Dean et al., 2016a; Dean et al., 2016b; Jorgensen et al., 2009; Millock & Nauges, 2010; Onyenankeya et al., 2021; Russell & Fielding, 2010; Russell & Knoeri, 2020).

Various studies, which link end water use to contextual factors in WSSs have considered individual, household, and WSSs levels in urban, peri-urban, and rural areas. These studies have been carried out both in developed (Abu-Bakar et al., 2021; Benito et al., 2019; Cominola et al., 2023; Mazzoni et al., 2023; Charlotte et al., 2016) and in low- and middle-income countries (Al-Amin et al., 2011; Arouna & Dabbert, 2010; Chukwuma, 2017; Charlotte et al., 2016; Keshavarzi et al., 2006; Polania & Vanessa, 2019; Onyenankeya et al., 2021; Rahayu & Rini, 2019; García & Brown, 2009; Strauch et al., 2021). Abstracting conceptual models of coupled human-urban water systems based on such studies have revealed the feedback between water use at system and household levels, performance of the systems, and the quality of WUA management. For example, the model developed by Muneepeerakul and Anderies (2017) integrated social, economic and environmental factors and proposed a link between the income generated from the use of water, and the extent to which the maintenance cost of water infrastructures could be sustained (Muneepeerakul & Anderies, 2017; Pande & Sivapalan, 2016).

Addressing challenges in rural water supply requires more than just technical solutions or community involvement alone, because human activities shape water supply systems and, in turn,

impact on human well-being. This social component necessitates a comprehensive understanding of how water supply systems are integrated into households and communities, as well as how individuals within specific socioeconomic contexts utilize water (Stern, 2014; Workman et al., 2021). However, studies on factors affecting water use usually focus on one level but not on both levels together. Studying water use at both the household and supply system levels is necessary to understand the factors affecting water use and two-way feedback between households and the system (Roobavannan et al., 2018). It is essential to consider both contextual factors at the household level and technical approaches at the water system level.

Single disciplines often fail to offer the comprehensive insights needed to fully understand or influence individual and household interactions with water systems. In studies on water demand reduction, research within each discipline has generally approached the topic from its own perspectives. This own perspective has resulted in a lack of interdisciplinary, problem-oriented collaboration aimed at developing an integrative understanding of water use at both household and system levels (Workman et al., 2021).

Therefore, to fill this gap, this study aims to identify contextual factors that influence water use by employing a multilevel framework at the household and water supply levels. The case study comprised four rural WSSs and four peri-urban WSSs in the Valle del Cauca Department of Colombia. In this study, we used a socio-technical approach that might provide insights into water use at the system level as well. This approach is helpful for addressing water use interventions and improving water demand management at both household and system levels.

3.1.1 Water supply in peri-urban and rural areas: the Colombian context and management institutions

Approximately 23% of Colombia's population, totaling nearly 12 million inhabitants, reside in rural areas, encompassing both remote rural and peri-urban zones. There are an estimated 11,000 water systems and 9,000 providers, although it is not representative of all systems, it reflects the current state of rural water supply systems nationwide (SIASAR, 2022). Despite these efforts, persistent water shortages often result in demand exceeding supply (Barbier, 2019).

Despite the abundance of surface water, access to water for rural communities in Colombia remains limited, with only 40% of the rural population having access to piped water as of 2017 (SSPD, 2019; United Nations, 2022). The SDG 6.4.1 indicator is calculated as the change in the ratio of gross economic value added by the water supply sector and the annual withdrawal of water from the public distribution network, expressed in USD/m^3 (Hellegers & van Halsema, 2021; United Nations, 2022). A higher value of the SDG indicator signifies greater water supply efficiency. As of 2019, the SDG 6.4.1 value for the entire urban services sector in Colombia was 54.27 USD/m^3, approximately 48% below the global average of 112 USD/m3 (United Nations, 2022). Unfortunately, there is no information regarding water use efficiency in rural areas that

could be obtained. In contrast, non-revenue water (NRW) estimates for urban areas vary widely, ranging from 7 to 90%. These estimates are measured across distribution networks, from the source to household connections (Liemberger & Wyatt, 2019; SSPD, 2020). In rural settings, measuring NRW can be challenging due to the absence of water metering fixtures or those that do not function properly.

The Colombian water management and supply framework operates across various administrative levels, involving numerous institutions including ministries and municipalities. This complex institutional structure encompasses a range of regulations and programs dedicated to water supply and management. Water User Associations (WUAs) play a crucial role, particularly in peri-urban and rural areas, and are subject to regulation by entities at the municipal, regional, and national scales. In rural contexts, WUAs often organize under regional water users' associations, exemplified by entities such as Fecoser and Aquacol in the Valle del Cauca department.

Within the institutional framework, national regulations, such as Law 142 of 1994 (Ministry of Housing, City and Territory - MVCT) and Decree 1076 of 2015 (Ministry of Environment and Sustainable Development - MADS), stipulate that the provision of rural water services is the responsibility of Water User Associations (WUAs). Furthermore, the legal framework requires water suppliers to ensure the provision of safe water, obtain permits for water intake, and implement a Water Use Efficiency Programme (WUEP). This program comprises activities and objectives proposed by water suppliers to reduce and optimize the utilization of existing water infrastructure.

In Colombia and other low- and middle-income countries, many existing institutional structures, especially national organizations, often fail to address the needs of peri-urban and rural communities adequately. As a result, policies instituted at the national and regional scale frequently lack alignment with practices at the rural scale (Barde, 2017; Molinos-Senante et al., 2019; Muniz et al., 2020).

Three main institutional bottlenecks challenge the water supply in rural and peri-urban areas. First, the process of decision-making and reaching agreements is complex because of conflicting objectives and interests among stakeholders from different sectors, as well as across various administrative scales and institutions. Second, weaknesses in water literacy persist, particularly due to the low wages or absence of salaries for many employees of WSSs, as well as limited access to information and technical support from institutions. Third, policies implemented at the national and regional levels often lack alignment with rural practices. The design and implementation of policies and projects have employed a top-down approach (Barde, 2017; Dean et al., 2016a; Dean et al., 2016b; McCarroll & Hamann, 2020).

Concerns about reducing high water demand, waste, and overuse have led to a need for water use efficiency and conservation. Exploring, understanding, and predicting water concerns and

solutions is a growing area in water management. In the drinking water supply sector, assessments typically includes either individual or system levels. Sociohydrology integrates these levels and focuses on the interactions between water systems and people (Blair &Buytaert, 2016; Roobavannan et al., 2018; Sanderson et al., 2017).

3.2. Materials and methods

In this study, we assessed the drinking water supply system using a socio-hydrology approach to determine which factors simultaneously influence water use at both individual and system levels, as well as their impact on water efficiency.

To understand how and how much water is used, it can be estimated at three levels (Table 3.1). A previous study in the Valle del Cauca department considered water use at household and catchment levels (García & Brown, 2009). In the present study, we examined both water users and water supply systems to determine the efficiency of water use as perceived by the end users. We used the household and water supply levels. People can increase their water use efficiency through "curtailment" habits that reduce water use, such as taking shorter showers, and "efficiency" measures by purchasing saving fixtures and storage appliances (Attari, 2014; Russell & Fielding, 2010). At the system level, we considered two sub-levels to define water system efficiency. First, we used the percentage of water losses between the intake and the storage tank as a measure of efficiency at the supply system level (see Figure 3.1). We used the water supplied (measured at the storage tank) and water used at the household level in litres per person per day (lpcd) to determine household level system efficiency.

3.2.1 Case study

Criteria for selection case study

For the present study, eight (8) locations in Colombia at peri-urban and rural scale were selected based on WSSs heterogeneity, different SEC characteristics, climatic conditions, presence of formal WUAs and sizes of WSSs. In addition, the selection criteria included: (1) interviewer security; (2) the willingness of stakeholders to participate; (3) accessibility to the location (e.g., distance from main cities, rural road conditions); and (4) whether the WSSs were in operation. The locations that were selected were eight WSSs in the rural zone of Restrepo and the peri-urban zone of Cali, located in the Valle del Cauca Department, close to the Pacific Ocean in the south-eastern region of Colombia (Figure 3.2) (Metabolism of Cities - Data Hub, 2023; NASA Shuttle Radar Topography Mission (SRTM), 2013).

The institutional structure regarding WSSs consists of seven main institutions at the department, municipal, and rural scales (Figure 3.3). All WUA belong either to Fecoser (Community

Aqueducts Federation of Valle del Cauca) or Aquacol (Association of Community Organizations Providing Water and Sanitation Services in Colombia), which are active in Restrepo and the peri-urban zone of Cali, respectively.

Table 3.1. Scale to assess water use efficiency (WUE) for domestic water use.

	Household scale	System (WSs)-scale	Catchment, basin, aquifer-scale
Definition	Water use behavior Curtailment Water use efficiency (saving fixtures and appliances)	Leakages and losses NRW (Non–revenue water)	Water use Leakages and losses
Method	Surveys End water use measurements; inventory of water-saving appliances	Water flux measurements across water utilities Water balance	Water balance
Stakeholders	Water users Water users' associations (WUA)	Water users' associations (WUA)	Water managers on a national scale Regional scale and municipality scale

In Restrepo, most of the WUA emerged in the 1980s when coffee production was one of the most important economic sectors, and the inhabitants were mainly coffee farmers. According to Fecoser[1], the National Federation of Coffee Growers of Colombia (NFCG) constructed the water supply infrastructure, which consists of an intake and a sand removal pre-treatment tank (see Figure 3.1). Since then, water infrastructure has been managed and operated by WUAs, without or with the Government's economic or technical support or planning. Over time, the growing population has increased domestic water demand, and the use of water for irrigation, cattle farming, and pig farming has constrained the water supply, leading to unequal access between domestic and other uses.

[1] Personal communication – Zoom-meting, October 11, 2021

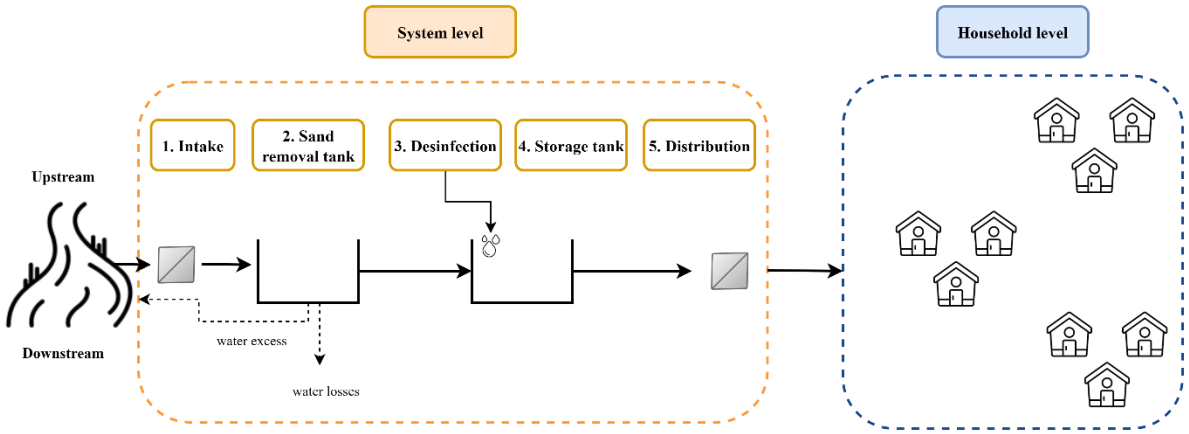


Figure 3.1. Schematic of a typical water supply and drinking water system. Water use efficiency is defined at two levels: distribution to household level (blue) and supply system level (orange)[2].

In peri-urban zones, WUAs originated during the 1960s and 1990s, and WSSs were constructed and designed by the environmental and health authorities, a local university and municipalities. Since then, these areas continued to expand. The growing population in Cali, due to violence that has displaced people from remote areas and other departments (Urrea and Canelo, 2017; Vergara et al., 2020), led to increase the migration from urban to peri-urban zones.

The systems tap either surface or groundwater sources (Table 3.2), and the type of treatment for drinking water varies depending on the water source. Additionally, seven of these systems are segmented into sectors where water is distributed to users intermittently (Charalambous & Laspidou, 2017; Sione, 2021).

3.2.2 Research approach

Field campaign

A field campaign was conducted to obtain self-reported patterns of water use and characteristics of fixtures and appliances used by households, as well as data on water flows at the system level, to estimate end water use and water supply in the WSSs. These WSSs were further classified as peri-urban and rural based on their distances from the capital city of the department, Cali.

The field campaign involved two methodologies: social research and technical measurements (Figure 3.4). To collect information about the SEC, we employed both online and face-to-face fieldwork methods, as well as social mapping techniques. As a starting point, meetings and workshops with local WUAs and staff from WSSs were carried out online (due to the COVID-19

[2] This figure represents the general configuration of a water supply system; however, each location studied in the present research may differ in its specific setup.

pandemic), assisted by a person from Restrepo, who collaborated on the project at the location. We contacted water leaders, using a smartphone or laptop and online meeting tools, such as WhatsApp (Meta Platforms, Inc., 2021), Zoom (Zoom Video Communications, Inc., 2021) and Teams (Microsoft, 2021), depending on the internet connection. Online invitations were sent via email to the participants in advance, including the meeting´s aim and program, as well as a request to confirm their presence. Participants signed an "informed consent" before the meeting. The groups, comprising between three and ten people, facilitated the participation of all attendees and stimulated them to pose questions and make suggestions.

Data collection

Criteria for household selection

Data collection involved an inventory of water users and utilities, as well as the number of dwellings and their locations. To understand the water-use habits of domestic users, questionnaires were designed. Households were randomly selected, covering all sectors at each site. The sector is a subarea that belongs to the total area where the water supply system is located. One adult per family was interviewed, and only adults aged 18 and above were considered for the interviews. The households were informed in advance by the manager of each water users' association. To collect data, we used a questionnaire survey that focuses on SEC and water use. The water bill number of the household's owners was used to select interviewees randomly. For the WSSs that do not bill, a list of customers was used. For "self-reporting", we did not ask participants to keep records; we asked for their perceptions by responding to the questionnaire items.

Data was collected between November 2020 and December 2021. During the first stage (November 2020 – April 2021), interviews and workshops were conducted online with local village leaders from the WUAs, to collect information on the SEC context and features of the WSS in each village. During the interviews and workshops, the purpose of the study was explained, and information about the number of water users per system, the type of water treatment plant, the main water uses and economic sectors in the villages, and how WSSs were established was collected.

We employed a cross-sectional survey, a widely recognized approach for collecting self-reported information on perceptions, attitudes, beliefs, and behaviours related to water usage (Gifford, 2016; Haslam & McGarty, 2014). Therefore, we asked the participants directly without making records over a longer period of time. A total of 965 rural and peri-urban households were sampled, with a response rate of 96%. The sample size represented approximately 20% of domestic water users from each of WSSs located in the peri-urban zone of Cali and rural Restrepo. The sample

size was determined using the "G*power" software, which computes the sample size and statistical power. In this study, we specified a small effect size ($f2 = 0.07$), significance level (α) of 0.05, and statistical power of 0.9 (Erdfelder et al., 2009). Following the removal of missing and erroneous data, the final sample size was 965 households. For data management and analysis, the questionnaire was translated from Spanish to English, questions were renamed, and reliable coding was established.

The second step involved (physically) visiting eight WSSs to attain official records, observing existing water supply infrastructure, and interviewing water suppliers. Teams were organized to measure water flows in the facilities of the WSSs and to conduct household surveys (Table 3.2). During the rainy season (May–December 2021), face-to-face surveys were conducted with adult members of households, and primary data were gathered, including the SEC, self-reported water use habits, and end water uses of the individual participants. The online survey software Qualtrics XM was used to conduct the surveys (Qualtrics, 2021).

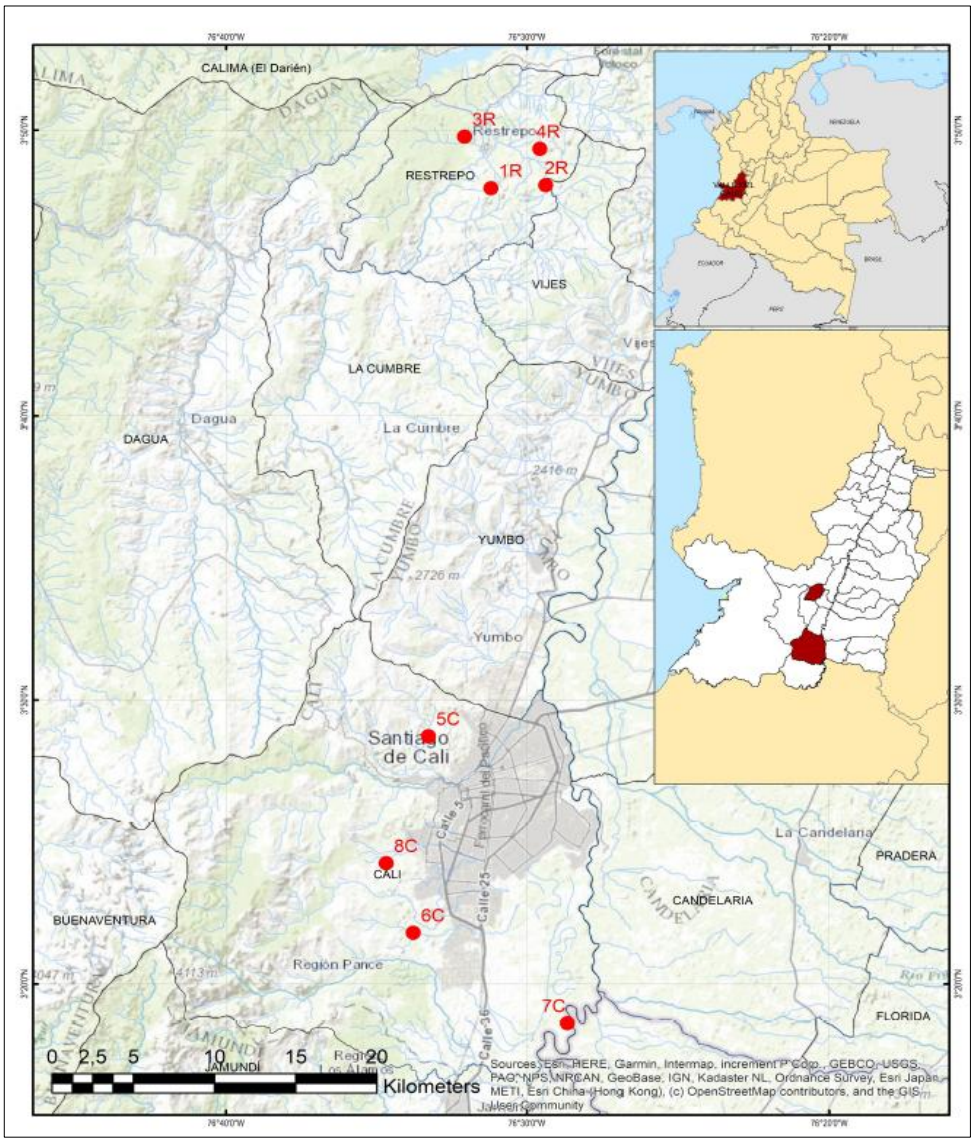


Figure 3.2 Location of Valle del Cauca department in Colombia, municipalities, and area of case study. The right panel shows the location of the WSSs.

Volumetric methods were used to measure water flows at the utilities. Water flow measurements at the water source and intake were measured assuming a constant flow; the outflow measurements were taken in the storage tank–hourly for 24 h, except for the "2R" WSS (Table 3.2.), where it was not possible to take water flow measurements because there was no "valve" to interrupt the flow of water partially and this would imply cutting off the water supply for users.

Estimation of end water use perceived at the household level based on self-reports

To estimate water used by domestic appliances and fixtures, several alternative methods exist (Abu-Bakar et al., 2021; Charlotte et al., 2016), such as water metering (Polania & Vanessa, 2019),

data loggers and sensors (Abu-Bakar et al., 2021), using water bills or census (Attari, 2014; U.S. Geological Survey, 2005), and asking water users about their water use habits and type of appliances and fixtures at home. In the latter method, participants report their perceptions of ,water use (Abu-Bakar et al., 2021; Attari, 2014; Chacón et al., 2011; Mourad et al., 2011). Not all WSSs had water meter fixtures, and few had metering at the household level. Therefore, questionnaires and water flow standards for conventional and efficient fixtures and appliances from the literature were used to estimate 'the perceived' end water use. We assumed that individuals taking traditional showers, using a bucket when they do not have a showerhead. We determined the end water use of domestic water use considering only indoor uses and excluding leakages.



Figure 3.3. Water institutions in the Valle del Cauca department.

Table 3.2 Characteristics of selected WSSs.

Municipality	**Restrepo**				**Rural area of Cali**			
Regional Wateruser's association (WUA)	**Fecoser**				**Aquacol**			
Zone	**Rural**				**Peri-urban**			
Local WUA	1R	2R	3R	4R	5C	6C[3]	7C	8C
Type of water source (number of sources)	Surface (2)	Surface (2)	Surface (1)	Surface (1)	Surface (1)	Surface (5)	Groundwater (1)	Surface (2)
Type of treatment for drinking water	MSF[4]-Chlorination	–	Chlorination	Chlorination	Filtration and chlorination	*CF*-MSF	Package	MSF
The water use efficiency program (WUEP) presented	No	No	No	No	Yes	Yes	No	Yes
Number of sectors	8	3	3	1	6	20	5	15
Total number of households	473	76	52	28	128	1925	797	545
Number of surveys (and percentage from the WSSs size)	107 (23%)	43 (57%)	17 (33%)	24 (86%)	61 (48%)	390 (20%)	181 (23%)	142 (26%)
The average number of people per household estimated	4	3	4	3	4	4	4	4

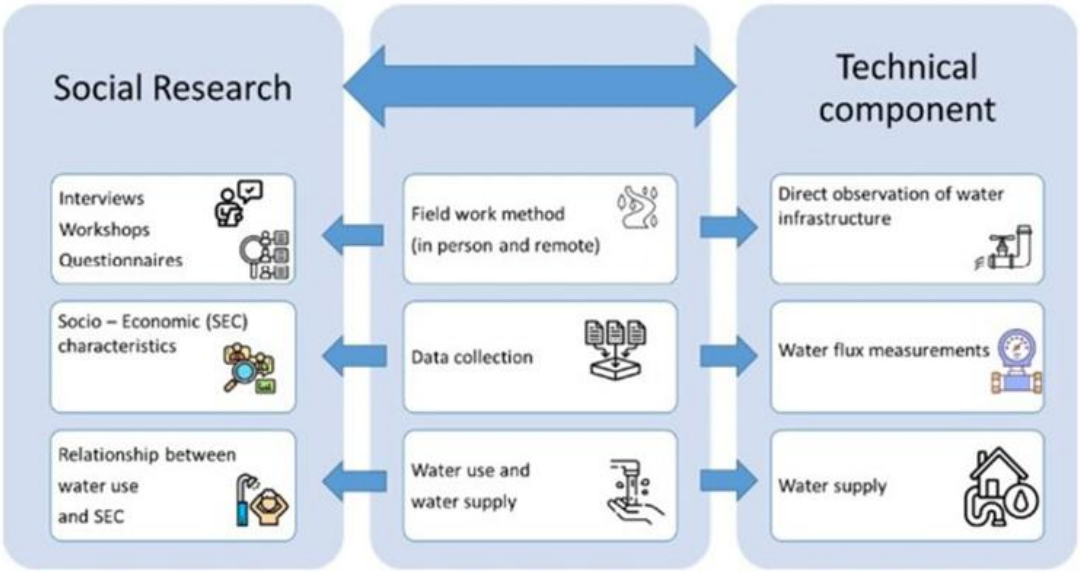


Figure 3.4. Methodology of social research and technical measurements.

[3] It has two water treatment plants (6_C1, 6_C2).
[4] Not functioning. MSF, multi-stage filtration; CF, coagulation and flocculation. Adapted from Veldt and Burger (2015).

The questionnaire consisted of closed-ended questions related to socio-economic factors, types of appliances, and water habits. Detailed information regarding these questions can be found in the codebook (see Appendix A1), which was adapted from previous studies (Attari, 2014; Dean et al., 2016a; Dean et al., 2016b; Jorgensen et al., 2009; Manouseli et al., 2018; Newton & Meyer, 2012), and the frequency per day or week for each water use. A Likert scale (1–5) was used to collect the responses for categorical variables (Edmondson, 2005). Water flow values for appliances and fixtures were selected, and water use per person per day for specific uses, such as cooking and cleaning the house, and with and without water-saving appliances and fixtures were collected based on literature (Attari, 2014; Crouch et al., 2021; García & Brown, 2009; Jorge et al., 2015; Kunitsuka, 2014; Restrepo Tarquino, 2010; Singh & Turkiya, 2013; USGS as cited in BID, 2014).

Estimation of perceived end water use per user was then calculated based on equations 1–8. Similar surveys and equations have been used earlier to calculate water use (Mourad et al., 2011). For example, the daily amount of water used for a shower per person was calculated by multiplying the number of self-reported showers by the respondent by the estimated water flow from the shower and shower's length. It was assumed that the shower was used even when the service water was not continuous. It is then multiplied by the number of people in the household, assuming that household members tend to behave similarly. Most respondents did not respond to the question about the frequency of flushing toilets, because they considered it to be private information. Estimating other uses also proved to be difficult. Often, the house had older or non-standard fixtures and appliances. Therefore, we assumed that toilets were flushed three times per day per person (Sant'Ana &Mazzega, 2018), and the following lengths of tap opening were considered: one minute for hand washing and tooth-brushing, and three minutes for dish washing. The frequency of each use was collected through the survey.

Water supply at system level

The WSSs in our case study provide water through small dams and settling ponds, connected to community water tanks, located upstream close to the intake (see Figure 3.1). Seven of these WSSs use gravity to transport the (treated) surface water to the households, while only the “7C” supply relies on pumping, being dependent on groundwater. At least in three of the systems (“2R,” “6C,” “7C”), pipes and storage tanks between the intake and the system, and water flux meters have fallen into disrepair.

The water supply flows were estimated based on the inflow and water level measurements of the storage tanks. The inflow of the storage tank (Qiin) and water levels (Ii) were measured every hour for 24 h. The changes in storage (ΔSi) were obtained from Equation 5, and the hourly outflows (Qout) were calculated using the water balance (Equation 6). Finally, total outflows, Qtotal, for 24 h were obtained as the sum of all hourly outflows. Water supplied per person (W) in each WSSs

was then calculated by dividing the total outflow Qtotal by the people (N) supplied per day (Equation 7).

Water losses were attributed to leakages during the transmission and distribution of water, as well as leakages and spills at utility storage tanks (Charalambous and Laspidou, 2017; Lambert and Hirner, 2000).

The percentage of water losses was estimated by comparing intake and outflow (see Figure 3.1, Equation 8). Information on leakages was not available for whole systems due to barriers to access to the facilities and other difficulties, such as those related to the "2R." Water loss was estimated for each water supply system, not per household.

Estimation of water use based on water habits of households in each WSSs

	Equation	Variable
Equation 1. Water use (WU_i)	$WU_i = f * V_i * t$	i: use type *f*: frequency (times per day or week) *V*: water flow per use (l/min) t: the length of water use
Equation 2. Total water use per person (TWU_i)	$TWU = \sum_{i=1}^{n} WUi$	n: total number of water uses per household

Estimation of water use based on water supply in each WSSs. Calculations are provided for a typical utility storage tank

	Equation	Variable
Equation 3. Initial water storage	$V(m^3) = L\,(m) * w\,(m) * l_0(m)$	V: volume L: length w: width l_0: initial water level
Equation 4. Hourly water storage	$S_i(m^3) = L(m) * w(m) * l_i(m)$	l: hourly water level, i: hour, S: storage
Equation 5. Incremental change in storage	$\Delta S_i = S_i - S_{i-1}$	ΔS_i change in storage in hour i
Equation 6. Water balance	$Q^i{}_{out} = Q^i{}_{in} - \Delta S_i$	$Q^i{}_{in}$: volumetric flow rate coming into the tank, $Q^i{}_{out}$ is the flow rate exiting the tank in hour i
Equation 6a. Total outflow (24 hours)	$Q_{total} = \sum_{i=1}^{n} Q^i{}_{out}$	Q_{total}: total daily outflow from the tank
Equation 7. Water supplied per capita	$W = \frac{Q_{total}}{N}$	W = water supplied per person per day N: number of people

Equation 8. Water losses	$w_{losses}(\%) = \frac{Q_{intake} - Q_{outflow}}{Q_{intake}} * 100$	Q_{intake} : volumetric flow rate is taken in from the water source $Q_{outflow} = Q_{total}$

Analysis method

To explore the associations among end water use, water supply and SEC factors, we used descriptive statistics. Firstly, we examined the dispersion of estimated end water use, using the coefficient of variation (CV) (Doane & Seward, 2013; Soetewey, 2020). As part of the descriptive characteristics, a correlogram was used to study the relationships between these variables (Soetewey, 2020). Analysis of variance (one – way ANOVA) was conducted to compare the means of end water use perceived by users between peri- urban and rural zones and among the WSSs. Further, it was tested whether the means of end water use were significantly different in the various WSSs. To identify which groups were responsible for the differences, a post hoc comparison was used (Creswell, 2014; Doane &Seward, 2013; Patil, 2021; Soetewey, 2020) and for the statistical analysis, R software version 4.2.3 was used (R Core Team, 2021) and the statistical packages (Patil, 2021; Revelle, 2022).

Limitations

We gathered data through a survey administered during interviews. We did not furnish households with a form to be completed every week. Water usage for non-domestic purposes was not recorded in the questionnaires during field data collection.

We faced technical and logistical limitations in estimating the water balance due to the remote locations of some of the WSSs. Some systems still use handmade designs, and the usual standards are often not applied. The validity of the results is also limited by insufficient historical measurements at the system level, such as intake inflow, leakage and losses. Metering fixtures were not installed at the household level. Therefore, estimated perceived water use serves as an approximation of the water used at the household level in the studied systems.

In the case of 6C, the water system operated intermittently, meaning that users did not have continuous access to water; instead, water was supplied in shifts. Additionally, in the case of 7C, the physical configuration of the system introduced limitations in accurately measuring the volume of water. The pumping system operates intermittently, and there is no macro flow meter in place. Consequently, measurements were taken only when the pump was operational.

We exclusively assessed the water loss from the intake to the water storage tank. However, we did not assess losses storage tanks to households. Additionally, we did not account for other commercial losses, including meter inaccuracies and unauthorized water use.

To estimate water losses, various scenarios were considered to fill the information gaps; as a result, a range of percentages of water losses was obtained (Karamountzos, P., 2022). The information was not available for whole systems due to limitations such as the ease of access to the facilities.

Water flux measurements in the water source and intake were taken at a single point and for a specific time on a single day. During the field interviews, questionnaires were only conducted during one season for each system. In Alto Cielo, La Tesalia, it was not possible to take water flux measurements for 24 hours because there was no accessible point for measurements.

Surveys and self-reports enabled us to study socio-economic and psychosocial factors, providing a better understanding of water use trends and habits. Nevertheless, the results from surveys are often an approximation of real behaviour rather than real behaviour. Moreover, respondents may be biased, leading them to exaggerate their positive behaviours or inaccurately perceive their water usage (Abu-Bakar et al., 2021; Hasan et al., 2021; Russell & Knoeri, 2020).

3.3. Results

Table 3.1. presents the characteristics of the selected WSSs, including the number of households and sectors, as well as the heterogeneity of these systems, such as the type of water source and treatment.

In three out of the eight case studies, technical and financial capacities were strong, whereas in the remaining five, these aspects were weak. According to our interviews[5], water managers identified challenges in water supply arising from conflicts among various water uses, including domestic, agricultural, livestock, and tourism. Additionally, low water prices pose an obstacle to the system's sustainability, and water sources are being depleted due to urbanization.

3.3.1 Perceived water use at household level

Based on self-reported habits and water use estimates, the overall average water use for domestic indoor purpose at the household level was calculated to be approximately 253 L per person per day (lpcd) (Figure 3.5). The range of values varied from a minimum of 39 lpcd to a maximum of 1016 lpcd, with 75% of water users consuming less than 303 lpcd. The coefficient of variation (CV) for water use was 0.4, indicating relatively homogeneous estimates of end water use.

Personal hygiene, including hand washing, teeth brushing and showering, accounted for an estimated 70% of total water use. Among these, showering represented the highest proportion at (54.8%). Participants reported showering once (64%), twice (22.79%), or even three times (2.27%)

[5] Personal communication – Zoom-meting, October 11, 2021

per day, with shower durations ranging from 3 to 15 min Notably, 60% of the participants reported an average shower duration of 8 min. Comparable findings were observed in the Netherlands in 2013, where showering was the primary water use activity (41%), with an average shower duration of 8.9 min. Similarly, in the eight administrative regions of the Federal District located in the centre west of Brazil, shower durations ranged between 6.3 and 9.2 min. Across 18 countries worldwide, the average reported shower time was 8.1 min (Mazzoni et al., 2023; Sant'Ana & Mazzega, 2018; Vewin – Association of Dutch water companies, 2017). Other studies have also indicated that showers are a key component of indoor water use, accounting for about one-third of indoor use (Makki et al., 2013). The volume of water used for showering depends on the implementation of efficient appliances and the duration of the shower. Even with the use of efficient fixtures, increasing the shower duration by a minute can result in approximately double the volume of water usage (Skipton & Dvorak, 2023). Our results indicate that participants allocated their water usage as follows: 0.3% for watering plants, 1.6% for housecleaning, 3% for cooking, 4.6% for laundry, 11.9% for flushing the toilet, and for 17.5% dishwashing, respectively (Figure 3.5).

Self-reported water use varies by geographical region. In peri-urban areas, nearly 50% of users perceived themselves as using less than 250 lpcd, compared to 75% of users of the WSSs in rural areas. Overall, peri-urban zones exhibited higher mean values for self-reported water use compared to estimations in rural zones. The average estimated end water use in peri-urban zones was 263 lpcd, which was 27% higher than in rural zones. The ANOVA test reveals a significant difference in perceived water use between the two zones (p-value>0.05), indicating that household level perceptions of water use vary depending on location. Specifically, perceived water use per capita in peri-urban systems is significantly higher than in rural systems.

The reduction in water use for various household activities involves two actions: curtailment and efficient use (Attari, 2014). Curtailment involves reducing the duration of activities, such as showering, while efficient use entails installing or switching to water efficient appliances and fixtures (Attari, 2014). From the surveyed households, the results showed that, on average, the perception of shower time is lower in rural zones (3.56 minutes) compared to peri-urban zones (7.49 minutes). This difference may be attributed to higher access to showers in the peri-urban zones (98%) compared to the rural zones (85%). Therefore, it was assumed that more rural households may use buckets for bathing due to the lack of shower heads, resulting in shorter showers compared to inhabitants of peri-urban zones. For instance, Ramsey et al. (2017) indicated that traditional bucket bathing proves to be more water efficient, as individuals use on average 20L of water per bath.

Furthermore, participants were asked about the type and use of basins, toilets, faucets, washing machines, and garden hoses (Appendix A1). Most households either had conventional appliances and fixtures or incomplete plumbing (Meehan et al., 2021). Among the total interviewees, 79% had conventional showers. However, when considering the type of showerheads and shower time, the estimated water use for reported showering was 79.6% higher in peri-urban zones compared

to rural zones, with values of 150 lpcd and 83.3 lpcd, respectively. Additionally, households in peri-urban areas (88%) had a higher proportion of conventional faucets than rural households (68%). However, in the peri-urban areas, 61% of households had water-saving flushing toilets compared to 38% with conventional toilets.

A comparison of household water use, estimated by self-reported behavior, with absolute basic consumption (ABC) [52–100 lpcd], and realistic everyday acceptable limited needs consumption (REAL) [92–175] (Crouch et al., 2021) indicates that the mean water use (262 lpcd; 206 lpcd) exceeded the ABC and REAL references in peri-urban and rural zones, respectively. When referring to the water supplied by the system in liters per capita per day, as presented in Table 3.3 "Estimated Water Supplied and Perceived Water Used," it is noteworthy that only the 8C water system, with an estimated supplied volume of 136 lpcd, fell within the REAL range. This may occur likely due to several factors: water systems 8C had implemented a water use efficiency plan, installed a water flow meter, and assigned two plumbers to oversee the operation and maintenance of the water infrastructure. Installing a water flow meter and retaining a plumber for operation and maintenance (O&M) exemplifies system-level measures. These actions directly impact the volume of water supplied by the system by helping to control leakages and spills. Installing a water flow meter provides better control over the volume of water distributed by the system to users. Consequently, instances of overuse and waste can be minimized. In contrast, systems 1R and 7C systems, which are similar to 8C in terms of the number of users, lacked a water use efficiency plan. Additionally, 1R had only one plumber, and 7C did not have a water flow meter (see footnote 1).

In addition, the estimated, self-reported water use was found to be between 116 and 204% higher than in the rural areas of Bangladesh (83.2 lpcd) (Al-Amin et al., 2011), India (117 lpcd) (Singh & Turkiya, 2013), Nigeria (95.8 lpcd) (Chukwuma, 2017), urban Australia (146 lpcd) (Beal et al., 2013), and Syria (130 lpcd) (Mourad et al., 2011). Conversely, in Malaysia (226 lpcd) (Hasan et al., 2021), Mexico (192 lpcd) (Ojeda de la Cruz et al., 2017) and various areas in Valle del Cauca in Colombia (160, 200, 204 lpcd respectively) (García & Brown, 2009; Restrepo Tarquino, 2010; SSPD, 2022), the self-reported range was between 12 and 58%. In urban Brazil, end water use values were 117 lpcd, 145 lpcd, 221 lpcd, and 226 lpcd, representing different income levels from low to high (Sant'Ana & Mazzega, 2018).

Figure 3.6. presents the ANOVA results assessing whether the mean estimates of perceived water use per capita were similar across the eight distinct WSSs at 5% significance level (Patil, 2021). It can be observed that all the rural systems exhibited similar mean estimates, but these were significantly lower than one or more peri-urban systems. Furthermore, there are significant differences among peri-urban systems.

Figure 3.7. illustrates the correlations between SEC factors and perceived water use. In the Figure, dark blue boxes represent a strong positive correlation, while dark red boxes indicate a strong negative correlation. Crosses displayed on the correlation coefficients signify non-significant

correlations at 5% significance level, with the Holm adjustment method (Friendly, 2012; Soetewey, 2020). It can be observed that end water usage per capita decreased as the number of individuals in a household increased, i.e., as more people dwell in a house. Additionally, perceived water use increases with education level, which was assumed as a proxy for household income. This relationship may be explained by the fact that individuals with high income levels typically have greater access to additional appliances and devices, as well as an increased number of toilets and showerheads per household. Additionally, in some cases, high-income households may have amenities such as swimming pools and extensive gardens (Baker, 2014). Whereas water use tends to decrease as the average age of household members increases. The variable "income" was removed from the analysis because approximately half of the participants did not respond to it.

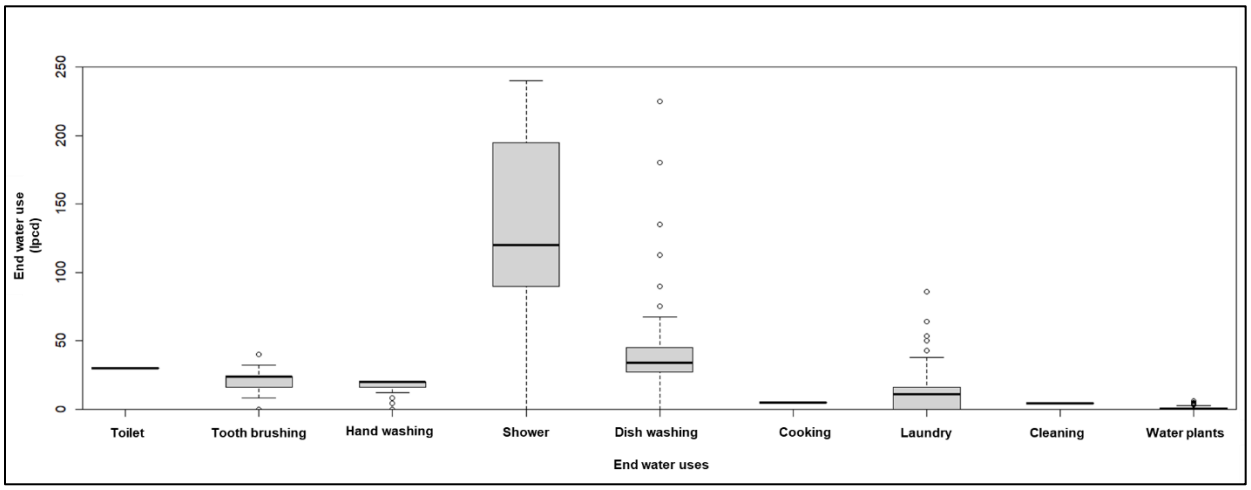


Figure 3.5. Box plot illustrates perceived domestic indoor water use.

Further examination of socio-economic factors in each zone revealed similarities in household sizes within each zone. Additionally, it was observed that individuals with low levels of education tend to reside in rural areas. For instance, in the peri-urban zones, 8.4 and 1.2% of people have earned bachelor's and postgraduate degrees, respectively, compared to 2.5 and 0%, in the rural zones.

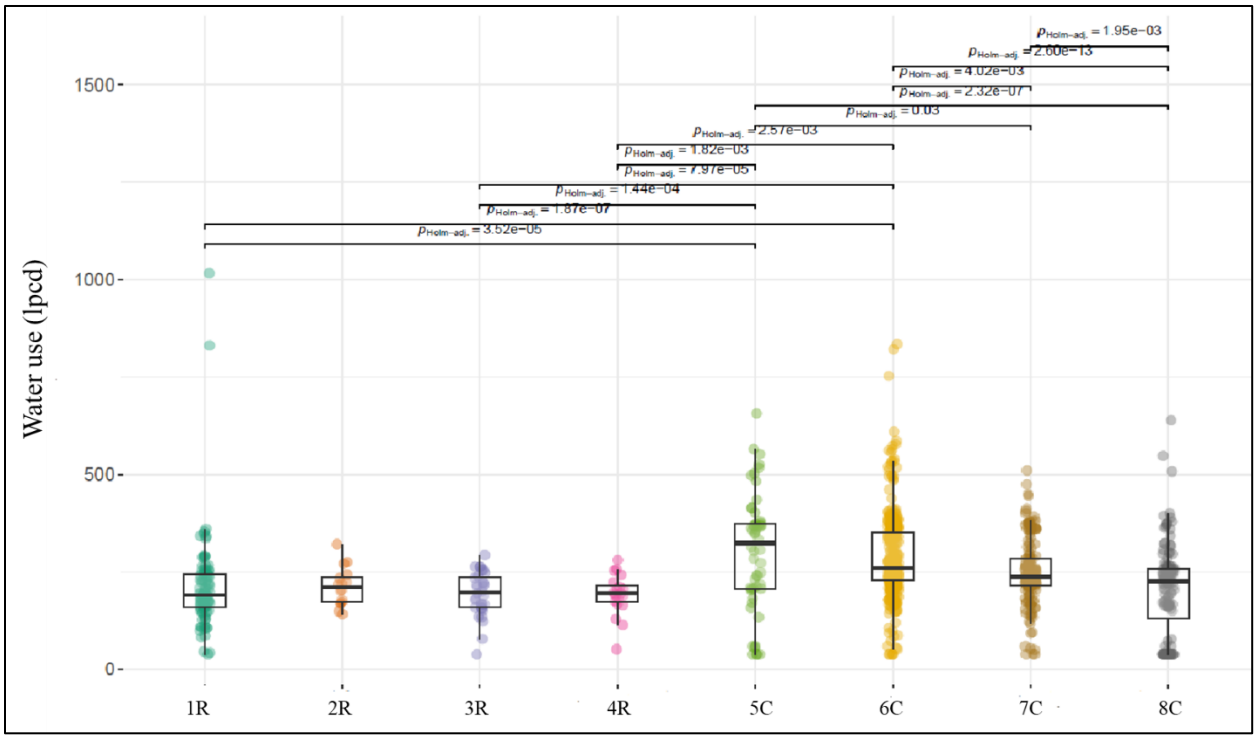


Figure 3.6. ANOVA by WSSs. On average, he perceived water use in rural (R) systems significantly differs from peri-urban (C) systems. Significant differences exist within peri-urban systems. The horizontal bars in the graph indicate pairs of WSSs with significantly different means, with corresponding values shown.

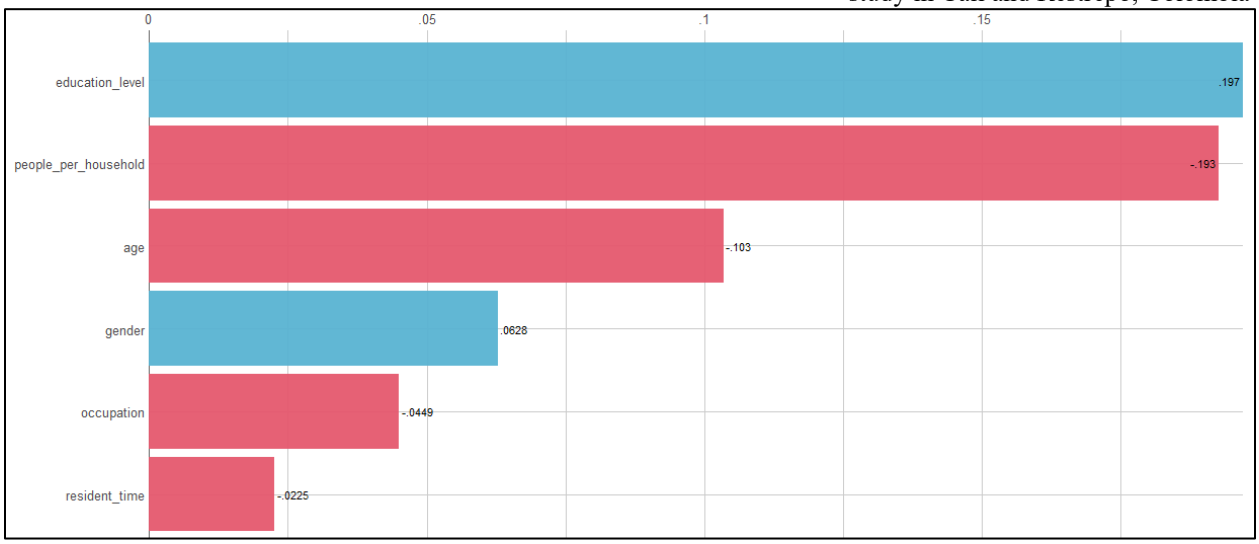


Figure 3.7. Correlogram and ranking of correlation test for socio-economic factors and water use at the household level.

Additionally, t the peri-urban zones had, on average, younger individuals compared to the rural zones.

The SEC factors mentioned were used as independent variables, along with zone type as a binary variable (i.e., whether a system is rural or peri-urban), to study whether these factors explain the variance in perceived water use within peri-urban and rural supply systems. Appendix A1 shows that the number of people per household, education level and zone are significant. A higher number of people per household was associated with lower perceived water use, while water use was perceived to increase with higher education levels, residence in peri – urban areas. This trend may be attributed to the fact that higher education often correlates with higher income levels (Baker, 2014).

SEC factors accounted for only 10% of the variance, a result consistent with previous studies (Abu-Bakar et al., 2021; Cominola et al., 2023; Fielding et al., 2012; Jorgensen et al., 2009; Piedra-Muñoz et al., 2018; Russell & Knoeri, 2020). These studies have highlighted the importance of education level, age, and income as crucial variables in understanding water use or water conservation. Usually, there is a relationship between educational level and water use, which can be either positive or negative.

Our results indicate a positive relationship, suggesting that water use increases with higher education levels. This finding aligns with that of previous studies. This suggests that individuals with higher levels of education tend to use more water. However, they also have more financial resources, which enable them to invest in water saving devices. However, they still used more water because they had more appliances and devices. By including additional factor groups, such as technical and behavioral factors, the amount of explained variance might increase.

3.3.2 Water supplied at the system level

In this context, water supply on a system level refers to the water supplied from storage tanks through the distribution network to households (see Figure 3.1). This estimation was based on the water balance method described in Section 2, resulting in a range of percentages of supplied water and losses (Table 3.3. (Karamountzos, 2022). However, due to missing data for Q_intake (intake flows) for several systems, information on system water losses from intake to water treatment tanks was only available for 1R, 3R, 4R, 6C1, 6C2 and 8C. Interestingly, the losses due to leakage were found to be similar for both peri-urban and rural WSSs. A comparison between perceived end water use *per capita* (lpcd) ("perception of water used") and water supplied *per capita* (lpcd)(W) reveals a huge difference (Table 3.3). This disparity highlights the fate of water distributed from storage tanks to households and underscores the potential for water losses between the distribution point and households.

Table 3.3. Estimated water supplied and perceived water used.

Zone	WSSs	Water supply		Total water losses	Perception of water used	Perception/W	Number of employees
		Qtotal	W	(%)			
		(m^3/day)	(lpcd)		(lpcd)	(−)	
Rural	1_R	949	250	47–55	212.75	0.85	26
	2_R	471	2066	-	211.82	0.10	4
	3_R	449	2159	42–47	193.62	0.09	5
	4_R	97	1151	70–89	191.34	0.17	3
Peri-urban	5_C	304	594	–	301.65	0.51	8
	6_C1	983	269	56–59	285.33	1.06	55
	6_C2	1085		6_C2			
	7_C	955	300	–	202.55	0.83	5
	8_C	296	136	49–62	249.65	1.49	6

Table 3.3. also shows the ratio of perceived end water use at the household level and water supplied from the storage tank to households via the distribution of WSSs. Values greater than one indicate that the perceived water use exceeds the estimated water supplied by the system. From the perspective of water use perception, this suggests that users overestimate their water use. In relation to the water supply system, values over one might indicate that water suppliers underestimate demand or that water is supplied intermittently. A value less than one may imply that users underestimate their water use. Previous studies have shown that most people tend to underestimate their water use for all conventional appliances and fixtures (Attari, 2014; Haeffner et al., 2023). This discrepancy may arise if the water supplier overestimates demand or if there are potential water losses in the distribution network, which indicate inefficient water supply, e.g., due

to losses or use for non-domestic purposes (García & Brown, 2009). Both scenarios are indicative of less-than-optimal governance of water systems.

Non-Revenue Water (NRW) comprises physical losses and commercial losses (Lambert & Hirner, 2000). The average national NRW rate is approximately 40% (SSPD, 2020). An estimation of NRW in urban supply systems worldwide suggests that in Global South countries, 60% of these losses are physical, while 40% are commercial (Kingdom et al., 2006). Water losses are only available for 6_C and 8_C because data for Q_intake are availability. Our results indicate that the estimated physical losses range from 42 to 89%, suggesting that the upper limit of this range is higher than the global average for physical losses. However, despite this, the ratio of perceived water use to water supplied through the network for these two systems is around 1. A value close to one suggests efficient use of water for domestic purposes; however, a limitation of this finding is that outdoor usage was not included in the surveys.

Most rural systems exhibit very low ratios of perceived water use to the water supplied. This discrepancy suggests that water may be lost during conveyance or used for non-domestic purposes. Studies have shown that households in rural areas often use domestic water for non-domestic activities, such as cattle and coffee processing, which can account for up to twice the amount of water needed for domestic purposes.

Organizational issues also arise in rural systems. Rural systems typically have limited staffing, as shown in Table 3.3. Staffing mainly comprises people who participate in the community. Staffing and NRW fall within the category of indicators used to assess the quality and provision of rural drinking water supply services (Molinos Senante et al., 2019). The engagement of communities in decision making processes, technical determinations to decrease water use, and their understanding of water use indicators, such as NRW, are crucial for implementing measures to reduce water usage (Flórez et al., 2019).

An exception is system 1R, which distributes water to a larger area for a larger population across different sectors of the water supply system. The water users' association in this system comprises several people on the board, although the majority serve voluntarily. While the plumber is primarily responsible for day-to-day operations and maintenance, the community comes together to address major damage or conflicts over water. In the event of conflicts, complaints are reported to the local or regional government. These unique attributes of system 1_R distinguish it from other rural systems, which likely contribute to its better governance of the water system.

In contrast to rural systems, peri-urban systems typically supply water that meets the demand of the households (as indicated by perceived use). These systems, often larger and closer to urban centres, experience minimal or no non-domestic use. Some of these systems have WUEP in place, indicating greater emphasis on efficient water use compared to rural areas. The served population in peri-urban areas tends to be more educated and more specialized in their occupations (unlike

mostly farmers in rural areas). Although this demographic was associated with higher perceived water use per capita on average, peri-urban systems are more professionally managed, resulting in better overall system management.

In system 5_C, we can observe an exception with a low ratio between perceived water use and water supplied through the network, approximately 0.5. Unlike other peri-urban water systems, the community and area served by 5_C is smaller, although the population density is comparable to that of 1R. Water in this system was mainly used for domestic purposes, but there were also commercial activities. Similar to 1R, operation and maintenance activities were managed by a single person, the plumber. However, the size of the WSSs in 5C is smaller than that of 1R, and the community does not provide the same level of support as in 1R. These differences may explain why the ratio value in 5_C is smaller than in 1R.

The availability of better-quality employment opportunities in peri-urban areas, coupled with their proximity to urban areas, enables a better capacity for professional management of water supply systems. In peri-urban zones, these systems often function more akin to a company, with sufficient financial resources and minimal reliance on subsidies for operations and maintenance (O&M). Consequently, revenue from water bills contributes to covering O&M costs. Conversely, in rural areas, water systems are not self-financed and typically rely on public or private assistance, subsidies, or community support for their O&M.

The infrastructure of utilities' water supply systems is heavily influenced by the socio-economic context, especially in low and middle-income countries, where the infrastructure is often old and deteriorating. In this study, the average age of the infrastructure in water supply systems exceeds 10 years, with only three systems having a recent renewal. Moreover, aspects such as poor maintenance, inadequate operation, low water prices, population growth, and limited skills in water administration further contribute to performance issues.

Regarding indoor infrastructure, the presence or absence of water reservoirs in households may have influenced users' perceptions. We did not inquire about this type of infrastructure in the questionnaire. However, during interviews with water managers, it was mentioned that some users have storage tanks to store water during the two-to-three-day gaps in supply, as the water distribution is not continuous. These tanks are transparent, allowing users to monitor the water levels at any time while using water. This practice likely fosters greater awareness of water consumption among users.

3.4. Discussion

In this study, we identified that household size, education level and age are the critical socioeconomic (SEC) factors that influence water use at the household level. With a higher education level, people use more water. In peri-urban areas, people use more water per capita because they have more appliances. While peri-urban users were perceived to use more water, associated with younger and more educated households, these factors may also explain why systems were better managed by suppliers in the peri-urban zone.

The eight systems considered in this study shared similarities, such as being established over the last four decades, having transitioned from hand water collection to piped systems, belonging to the same department of Colombia, and being affiliated with similar water associations. However, the water infrastructure, water treatment and water management. were different.

Contextual factors, such as distance from urban areas represented by zone and characteristics of water supply systems (Table 3.2.), including the number of water users and the level of organization within the community, are related with water use at system level. Water services serve most peri-urban areas more effectively than rural areas. The rural systems had very low ratios of perceived water use to water supplied, indicating that either water is lost in conveyance, or water is used for non-domestic purposes. An overestimation of lpcd at the household and system levels may result from a difference between the value of household size provided by respondents and that provided by the water suppliers.

Our study showed that water supply was higher in rural areas when compared to peri-urban, despite the fact that the perceived end water use was higher in peri-urban areas (Table 3.3.). This apparent contradiction can be explained by the distance from the capital cities. Peri-urban water supply systems serve a large population compared to rural systems, and are generally better organized, operating as drinking water supply companies even though these are Water User Associations (WUA). Our workshops, interviews and results revealed that most WUA members in isolated rural areas were part-time volunteers, and in general, these are low in number. Additionally, given that this region had a low prevalence of technical and professional education, water managers in rural areas lacked the time, money, and water literacy necessary to support full-time water management.

Most of these studies have emphasized the role of SEC factors on (in)efficiency of the end water use and water supply systems, with little consideration of the distances of water supply systems from urban areas that limit income opportunities, technical outreach and their effect on water use at the system level as perceived by the water users. Our results indicate differences in SEC and water usage between peri-urban and rural systems. When referring to the SEC, we aim to emphasize that the contextual factors such as household size, education level and age, are relevant to assessing water usage at the household level. This focus is important because decision makers often highlight the need to consider the diversity of socioeconomic conditions. Indeed, numerous studies have demonstrated a correlation between higher income levels and increased water use.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Dr. Cath Cotton, Policy Advisor Academic Integrity/TUDelft. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SP: Conceptualization, Formal analysis, Supervision, Writing – review & editing. MH: Conceptualization, Writing – review & editing. JR: Conceptualization, Supervision, Writing – review & editing. LR: Conceptualization, Formal analysis, Supervision, Writing – review & editing.

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Conflict of interest

The 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. The author(s) declared that they were editorial board members of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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Chapter 4

4. Curtailing water use and adopting water saving devices: rebound effect in domestic water use in Colombia

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This chapter is based on: Callejas M., D., C, Pande, S., Rodríguez, J., P., Rietveld, L. (Under Review). Curtailing water use and adopting water saving devices: rebound effect in domestic water use in Colombia. Advances in hydrological science in Latin America. Special issue of the Hydrological Sciences Journal.

Abstract

Water demand exceeds the available supply in several regions worldwide. Non-priced measures to reduce domestic water use involve implementing water-saving devices without considering water use behaviour. Previous studies have shown a mismatch between water use efficiency and curtailment behaviours; after the initial implementation of water-saving devices, water use decreases for a short period before increasing again, a phenomenon known as the "rebound effect". Household water use was examined using contextual factors and the Risk, Attitudes, Norms, Abilities, Self-regulation and trust approach in rural and peri-urban water supply systems in Colombia. The maximum water-saving potential (SP) was higher when the education level was high. Attitudes, abilities, and social norms were associated with SP. Attainment of high education, attitudes, and abilities were positively associated with showering duration (SD). The misalignment between SP and SD highlights the potential risk of the rebound effect.

Keywords: household use, water use behaviour, efficient use of water, curtailments, RANASt rebound effect.

4.1. Introduction

Population, welfare, and service level growth in rural and peri-urban zones increase domestic water demand, putting high pressure on water-supply systems. Long dry periods caused by climate change and increased water use by agriculture and industry have simultaneously led to the depletion of surface and groundwater sources, affecting the supply of drinking water and other domestic water (Bonilla-Granados et al., 2022; Singha et al., 2022; Fischer & Sanderson, 2022). Therefore, several water demand management (WDM) policies have been devised to mitigate the consequent water stress (Abu-Bakar et al., 2021; Acosta et al., 2019; Adank et al., 2021; Andreas et al., 2021; Cominola et al., 2023; Khair et al., 2019; Marinoski et al., 2014; Mazzoni et al., 2023; Requejo-Castro et al., 2017; Singh & Turkiya, 2013).

WDM policies usually comprise both priced and non-priced measures to alleviate the depletion of water sources and to reduce the water demand. For domestic water use, non–priced measures include the implementation of in-house technologies such as saving devices (Abu-Bakar et al., 2021; Lee et al., 2011; Mayer et al., 1999). However, the installation of water-saving devices does not always guarantee a reduction in water usage.

Numerous studies in the agricultural sector have even shown that, after the implementation of low-flow devices, the use of water increased again after a short period of decrease. This phenomenon is called the "*rebound effect*" (Beal et al., 2014; Freire-González, 2019; Wheeler et al., 2020; Xu et al., 2021). Similar rebound effects have also been observed for domestic water use; however,

rebound effect for domestic water use has been studied mainly under extreme climate conditions, such as post-drought and post-flood contexts (Abu-Bakar et al., 2021; Beat et al., 2014; Campbell et al., 2004; Fielding et al., 2012; Gonzales et al., 2017). It frequently appears that when savings are compromised by a change in water use, for example by increasing the shower time when saving devices are installed, the volume of used water returns to its previous level or, in the worst case, becomes even larger (Abu-Bakar et al., 2021, Campbell et al., 2004; Russell & Knoeri, 2020). A review study of 114 residential end-use studies has confirmed that the installation of low-flow showerheads may increase the frequency and/or length of each shower. The increase in end water use can be linked to an increase in the promotion of efficient saving devices (Abu-Bakar et al., 2021; Mazzoni et al., 2023; Campbell et al. (2004).

People's water-saving routines, such as washing just full loads of laundry in a machine, taking shorter showers, and turning off the tap while brushing their teeth, are examples of curtailment behaviour (Addo et al., 2018; Attari, 2014; Russell & Fielding, 2010). Such behaviours in conjunction with the installation of water saving devices are key for achieving a long-term reduction in water use, while overemphasis on installing water saving devices without taking curtailment measures into consideration will only partially address this problem.

Various studies have identified the factors that influence household water usage (see Table 4.1.). The factors affecting the installation of water-saving devices and curtailment behaviours are typically studied separately, including only a limited assessment of water use behaviours and the factors that influence each case. Such assessments are crucial to identify whether a rebound effect might occur, to provide insights into the factors that drive water use behaviours, and to develop programs that promote the simultaneous adoption of both water saving and curtailment behaviours.

This study aims to identify the contextual and psychological factors associated with household water use in rural and peri-urban water supply systems (WSSs) of the Valle del Cauca province of Colombia, using the RANAS (Risk, Attitudes, Norms, Abilities, and Self-regulation) approach (Contzen & Mosler, 2015; Mosler, 2012). Specifically, we used the RANAS approach to systematically examine the factors that influence the adoption of saving devices and curtailment behaviour (Mosler, 2012).

4.1.1 Theoretical framework: Behaviour and water Use

To understand household water use, theories used in environmental psychology, such as the theory of planned behaviour (TPB), the new environmental paradigm (NEP), and the norm activation model (NAM), have been employed to identify variables of water use and conservation behaviours (Russell & Fielding, 2010; Steg & de Groot, 2018). TPB establishes that behaviour results from the intention to engage in a specific behaviour (Steg & de Groot, 2018); NEP emphasises beliefs

about humanity's ability to upset the balance of nature (Russell & Fielding, 2010); and NAM focuses on personal norms that precede environmental actions (Steg & de Groot, 2018). Hence, several conceptual models in previous research, including the integrated social and economic household water consumption model (Jorgensen et al., 2009) and the conceptual model of the variables of water-use behaviour (Russell & Knoeri, 2020). As a result of the implementation of their model, Russell and Knoeri (2020) found that water conservation habits were the most significant predictors of water conservation intentions and self-reported water bills. Therefore, a number of studies have identified contextual and psychological factors to assess current behaviour and behaviour change.

However, few studies have incorporated into their respective models the role of users' trust in institutions and their influence on environmental behaviour, although it has been observed that there is a relationship between trust in institutions and water conservation by water users (Caspers, 2020; Graymore et al., 2010; Graymore & Wallis, 2010; Jorgensen et al., 2009). Contzen et al. (2023) also highlight that trust in relevant actors of technology is a potential determinant for extending RANAS and assessing trust in water authorities. We adapted RANAS to include the trust factor as an additional psychological factor, here called RANASt. The conceptual framework of the current study is based on the conceptual model of the efficient use of water proposed by Callejas Moncaleano et al. (2021).

For the present study, we selected an approach that aggregates most of the psychological factors that have been linked to water use and conservation (Table 4.1.), being RANAS, referring to Risk, Attitudes, Norms, Abilities, and Self-regulation (Mosler, & Contzen, 2016). Different from existing approaches used to study water use behaviour, the RANAS approach methodically measures behavioural factors and evaluates their influence on behaviour. The conceptual behaviour model is grounded in robust psychological research and theory, including "The theory of planned behaviour (TPB)" (Mosler, 2012).

Unlike existing approaches to studying water use behaviour, RANAS has been applied in various studies on hygiene and sanitation behaviours, indicating its replicability and versatility in examining diverse behaviours. Therefore, the RANAS approach could be applied to future studies and adapted to different contexts.

The rebound effect refers to the phenomenon where the use of a resource rises following an improvement in efficiency. In literature, the term rebound effect usually refers to energy efficiency. In 1866, Jevons introduced the rebound effectand noticed that, while more efficient steam engines decreased coal usage, they also led to lower coal prices, which ultimately spurred higher demand for coal. In the context of economy, other researchers have also discussed the positive impact of energy efficiency on energy conservation (Song et al., 2018). According to traditional literature on the rebound effect related to energy efficiency, it can be categorised into

three types: direct, indirect, and economy-wide. Direct rebound occurs when there is an increase in demand for a service that has become more efficient. Indirect rebound refers to shifts in the demand for other goods and services that are funded by the monetary savings gained from the cost reductions achieved through more efficient systems in a specific service. Economy-wide rebound involves changes in prices, supply, and demand throughout the entire economic system (Freire-González, 2019).

Studies on the energy rebound effect, both theoretical and empirical, have progressed swiftly and yielded significant findings in the energy field. The development of the rebound effect then has resulted in application in other fields and sectors, such as water use. Studying the potential rebound effect is essential in water management demand because it impacts the efficacy of regulations and strategies aimed at improving water use efficiency. In the water use field, various studies confirm the existence of the rebound effect in the agriculture sector. Improvements in technology, such as the installation of water-saving devices, do not necessarily translate into water savings and reductions in water use. Recently, various researchers have identified the usefulness of the rebound effect as a concept in the better management of water resources (Song et al., 2018). In water supply systems and at the household level, there has been limited research investigating the behaviour associated with the installation of water-saving devices and their relationship with curtailment behaviour.

Table 4.1. Summary of studies having identified factors of water use, saving and conservation behaviour

Citation	Factors	Subcategories
(Cominola et al., 2023)	Observable	Socio – demographics Property characteristics
	Latent	Awareness, perception, habits
	External (water supply scale)	Hydrological parameters; water price
(Mazzoni et al., 2023)	Characteristics of residential end water use	Socio-demographic (family size and income)
		End-use frequency of use
		Having a saving appliances and fixtures
(Abu-Bakar et al., 2021)	Exogenous factors (Environmental) – (water supply scale)	Geographical variables (water sources, precipitation, evaporation, climate change, weather condition, altitude) Seasonal variables (precipitation, evaporation, climate change, weather condition, tourism) Population variables (migration, tourism)
	Endogenous /Contextual	Socio-economic (affluence; education; occupation; occupancy) Socio-demographic (occupancy; age, gender, tenure)

		Household characteristics (Metering; Number of fixtures and appliances; efficiency of appliances and fixtures (af); household size; outdoor usage)
	Behavioural	Environmental concerns, knowledge, awareness, water conservation behaviour (duration and frequency use), implicit attitudes, social norms
(Addo et al., 2018)	Water conservation behaviour (COM) dimensions	Capability (physical and psychological) Opportunity (physical and social) Motivation
(Russell & Fielding, 2010)	Water conservation behaviour	Attitudinal; Beliefs; Habits and routines Personal capabilities Contextual factors
(Carrus, et al., 2010)	Water conservation behaviour	Exogenous variables: socio-economic status (SES); country affluence; perceived water accessibility. Concern regarding water usage; indifference about water problems; self-reported water conservation
(Graymore & Wallis, 2010)	Water-use behaviour in rural and urban areas	Context: water sources; trust; perception of abundance Situational and personal factors
(Jorgensen et al, 2009)	Water saving behaviours	Direct drivers: climate variability, incentives/disincentives, regulations, property characteristics, household characteristics, person characteristics. In-direct drivers: person characteristics, institutional trust, interpersonal trust, fairness, environmental values and conservation attitudes, socio-economic factors

4.2.Methodology

At the household level, water is used for domestic purposes, such as drinking, washing, showering, toilet flushing, and watering indoor plants, as well as for outdoor uses, such as garden watering and car washing. The main daily per capita domestic water usage is showering, toilet flushing, and washing, and various studies have revealed that showering uses most of this water (Makki et al., 2013; Mazzoni et al., 2023; Vieira et al., 2017). Makki et al. (2013) also state that a shower is sometimes considered leisure use (Marinoski et al., 2014; Makki et al, 2013). The adoption of low-flow shower heads has therefore been identified as an effective water conservation measure (Russell and Fielding, 2010).

In our study, we use two variables to measure indoor household water use: the maximum water-saving potential (*SP*) of the entire household and the showering duration (*SD*). *SP* is associated

with efficiency behaviour; it involves adopting water-efficient appliances and devices, such as water-efficient washing machines and dual-flush toilets. *SD*, on the other hand, is linked to curtailment behaviour, depending on people´s awareness, willpower and comprehension of water use to stick to their water-saving decisions (Addo et al., 2018; Koop et al., 2019; Russell and Fielding, 2010; Savari et al., 2022). *SP* pertains to efficiency, which includes considerations such as the installation of washing machines, dual-flush toilets, and water-saving showerheads. *SD* is associated with curtailment such as taking shorter showers. Both variables were obtained from household self-reports. In our questionnaire, we included a question to ask the users which type of water saving device they use at home, such as saving or conventional. We also asked participants to fill in their shower time and frequency.

4.2.1 Households' surveys

We employed a survey methodology for collecting self-reported data on water use perceptions, attitudes, beliefs and water saving potential and showering duration behaviours (Gifford, 2016; Haslam & McGarty, 2019). We conducted cross-sectional surveys in rural villages and peri-urban zones in the Valle del Cauca Department located in the western part of Colombia between November 2020 and December 2021 (Figure 4.1). During this period, the weather was dry and wet owing to the bimodal rainfall regime in Colombia. When the study was conducted, so-called COVID measures were active.

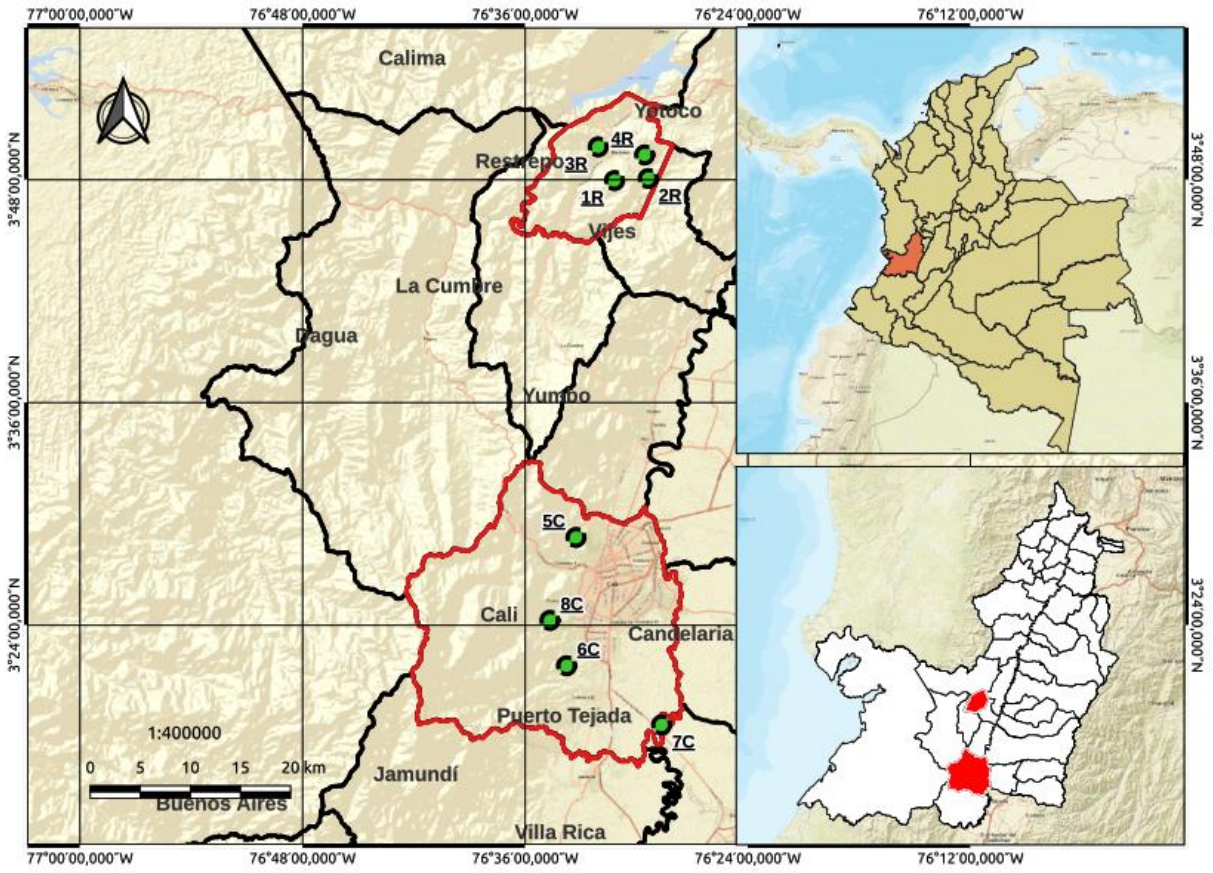


Figure 4.1. Location of water supply systems.

Eight WSSs were selected with the assistance of the water users' associations Fecoser and Aquacol: four in the rural zone of Restrepo, and four in the peri-urban zone of Cali. The random route procedure was used to select households (Haslam & McGarty, 2019); for those WSSs that were divided into sectors, all sectors were considered. Only adults (>18 years old) were considered for the interviews, with one adult per household. The sample size was estimated using "G*power" software that calculates sample size and statistical power, while in this study we set a small size effect ($f^2 = 0.07$), a significance level (α) of 0.05, and a statistical power of 0.9 (Erdfelder et al., 2009). After eliminating the missing and mistaken data, the final sample size comprised 926 households.

A team of seven local people was involved in conducting the surveys. Before data collection, workshops were conducted to train the interview team under the supervision of a leader and a remote field supervisor. Interviews with households lasted approximately 45-90 minutes and were conducted in Spanish. The questionnaire was written in English, translated into Spanish, and a few questions and local words had to be adjusted after it was tested. Data were obtained from face-to-face interviews on a smartphone and collected using Qualtrics software (2020). Before conducting the survey, the participants received information about the study, and informed consent was

collected. This study was approved by the Human Research Ethics Committee of Delft University of Technology.

Questionnaire

This study applied a questionnaire survey method to assess and measure the variables of the RANASt. The questionnaire was designed based on a literature review and further adapted based on the input needed for the RANAS approach as well as previous studies (Ajzen, 1991; Attari, 2014; Caspers, 2020; Dean et al., 2016; Jorgensen et al., 2014; Khair et al., 2019; Meis-Harris et al., 2021; Mosler, & Contzen, 2016; Russell & Fielding, 2010).

The RANAS approach is based on theories and models applied in the field of health. Risk factors include the health belief model, protection motivation theory, and the health action process approach which focus on understanding and awareness of health risks. The TPB describes attitudes, normative and ability factors, and the self-regulation factor, postulated by Prochaska and DiClemente in 1983, which refers to the continuance and maintenance of the behaviour. The theories aggregated in the RANAS approach have proven useful in explaining and changing various health behaviours (Mosler, 2012). The factors associated with the RANAS approach are structured into five groups that permit the identification, measurement, and integration of factors to examine the behaviour at an individual level in a specific group of people (Contzen & Mosler, 2012; Lilje & Mosler, 2018). This approach has mainly been applied to study behavioural changes related to Water, Sanitation and Hygiene, such as water treatment practices, handwashing, and reuse (Contzen et al., 2023; Daniel et al., 2019; Rahaman et al., 2022).

Questions in the questionnaire included contextual and psychological factors. Numeric and categorical variables were included, and for the categorical variables, a rating Likert scale format (1-5) was used to collect the responses, which has commonly been used to measure psychological factors (Edmondson, 2005; Tutz, 2021). Trust, a new factor, complemented the questionnaire. The codebook, including all variables, is presented in Appendix A2.

The group of contextual factors included social-economic variables such as gender, income, education level, occupation, and location, and a technical variable, being “type of device or appliance it is saving or conventional”. Education level was used as an indicator of the level of income, considering that education has been linked to socioeconomic status and that it has been identified as a measure of a person's knowledge-related assets, or "human capital" (Baker, 2014; Manstead, 2018). Furthermore, only 50% of the participants responded about their income level, whereas 80% of the participants responded about their education level. In addition, information on technical variables was collected, such as the type of shower head used and whether it was a conventional or low-flow device. Each factor of the RANASt included one or more subfactors, and each subfactor corresponded to a variable or item, as described in Table 4.2.

Table 4.2. Psychological factors from the RANASt approach.

Factor	Subfactors	Description	No of items
Risk	Vulnerability	Subjective perception of the individual risk of use water inefficiently	6
	Severity	Subjective perception of the consequences of use water inefficiently	6
	Knowledge	knowledge about water inefficiency causes, consequences and prevention	7
Attitudes	Instrumental beliefs	Perceptions of advantages and disadvantages of engaging in a behaviour, these are benefits and cost of the efficient use of water, respectively.	10
Norms	Social	Subjective perception of the individual about if others use water efficiently or not	10
	Injunctive norms	Subjective perception of the individual about if others agree or not with the efficient use of water	2
	Personal norms	Personal obligation to use water efficiently	1
Ability	How to do knowledge	A person's knowledge of how to execute the behaviour	7
	Confidence in continuation	A person's perceived ability to continue to practice a behaviour and self-confidence in being able to deal with barriers might occur	3
	Confidence in recovering	Personal perception about the ability to overcome the obstacles, to continue the behaviour after disruptions	1

Self-regulation	Action planning	The extent of a person's endeavour to plan a behaviour's execution, including how, when, and where.	3
Trust	Water authority	Reliability, good reputation and trustworthy in the authority	3

Adapted from Contzen & Mosler (2015) and Mosler (2012)

Various methods exist for assessing the water use of household appliances and fixtures, ranging from direct measurement to estimation techniques (Abu-Bakar et al., 2021; Tamason et al., 2016). These include water metering, the use of data loggers and sensors, and the analysis of water bills or census data (Abu-Bakar et al., 2021; Attari, 2014; Polania, J., & Vanessa, A., et al.,2019). Another method involves surveying water users about their usage patterns and the types of appliances and fixtures in their homes, which has been used to estimate unmetered domestic water use (Tamason et al., 2016). In this method, participants share their perceptions of water usage (Abu-Bakar et al., 2021; Attari, 2014; Chacón et al., 2012; Mourad et al., 2011). Since not all WSSs are equipped with water meters, and only a few have household-level meters, questionnaires were used along with water flow standards for conventional and efficient fixtures and appliances from existing literature to estimate the "perceived" water usage.

For SP, the values of water fluxes for conventional and saving devices and appliances were gathered from previous studies (Kunitsuka, 2015; García & Brown, 2009; Restrepo, 2010) (Appendix A2), and the type of device (td) is based on the self-report answers in the survey. We asked the respondents to ascertain whether they had installed water-efficient devices and appliances in their homes, including low-flow showerheads, dual-flush toilets, flow restrictors in taps and faucets, and water-efficient washing machines. To estimate SP, we used td, weighing the contribution of the volume of water used by the device (Wd), and the overall saving volume of the entire household (Ve). td was assumed to be a binary variable, where 0 is a conventional device and 1 is a saving device. Wd represents the weighting factor for the contribution of devices and appliances to the usage breakdown in each household, and Ve is the average water use (in liters), using the saving device or appliance, for one use of the shower, toilet flushing, tap, washing machine or hose, respectively. Equations 1, 2, and 3 were proposed based on previous studies, which used similar variables and equations to evaluate the potential of water saving at the household level based on the flow rates and devices (Mourad et. al, 2011; Vieira et. al, 2017).

SD was calculated based on self-reported responses using two variables, the length of each shower in minutes (*t*) and the frequency of showering per day (*f*), as shown in Equation 4 of Table 4.3. Our analysis accounted for both water saving and non-water-saving showers. Additionally, we

assumed continuous supply and sufficient pressure in the distribution system during shower usage.

Table 4.3. Estimation of dependent variables (DV).

	Equation	Variables
Equation 1	$W_d = \sum_{i=1}^{n} V_i \text{ x } td$	*td*: type of device or appliance; 0: conventional; 1: saving V_i: difference between the volume of conventional and saving device or appliance per each individual water use, I (shower, toilet flushing, tap, washing machine, hose). W_d: weighing to contribution of the volume of water used by the device
Equation 2	$V_e = \sum_{i=1}^{n} V_i$	V_i: difference between the flow of conventional and saving device or appliance per each individual water use, i V_e: overall saving volume
Equation 3 the maximum water saving potential	$SP = \frac{W_d}{V_e}$	W_d: weighing to contribution of the volume of water used by the device V_e: overall saving volume.
Equation 4 Shower duration	$SD = f \text{ x } t$	*f*: daily frequency of using shower (times per day) *t*: the length of each shower (min) *SD*: shower duration (min/day)

4.2.2 Multiple Regression

The multiple regression method is widely used to analyse social and behavioural data variables to identify predictors that support a theory or to explain the amount of variance in the dependent variable (*DV*), explained by a group of independent variables (Bolin, 2022; Lewis, 2007). Multiple regression is defined by Equation 5, where *Y* is the dependent variable (*IV*), X_1,X_2, X_n are the independent variables, β_0 is a coefficient which represent the intercept, β_1, β_2, β_n are coefficients, which represent the slope with respect to X_1, X_2, X_n (Doane & Seward, 2013; Soetewey, 2023).

Equation 5 $Y= \beta0+\beta1X1+ \beta2X2+\ldots+\beta nXn+\in Y= \beta0+\beta1X1+ \beta2X2+\ldots+\beta nXn+\in$

Multiple regression analysis was used to examine the contextual and psychological factors associated with water use. We differentiated between water efficiency and curtailment using two multiple regressions for *SD* and *SP*, respectively. In these two cases, the *IVs* comprising contextual

and psychological factors, were the same. We used to the so-called "forced entry" method, entering all *IVs* simultaneously into the equation, and the total contribution of all variables as a set is given (Lester et al, 2014). Statistical analyses were performed using RStudio software (R Core Team, 2021).

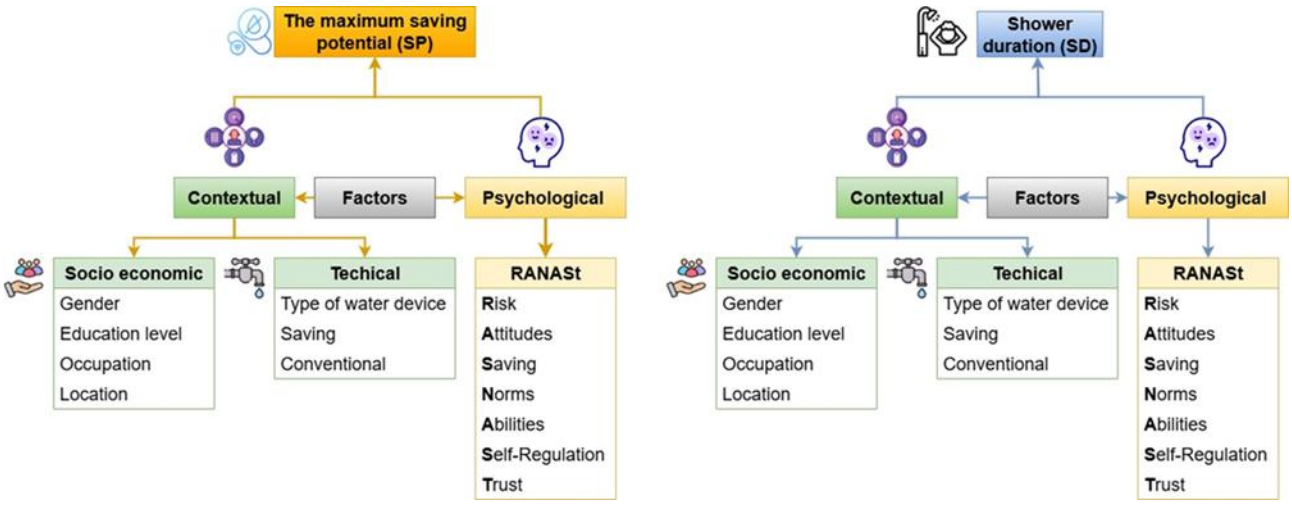


Figure 4.2. Force entry method applied to determine whether *DV* explains a significant amount of variance in *IV*.

4.3. Results

4.3.1. Multiple regression analysis for saving potential and shower duration

Table 4.3 presents the significant contextual and psychological factors that influence the two dependent variables: *SD* (in min/day) and *SP*. To measure these variables, the questions listed in this table were used. We considered as significant variables those with estimates that have p <0.001.

Significant factors associated with maximum water saving potential

The contextual and psychological factors collectively accounted for 39% (R2adj = 0.39) of the variance in the estimated SP, and the model was significant overall (p-value < 0.001) (Table 4.4.), with significant variables referring to the descriptions and columns marked with two and three stars. Overall, education level, location, risk, attitudes about costs-benefits, social norms, abilities, and trust all explain maximum saving potential. Social norms refer to what people observe or perceive as what others do and what behaviours are deemed acceptable (Seimetz, et al., 2016; Warner et al., 2022).

Within the group of contextual factors, a highly significant relationship was found between *SP* and education (b = 0.14, *p-value* < 0.001, item 3) and location (b = -1.26, *p-value* < 0.001, item 5. *SP* is higher when participants' education level is high, and it is lower in a peri-urban zone than in a rural zone. Among the psychological factors, participants' beliefs about the efficient use of water helps to reduce additional costs (attitude, cost-benefit) (b = -0.298, *p-value* < 0.001, item 14), social norms related to households' perceptions of water usage by industry (b = 0.251, *p-value* < 0.001, item 20), and knowledge about recycling water from washing machines (ability, action-knowledge) (b = -0.143, *p-value* < 0.001, item 22) were the significant explanatory variables associated with *SP*. In the context of Item 20, social norms refer to households' perceptions of the likelihood that a specific sector uses water efficiently. The results indicate that households' perception of the industrial sector's efficient use of water is associated with *SP*.

Table 4.4. Multiple Linear Regression output for variables associated with water use (SP and SD)

Factors	ítem	Maximum water saving potential (*SP*)					
			B	Std. Error	t value	Pr(>|t|)	
		(Intercept)	1,088	0,168	6,481	0	***
		Variable code					
Contextual							
Socio-economic	1	Q9_sec4	0,086	0,039	2,238	0,026	*
	3	Q15_sec11	0,149	0,036	4,159	0	***
	5	zone1	-1,267	0,196	-6,46	0	***
Psychological							
Risk	9	Q57_3_beh_r_r3	0,095	0,039	2,408	0,016	*
	10	Q59_beh_r_r4	-0,095	0,034	-2,81	0,005	**
Attitudes	12	Q61_beh_r_at2	-0,106	0,048	-2,203	0,028	*
	14	Q64_4_beh_r_at4	-0,298	0,066	-4,506	0	***
	15	Q65_beh_r_at5	0,116	0,038	3,059	0,002	**
Norms	16	Q68_4_beh_r_n2	-0,162	0,049	-3,304	0,001	**
	17	Q69_2_beh_r_n3	0,194	0,061	3,181	0,002	**
	18	Q69_3_beh_r_n3	-0,196	0,067	-2,93	0,004	**
	19	Q69_4_beh_r_n3	-0,144	0,058	-2,477	0,014	*
	20	Q69_5_beh_r_n3	0,251	0,061	4,123	0	***
Abilities	22	Q73_6_beh_r_ab1	-0,143	0,036	-4,013	0	***
Trust	23	Q78_2_beh_r_tr1	0,142	0,072	1,969	0,049	*
	25	Q78_3_beh_r_tr1	-0,204	0,063	-3,238	0,001	**
Multiple R^2		0,45					
R^2adj		0,39					
F-statistic		7,365					
p-value		< 2,2e-16					
Significant codes		B	Unstandardized coefficients				

Factors	item	Shower duration (*SD*)					
			B	Std. Error	t value	Pr(>|t|)	
		(Intercept)	-0,371	0,191	-1,939	0,053	,
		Variable code					
Contextual							
	2	Q10_sec51	0,21	0,083	2,544	0,011	*
	3	Q15_sec11	0,177	0,041	4,353	0	***
	4	Q16_sec12	-0,103	0,041	-2,488	0,013	*
Psychological							
Risk	6	Q55_1_beh_r_r1	0,147	0,059	2,491	0,013	*
	7	Q55_2_beh_r_r1	-0,15	0,062	-2,406	0,016	*
	8	Q55_5_beh_r_r1	-0,204	0,084	-2,442	0,015	*
Attitudes	11	Q60_beh_r_at1	0,118	0,042	2,8	0,005	**

	13	Q62_beh_r_at3	-0,187	0,052	-3,636	0	***
Abilities	21	Q73_5_beh_r_ab1	-0,141	0,043	-3,305	0,001	**
Self-regulation	23	Q76_2_beh_r_sr2	-0,146	0,059	-2,468	0,014	*
Multiple R^2		0,29					
R^2adj		0,21					
F-statistic		3,665					
p-value		< 2,2e-16					
Significant codes		B	Unstandardized coefficients				

From the interviews, it was found that the perception of how well-being is affected because of shortages (risk, perception of severity) (b = -0.095, p-value = 0.005, item 10), beliefs about considering water use efficiency as a priority (attitude) (b = 0.116, p-value = 0.002, item 15), social norms linked to perception of water used by elderly people (b = -0.162, p-value = 0.001, item 16), agriculture (b = 0.194, p-value = 0.002, item 17), livestock use (b = -0.196, p-value = 0.004, item 18), and authority trustworthiness (b = -0.204, p-value = 0.001, item 25) showed a moderate relationship with SP. The effect of the perceived negative effect on well-being due to shortages (item 10) to SP (Table 4.4.) may be explained by the circumstances in which people who not only perceived but also experienced shortages or droughts might know the causes and preventive actions, which raises their knowledge and awareness of water conservation and prompts the introduction of water-saving devices (Piedra-Muñoz et al., 2018).

The results did not reveal a significant effect on the prediction of SP about variables, such as risk, cost-benefit attitudes, social norms, and trust. The perception that inefficient water use is connected to price increases (risk, perception of severity)(b = 0.095, p-value = 0.016, item 9), belief about how much time is needed to use water efficiently (attitude, cost-benefit) (b= -0.10, p-value = 0.028, item 12), and social norms based on water users' perception of other people's water use specifically, respondents' perceptions of tourists' water use (b = -0.14, p-value = 0.014, item 19), and the authority reputation of WSS (trust, authority reputation) (b = 0.14, p-value = 0.049, item 24).

In our study, four social norms were associated with *SP*. Specifically, social norms linked to perception of water used by elderly people may be explained by the age and type of economic activity in which they are engaged. According to earlier research, attitudes toward water usage can differ across generational lines. Older individuals tend to use less water than their younger counterparts (Piedra-Muñoz et al., 2018). Our results show that people who are, on average, between 24 and 55 years old strongly believe that elderly people use water efficiently. This result aligns with previous studies that found that elderly people use water more effectively than younger adults (Abu-Bakar et al., 2021; Piedra-Muñoz et al., 2018). Previous studies that offered an explanation of this relationship that elderly people are aware

of water conservation because they, for example, faced droughts, thereby considering the influence of previous experience and knowledge.

Interviews with water managers revealed that livestock, agriculture, tourism, and industry are the key economic activities in the rural zone. Water usage across economic sectors often triggers conflicts among users. However, individuals employed in industries that implement water conservation strategies may strongly believe in the sector's efficient water usage. These divergent perspectives among user groups can influence domestic users' perceptions and beliefs regarding water use by economic sectors, potentially impacting the adoption of saving devices. This observation is in line with Warner et al. (2022)'s suggestion that people who follow social norms tend to adapt to a specific situation.

Finally, our findings show that SP decreased for respondents who trusted the water supply service, while Graymore et al. (2010) found that in addition to individuals' attitudes towards others' water usage, trust in water authorities can positively influence actions to save water. Our study also revealed a correlation between trust in water authorities, adherence to social norms, and engagement in water-saving behaviour. However, in our case, a negative relationship was found between trust and SP. Although these results differ from those reported by Graymore et al. (2010), our findings reveal a relationship between trust in water-supply services and water usage by users.

Based on our results, when users perceive that efficient use of water can help to reduce additional costs (attitude factor, item 14, Table 4.4.), paradoxically, their willingness to invest in saving devices decreases. However, individuals who believe that efficient water use is a priority (attitude factor, item 15, Table 4.4.) are likely to have a higher willingness to adopt saving devices. It might imply that better knowledge and awareness of the monetary benefits of water use efficiency and its importance for water conservation may be crucial to improve adoption of saving devices and appliances (McCarroll & Hamann, 2020).

Significant factors associated with shower duration

Together, contextual and psychological factors explain 21% (R2adj = 0.21) of the variance in the *SD*, with the model showing overall significance (p-value < 0.001) as shown in Table 4.4. Significant variables were identified in the descriptions and columns marked with two and three stars, respectively. Education level and users' beliefs about how much money is needed to use water were the best explanatory variables for *SD*.

Within the group of contextual factors, attainment of a high education level was positively associated with shower duration (b = 0.17, p-value < 0.001, item 3), whereas gender and occupation were less significant (b = 0.21, p-value = 0.011, item 2 and b = -0.103, p-value = 0.013, item 4). Individuals with lower and middle levels of education tended to take shorter showers. This result may be attributed to their preference for curtailment behaviour rather

than investing in water-saving devices. The use of such devices involves financial expenditure that could impact a household's wealth. In terms of cost-benefit evaluation, curtailment behaviour in this context represents a less expensive option. This finding is consistent with the results of our study, which indicate that participants with a low or middle level of education often hold the belief that substantial investments are necessary for efficient water use.

Among the psychological factors, participants' belief that a large amount of money is required to use water efficiently (attitude, cost-benefit) (b = -0.187, p-value < 0.001, item 13) was a significant explanatory variable. Beliefs about the physical effort to use water efficiently (attitude, cost-benefit) (b = 0.118, p-value = 0.001, item 11) and the ability to check for water leakages at home (ability, action knowledge) (b = -0.141, p-value = 0.001, item 21) were moderately significant; however, attitude (item 11) was positively associated, and ability (item 21) was negatively associated with *SD*.

The belief that a substantial amount of money is required to use water efficiently (Item 13) reflects a cost-benefit assessment, while the ability to detect water leakages represents knowledge (Item 21). In the RANAS model, the cost-benefit evaluation corresponds to the attitude factor, and knowledge is linked to the action-knowledge factor, as presented in Table 4.2. Specific action knowledge connects to how these users take action to reduce water use instead of adopting low-flow devices. These beliefs regarding the cost-benefit and knowledge of efficient water use are connected to *SD*. In relation to the ability factor, respondents who believed themselves to be capable of detecting water losses (Ability factor, item 21) tended to take shorter showers. This ability is indicative of know-how, technically called water literacy, which encourages users to engage in water curtailment behaviours (Dean et al., 2016).

Our results showed that participants' risk perception related to the knowledge of potential consequences of not using water efficiently such as droughts (risk, knowledge about consequences) (b = 0.14, *p-value* = 0.013, item 6), water use conflicts (b = -0.15, *p-value* = 0.016, item 7), and interruptions in the water supply service (b = -0.204, *p-value* = 0.015, item 8) were weakly associated with *SD*. Similarly, the frequency with which an individual seeks alternatives for efficient water use, which reflects the extent of their effort to reduce water use, is weakly associated with *SD* (self-regulation, action plan) (b = -0.146, *p-value* = 0.014, item 23).

There are some possible explanations for the weak relationship between the variables of item 6,7 and 8 which represent the risk factors and *SD*. First, it appears that the information users have received about inefficient water use and droughts has not resulted in fear-based associations and might therefore be neglected by users, a finding that aligns with that of a previous study (Vining & Ebreo, 2002). Second, it is possible that participants may lack

experience with droughts, water-use conflicts, and interruptions in water supply. Piedra-Muñoz et al. (2018) pointed out that previous experience with drought is a factor that influences individuals' actions to reduce water use.

In relation to interruptions in the water supply service (item 8), our results revealed a negative relationship between participants´ risk perception and *SD*. Respondents who perceived inefficient water use as leading to interruptions in the water supply reported shorter shower durations (item 8, Table 4.4.). This may indicate that awareness of such interruptions, a tangible issue for users, can influence behaviour and prompt actions to reduce water use, such as taking shorter showers.

Self-regulation refers to the extent to which a person plans to reduce water usage, including specific details regarding how, when, and where this action will be implemented. Although self-regulation is weakly connected, we reflect on the fact that this factor requires both skills and knowledge, which previous studies have also identified as drivers of water use. Onyenankeya et al. (2021) emphasized that the lack of skills for adopting conservation practices is a barrier to household water conservation. Additionally, Onyenankeya et al. (2021) highlighted that both knowledge and skills are critical factors in promoting pro-environmental behaviours, including water conservation. Regarding the benefit-cost evaluation, even if the cost of water supply services appears low compared to the expenses required for operation and maintenance, some rural households remain unwilling to pay. This might be because many residents, particularly in rural areas, are either living in poverty or earning just enough to get by and as a result, lack the financial means. Secondly, a lack of knowledge about the necessity and benefits of paying for the water supply service can lead to users' unawareness that paying for water services is important (Onyenankeya et al., 2021). Similarly, the evaluation of benefits-cost of adopting saving devices might be explained by limited knowledge about the use and benefits of water-efficient technologies contributing to the minimal adoption among rural households.

Unlike previous studies that focused solely on the relationships between *SD* and socioeconomic factors (Makki et al., 2013) or *SD* and psychological factors (Tijs et al., 2017), our findings reveal a potential chain of factors for understanding water use. This chain links socio-economic factors represented by SES, psychological factors such as attitudes evaluated through a cost-benefit analysis, and *SD*.

4.4. Discussion

Two outcome variables, *SP* and *SD* (in min/day), served as variables to quantify household water- use behaviour. Adopting saving devices and appliances, *SP*, has been proposed as a water use efficiency measure, and shower duration, *SD* has been proposed as a measure of

curtailment behaviour. Achieving efficiency often requires engagement and revolves around a singular event such as purchasing a water-saving device. Conversely, the act of curtailing water usage relies on individuals' determination, awareness, and understanding of water conservation practices, necessitating consistent adherence to these behaviours over time.

In the context of this study, both efficiency and curtailing behaviours are associated with contextual factors, such as education level and location. Among the psychological factors, our findings indicate that *SP* is connected with risk, attitudes, social norms, abilities, and trust, and *SD* is connected with attitudes, abilities, and self-regulation factors from the RANASt approach. These findings are aligned with those of previous studies; for example, Vazquez et al. (2023) indicate that risk perception is a good predictor of sustainable behaviour.

Specifically, shower time is driven by factors that directly depend on the individual and are termed here as “internal” drivers, such as specific skills about how to save water, and beliefs of high costs when investments are required. The adoption of saving devices, is primarily motivated by “external” factors, which refer to actions performed by others, the motivation, or the factors influencing the final decision. Examples of these factors include “What others do to save water”, “How the water supply service performs”, “How the payments or additional costs can be reduced”, and how reducing water consumption can lower costs when individuals are charged based on the volume of water used (see items 13,14,16-18,20 in Table 4.4.). These examples are intricately linked to social norms, institutional trust, and financial considerations, including cost -benefit analysis, (Carrus et al., 2010; Tijs et al., 2017). It appears that these factors do not directly contribute to water saving.

Overall, the main result that emerged from our data was that the adoption of saving devices and the practice of taking shorter showers were driven by distinct sets of factors (Table 4.4.). We initially expected that the factors leading to the adoption of water-saving devices would be the same as those influencing the behaviour of taking shorter showers. Although both behaviours are related to water conservation, they are driven by different psychological factors. The risk factors (items 7, 8, 10), attitudes (items 13, 14), and abilities (items 21, 22) were different and operated in opposing directions for each case. This implies that individuals who invest in water saving devices do not necessarily take shorter showers. This indicates a misalignment between water use efficiency and curtailment behaviours, suggesting that the adoption of water-saving devices may not necessarily translate into reduced water usage. Additionally, the misalignment between *SP* and *SD* highlighting the potential occurrence of the rebound effect.

Our findings on the rebound effect are in line with a previous study that showed that the increased use of water-saving devices sometimes results in an increase in water use (Steg & Vlek, 2009). Some researchers emphasize that the long-term opposite effect of this action

may be attributed to users' beliefs that they know that they have fulfilled their role in water conservation by simply adopting water-saving devices; for example, when individuals are aware that their showerhead is designed to be low-flow, they might perceive it as a permission to indulge in longer showers (Abu-Bakar et al., 2021; Fielding et al., 2012).

Another surprising finding from our study was that users who believe that the efficient use of water through the installation of low-flow devices can help reduce payments for excessive water use (item 14, Table 4.4.), were less inclined to install saving devices. This may be attributed to the current low water prices compared to the investment required for such devices, lack of benefits, or both. Based on our interviews, the average monthly water cost ranged from 5900 to 32000 COP (€1.42 – €7.69)[1]. Conversely, users who place a high prioritiry on efficient water usage are more inclined to increase their *SP*.

Our approach enables people in the water management field, such as researchers and policymakers, to assess curtailment water use and adopt water-saving devices, which are usually studied separately. Taken together, these findings highlight the importance of implementing these measures simultaneously to reduce water use and prevent the rebound effect. Curtailment behaviour may entail minimal financial expenditures compared to the adoption of saving devices, and water-saving programmes in water supply systems should focus on promoting actions to encourage users with a low or middle income to opt for curtailment behaviours.

4.5. Conclusions

In this paper, we have identified the contextual and psychological factors associated with household water use in rural and peri-urban water supply systems, using the Risk, Attitudes, Norms, Abilities, Self-regulation and Trust (RANASt) approach to understand better which elements influence water use reduction initiatives and the potential occurrence of the rebound effect. We used two dependent variables to measure water use: maximum saving potential (SP), represented by the installation of saving devices, and shower duration (SD).

Both SP and SD, which correspond to efficiency and curtailment, respectively, exhibit associations with education level. Individuals with higher education levels were more inclined to adopt water use efficiency initiatives and technologies, such as installing saving devices. In contrast, those with lower education levels were more likely to engage in curtailment behaviours, such as taking shorter showers.

Taken together, the results suggest that beliefs about the benefits of water use efficiency, social norms about water use efficiency in industry, and the ability to recycle water from washing machines correlate highly with SP. However, social norms about water use by older

people, agriculture, and livestock, as well as trust in water organisations, presented a moderated relationship with the installation of saving practices (related to SP). Attitudes, specifically those referring to the belief that investing in water use efficiency is expensive, are highly correlated with SD. Our results indicate that individuals' risk perceptions about the impact of shortages on well-being and their ability to detect water losses are moderate, particularly in relation to SD. The risk perception factor about the consequences of inefficient water use and self-regulation showed a low correlation with SD.

Social norms play a key role in how people perceive water use, as they affect people´s levels of concern with the issues and their beliefs about what should be done to reduce water use. The outcomes of this study indicate a positive relationship between the installation of saving devices and social norms, specifically people´s perceptions about water use efficiency in industry and agriculture. The existing link between water users and these sectors might explain it.

This study supports and extends the accumulating evidence that knowledge and abilities are positively related to reducing water actions. Knowledge and skills enable people to understand why water use reduction is necessary, what they can do to reduce it, and how they can achieve it. Understanding the importance of water knowledge is crucial for recognising the benefits of installing a water-saving device, including reduced water bill costs and lower water usage. Specifically, abilities such as repairing water losses and recycling water from the washing machines help reduce water use. Therefore, knowledge and abilities on water reduction play a crucial role in water conservation.

In this paper, we have reviewed a number of the social and economic models of end water use at the household level. We found that various studies identified different factors acting on water use behaviour. However, not one study has used the existing RANAS approach, which systematically aggregates socio-psychological factors to study water use behaviour at the household level. The RANAS approach has demonstrated its usefulness in identifying factors that influence Water, Sanitation, and Hygiene (WASH) behaviours. Thus, we proposed using the RANAS model, which integrates several factors that might impact water use. We extended the RANAS model by incorporating trust (RANASt), a concept that has not been fully explored, and may help develop adequate water reduction strategies.

The RANASt model draws linkages between psychological factors and their influence on water use to support actions to reduce water use. This model helps to identify where implementation of technology and curtailment actions may act to reduce water use. An extended model incorporating trust accounts to examine the relationships between users and water managers, focusing on the role of water organisations in reducing water use. Although the present findings are only preliminary, they support the notion that factors from the

RANASt model, specifically, cost-benefit assessment, social norms, abilities, and trust, are involved in individuals´ attitudes and perceptions about water use.

Rebounding water use behaviour has not been studied in communities in rural and peri-urban zones. Understanding the factors influencing the rebound effect on water use can help managers develop targeted strategies to reduce water use. By examining the contextual and psychological factors, we have identified the potential occurrence of the rebound effect. The results of this study indicate that a high level of education correlates positively with the installation of saving devices and taking longer showers. These results evidence the potential occurrence of the water rebound effect. Further research is necessary to investigate how changes in water usage affect rebound trends after the installation of water-saving devices.

Our results underlined that strategies to reduce water use and water conservation should not consider the installation of water-saving devices as the only approach. Strategies to achieve water reduction and saving goals could be strengthened by incorporating curtailment behaviours, such as encouraging people to take shorter showers. The present findings have the potential to be applied to policy decisions from demand management perspective. The overall approach outline in this study can be extended to other peri-urban and urban water supply systems.

Our study reveals that while people perceive water use efficiency as a priority, they do not always practice water conservation themselves. This research supports the idea that a cost-benefit analysis influences the decision to install water-saving devices or take shorter showers. In this context, "cost" includes three dimensions: money, time, and effort. The findings suggest that actions requiring less investment are linked to water-saving behaviours, whereas actions that demand financial investment but involve less effort are linked to the installation of water-saving devices. Additionally, the results indicate that psychological factors play a role in understanding support for water use reductions. These insights also help guide decision-makers in creating more effective interventions to promote water conservation.

Conflict of interest

The 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.

Author contributions

DC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SP: Conceptualization,

Formal analysis, Supervision, Writing – review & editing. JR: Conceptualization, Supervision, Writing review & editing. LR: Conceptualization, Formal analysis, Supervision, Writing – review & editing.

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Chapter 5

5. Applying the values-beliefs-norms theory to identify psychological factors associated with water use efficiency and curtailment behaviours

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This chapter is based on: Callejas M., D., C, Arias, D., Pande, S., Rodríguez, J., P., Rietveld, L. (2025). Applying the Values – Beliefs – Norms Theory to Identify Psychological Factors Associated with Water Use Efficiency and Curtailments Behaviours.

Abstract

In many regions, water demand exceeds water availability. Reduced environmental flows and water levels impact ecology, food security, and other water uses. Therefore, reducing water use needs urgently to be addressed. Although people's water use behaviours directly affect water demand, little attention has been given to how households use water. The present study aimed to understand the contextual and psychological factors that explain the efficient use of water and curtailment behaviour at the household level by applying the values, beliefs, and norms (VBN) theory. A face-to-face survey was conducted with 926 households in rural and peri-urban water supply systems in Colombia to assess the installation of saving devices (SP) and showering duration (SD) as indicators of household water use. The study findings indicate that household water conservation efforts, such as shortening shower times, can be bolstered by emphasizing biospheric values and individual norms concerning sustainable water use.

Keywords: water use, values-beliefs-norms theory, psychological factors.

5.1. Introduction

In many regions across the world, volume of water demand exceeds water availability (Alvarado Espejo et al., 2021; Corral-Verdugo et al., 2008; Gleick et al., 2011; Srinivasan et al., 2012). Population and demand growth, overuse, extreme weather events, and water losses through water supply systems, are the main reasons for the disparities between demand and availability. Moreover, inadequate water conservation habits and leakages at the household level add further pressure on the restricted water supply (Onyenankeya et al., 2021). Unbalanced demand and availability put pressure on natural water and supply systems increasing their vulnerability. Consequently, a reduction in environmental flows and water levels impacts water availability for ecology, food security and other water uses (Russell & Fielding, 2010).

From the total water uses, domestic use averages around 9%. The water use by the domestic sector is lower than the use by agriculture (Millock & Nauges, 2010; UNWater, 2021). Nevertheless, water availability to meet domestic water use is still an issue in low- and middle-income countries (Russell & Knoeri, 2020). In the meantime, the situation is deteriorating, considering that the projected volume of the demand of domestic water is expected to increase by 50 to 250% by 2050 (IPCC, 2022; Wada et al., 2016). Probably leading to conflicts of interest between the domestic, the agriculture and industrial sectors (Florke et al., 2018; Meza & Scott, 2016; Sanderson et al., 2017).

Therefore, reducing water use needs urgently to be addressed (van Valkengoed et al., 2022). Minimising water use is in line with the United Nations Sustainable Development Goal 6.4. This objective seeks to enhance water-use efficiency substantially across all sectors and ensure sustainable freshwater withdrawal and supply by 2030. The aim is to decrease the number of individuals affected by water scarcity, thereby mitigating its impact on populations and alleviating water shortages (UN, 2024).

Management of water use is frequently present in programs proposed by water and environmental authorities who deal with increasing uses and limited water sources to supply a growing population and to mitigate the effects of climate change. At system level, current approaches primarily involve exploring alternative sources for intake and investing in supplementary infrastructure. However, the implementation of these strategies requires both time and financial resources (Jorgensen et al., 2009). Meanwhile, within integral strategic plans to address water supply, reducing water use is also proposed. Minimising water losses in water systems has emerged as a priority, especially, in developing countries facing increasing pressure on water sources, leading to water scarcity. Therefore, measuring and assessing non-revenue Water (NRW) is crucial for enhanced control over water losses, reducing water wastage across water systems (Al-Washali et al., 2019; Chawira et al., 2022; Perera et al., 2018; Zyoud et al., 2016).

At household level, strategies to reduce water use can be classified as structural and non-structural (Roccaro et al., 2011). Structural measures include encouraging the adoption of water saving devices, efficient plumbing fixtures, and installation of flow metering. Non-structural measures include education programs, incentives, and increasing water prices. However, these strategies have only resulted in short-term reductions, and high-water use continues in some regions (Balmford et al., 2021; Fu & Wu, 2014; IPCC, 2023).

Despite people's behaviour having a direct effect on water use, little attention is paid to how water is used by households, and which psychological factors influence water use. However, including psychological factors in existing water strategies is crucial, because numerous environmental challenges stem from human behaviour and can therefore be mitigated through increased engagement and commitment in environmental actions by individuals (Corral-Verdugo et al., 2008; Millock & Nauges, 2010; Steg, 2016).

Studying relationships between current reduction measures and human behaviour, therefore, contributes to bridging the gap between technical and social factors influencing the reduction of water use (Carrus et al., 2010; Russell & Fielding, 2010; Singha et al., 2022; Steg & Vlek, 2009).

An increasing number of studies have been performed to identify behavioural factors of households for water use and water conservation (Abu-Bakar et al., 2021; Addo et al., 2018; Alvarado Espejo et al., 2021; Cominola et al., 2023; Fielding et al., 2012; Hasan et al., 2021; Jorgensen et al., 2009; Koop et al., 2019; Mazzoni et al., 2023; Russell & Fielding, 2010; Russell & Knoeri, 2020; Singha et al., 2022). Additionally, various methodologies, such as a participatory systemic methodology (PAWAME), have been proposed to reduce water consumption in rural areas. Furthermore, efforts have been made to engage stakeholders in water management (Flórez et al., 2019; Whitley et al., 2024).

These existing studies have identified and distinguished between psychological and contextual factors to understand the fundamental mechanisms that influence human behaviour through the lens of behavioural psychology. They have utilised the most applicable theories to identify the drivers of pro-environmental behaviour, including the theory of planned behaviour (TPB), the new environmental paradigm (NEP), the norm activation model (NAM), Values, Beliefs and Norms theory (VBN), and the technology acceptance model (TAM) (Corral-Verdugo et al., 2019; Russell & Fielding, 2010; Steg, L & de Groot, 2016). The TPB posits that behaviour is a consequence of the intention to engage in a specific behaviour (Steg & de Groot, 2018); the NEP emphasises beliefs regarding humanity's capacity to disrupt the equilibrium of nature (Russell & Fielding, 2010); the NAM highlights the role of individual norms that precede environmental actions (Steg & de Groot, 2018); and the TAM aims to identify the key factors that influence individuals' willingness to adopt technological solutions. Especially TPB, NAM, VBN, and the TAM have frequently been used to understand water use behaviour (Koop et al., 2019; Russell & Knoeri, 2020; Savari et al., 2021; Steg et al., 2018; Stern, 2000). However, studies applying the VBN theory have lacked in studies on water use efficiency and curtailment behaviour in water supply systems (Alvarado Espejo et al., 2021).

Although the VBN theory is designed to integrate its three components, most studies to examine water use behaviour have tended to focus on values, beliefs, or norms separately, or have only incorporated one or two of these factors, rather than fully using the VBN theory (Millock & Nauges, 2010; Shahangian et al., 2021; Tijs et al., 2017).

The VBN theory could be a prominent approach for studying water use because it explores intrinsic psychological factors that directly and indirectly influence water use. This approach can be integrated with conventional engineering approaches to study water use. However, there is a need for more research on the role of assigned values, beliefs and norms in driving behaviour, particularly in the context of household use and conservation behaviours.

Curtailment and installation of water saving devices and appliances are two types of conservation measures aimed at reducing water use. Efficiency behaviour involves personal

engagement, financial investments, and technical expertise. One of the measures to use water efficiently is the installation of water saving devices and water-efficient appliances. Curtailment refers to individuals' awareness, willpower, and understanding of water conservation practices to adhere to their decisions. It is crucial to differentiate between these two types of behaviours as they are influenced by distinct socio-economic and psychological factors (Addo et al., 2018; Koop et al., 2019; Russell & Fielding, 2010; Savari et al., 2022). The relationship between values, beliefs and personal norms and these two waters use behaviours at household level is still unknown.

In the field of environmental behaviour, the VBN theory has been a useful framework to explain environmental conduct and behaviour, especially focusing on factors related to ecological worldview, moral responsibility, and predisposition to environmental action (Addo et al., 2018; Lind et al., 2015). Notwithstanding, until today the VBN theory has not yet been used to explain water use at household level. Therefore, the aim of the presented study it to understand the contextual and psychological factors that explain the efficient use of water and curtailment behaviours at household level applying the VBN theory.

5.1.1. Values, Beliefs, and Norms Theory

Several studies have provided insight in the applicability of the VBN theory in predicting various types of sustainable behaviour. Stern (2000) proposed that the VBN framework can apply to environmental behaviour, such as values guiding principles that motivate beliefs and norms (Corral-Verdugo et al., 2019). The VBN theory appeared to be successful in explaining low-cost environmental behaviour and good intentions, particularly in situations when constraints on behaviour are not strong, such as willingness to change behaviour and policy acceptability. The VBN framework also posits values and deeply held guiding principles about right and wrong as it relates to water use behaviour within the context of socio-hydrology (Roobavannan et al., 2018).

The VBN theory draws from three key theories: value theory, NEP, and NAM (Lind et al., 2015; Stern, 2000). The NEP is commonly used as a tool to evaluate environmental beliefs and has also been used to investigate water conservation (Corral-Verdugo et al., 2003, 2008) . Schwartz (as cited in Singha et al., 2022), emphasized in 1977 that awareness is included as a key variable within the norm activation process. The premise of this theory is a causal order of the variables, starting from relatively stable environmental values, leading to beliefs about human-environment links, which, in turn, affect norms (Steg et al., 2005). Values must be distinguished from related concepts such as beliefs and norms (Dietz e al., 2005).

Various scholars have argued that environmental problems are rooted in human values (De Groot & Steg, 2008, Dunlap, Grieneeks, & Rokeach, 1983). Thereby pro-environmental

behaviour has explicitly been linked to environmental values in a number of studies, which connects to beliefs and personal norms in the VBN theory (Stern, 2000). In this framework, values are defined as desired, and general goals or ideas in life. Values guide decisions, attitudes and behaviours of individuals or other social entities across different situations, contexts and cultures (Balundė & Perlaviciute, 2023; De Groot & Steg, 2008).

Values represent people's concerns about environmental threats and their negative effects on the natural environment, themselves, or the impact on other people. These three situations refer to biospheric, egoistic, and altruistic values, respectively, which are the environmental values encompassed by the VBN theory and could be the most relevant values to assess water use (Price & Leviston, 2014; Steg, 2023; Wang et al., 2021; Yildirim & Semiz, 2019). Biospheric values are associated with an awareness of nature and the importance of environmental protection and conservation. Individuals with biospheric values may prioritize nature conservation for its intrinsic worth, irrespective of its direct benefits to humans. Biospheric values reflect people's intrinsic motivation to engage in pro-environmental actions because they perceive it as the morally right thing to do, rather than being driven by external incentives (De Groot & Steg, 2008; Lindenberg & Steg, 2007; Steg et al., 2014). This intrinsic motivation leads individuals to feel a sense of fulfilment and sense of meaningfulness. The stronger an individuals' biospheric values, the greater their concern for the environment and their motivation to engage in specific pro-environmental behaviours (Balundė & Perlaviciute, 2023; Steg et al., 2014; Venhoeven et al., 2020). Altruistic values involve a concern for the welfare of others. Individuals holding altruistic values may engage in nature conservation because of its benefits to fellow humans. Different from biospheric and altruistic, egoistic values pertain to individualistic decision-making, where individuals tend to evaluate choices based on cost-benefit analysis, focusing on their own benefit (Klöckner, 2013; Steg, 2016). The assessment of values can elucidate diverse perspectives on how individuals utilise, manage, and interact with environmental resources.

Beliefs indicate a person's worldview through ideas about what is true or not. For instance, beliefs about adverse consequences of environmental threats and perceptions of the personal ability to mitigate these threats. According to NEP, environmental beliefs can serve as indirect predictors of environmental behaviours (Corral-Verdugo et al., 2003). Awareness of consequences reflects the extent to which individuals knowing environmental issues stemming from high water use and overuse.

Norms are common understandings about how people have to behave in a certain context (Dietz et al., 2005). Personal norms, similar to biospheric values, represent intrinsic motivation and denote a sense of personal and moral obligation to participate in environmental behaviour (Gomes et al., 2022a; Lind et al., 2015; Price & Leviston, 2014; Roobavannan et al., 2018; Russell & Fielding, 2010; Russell & Knoeri, 2020; Stern, 2000). These norms are strengthened when individuals have a deeper understanding of the

environmental impact resulting from their actions, feel accountable for this impact, and have confidence in their ability to alleviate them through pro-environmental behaviour (Gomes et al., 2022a; van Valkengoed et al., 2022).

The VBN theory assumes that behaviour is directly determined by personal norms, which have to be activated through ascription of responsibility (AR) and awareness of consequences (AC). Within the VBN, AC is associated with a broad ecological worldview, as measured by the NEP. This ecological worldview encompasses accepting general beliefs such as the idea that human activity disrupts the natural equilibrium, resources are limited, and that humans should not rule over nature (Klöckner, 2013). The ecological worldview and AC are influenced by environmental values. AC pertains to the belief that environmental conditions can either enhance or pose a threat to other people, other species, or the biosphere. This awareness precedes the ascription of responsibility, which is characterised as an individual's feeling of obligation to minimise adverse environmental outcomes (Razzaghi Borkhani et al., 2023)

The causal chain within the VBN theory asserts that individual's underlying values influence their general beliefs about the environment (e.g. water is an essential resource for humans' life), and specific beliefs about the consequences of environmental change on the things they value (e.g. family security). These beliefs, in turn, affect an individual's perceptions of their ability to mitigate the threat to the things they value. Norms are activated by these beliefs, and these norms are also activated because people wish to be morally responsible which in turn prompts behaviour (Ives & Kendal, 2014; Klöckner, 2013; Price & Leviston, 2014).

5.2.Methodology

5.2.1. Procedures and study area

We collected self-reported data on water use activities, through a cross-sectional survey, with a focus on domestic use in the period from April to December 2021. A team of seven local individuals conducted the surveys. Workshops were conducted to train the interview team, supervised by a leader and a remote field supervisor. Interviews with households lasted about 45-90 minutes and were conducted in Spanish. The questionnaire underwent a process of translation from English to Spanish followed by reverse translation to ensure accuracy, and a few questions and local words had to be adjusted after it was tested. Data were collected via face-to-face interviews using Qualtrics software (2020) on smartphones. Prior to the survey, participants were provided with information about the study, including ethical considerations, and were asked to indicate their willingness to participate. Informed consent was then obtained. This study received ethical approval from the Human Research Ethics Committee of Delft University of Technology. The survey was pretested in April to May 2021 and then administered in person.

The study area comprised peri-urban zones and rural villages in the Valle del Cauca Department, situated in the western part of Colombia. The peri–urban area survey encompassed residents of suburban areas of Cali, while the rural area survey encompassed residents from villages within the Restrepo municipality, approximately 100 km north of Cali (see Figure 5.1.). During this period, the weather exhibited both dry and wet conditions, characteristic of Colombia's bimodal rainfall regime. When the study was conducted, COVID-19 measures were in place.

Peri-urban Cali and rural Restrepo exhibit heterogeneity in terms of geography, including altitude (989 – 1612 meters above sea level (masl)) and temperature. In addition, people with low, middle and high income and various education levels dwell in the study area. Cali, with a population of approximately 2.2 million people, is one of Colombia's fastest growing cities (DANE, 2018). The city's population growth is partly attributed to violence, which has displaced individuals from remote areas and other provinces, leading to increased migration to peri-urban zones (Urrea & Canelo, 2017; Vergara et al., 2020). The growing population and diversification of water uses have placed significant pressure on water sources, such as the Melendez and Lili rivers, which are prioritized for water security (Blanco-Moreno et al., 2022). The critical water use index, which measures water scarcity and use intensity, provides evidence of these challenges (IDEAM, 2022). According to DANE (2018), Restrepo has 16,847 inhabitants. In its rural areas, agriculture, such as coffee (27%), plantain (23%), pineapple (14%), and sugar cane (12%), as well as other crops, and cattle, dominate land use, leading to water conflicts (CIAT & CVC, 2014).

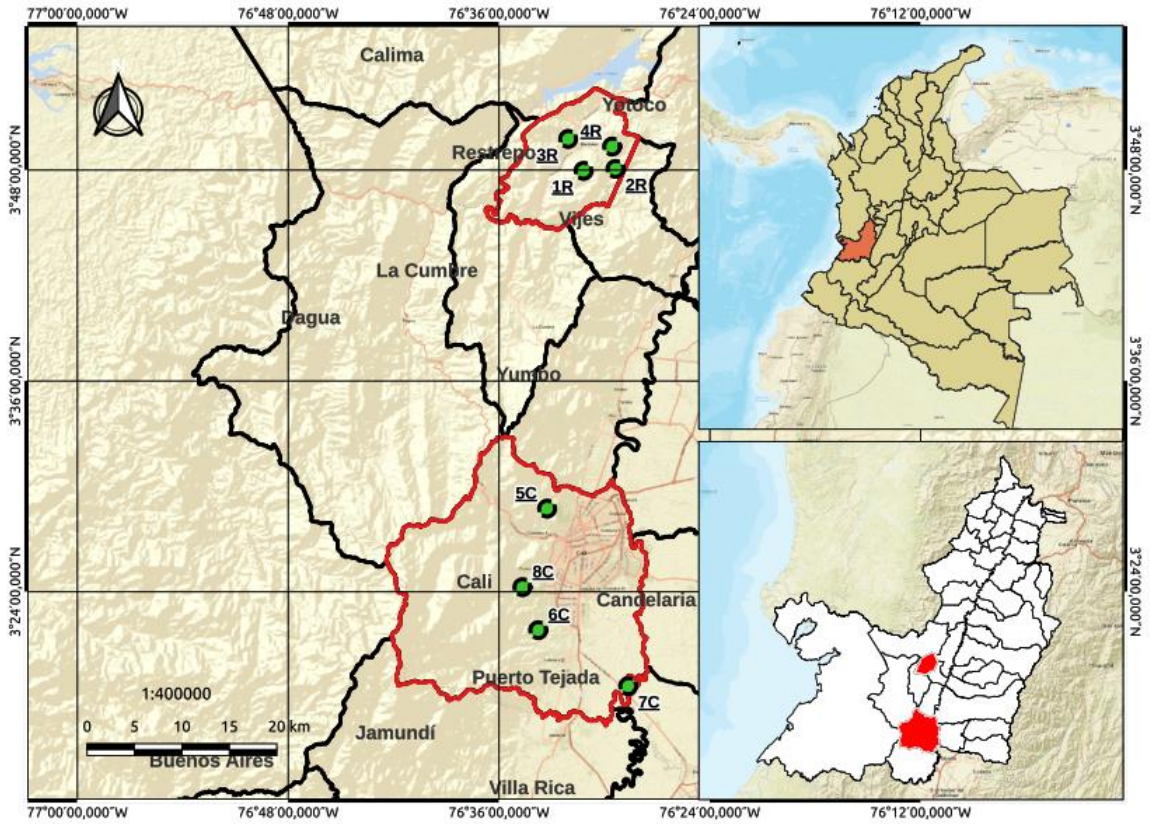


Figure 5.1. Location of water supply systems**.**

5.2.2. Households' surveys

In the study only households were targeted. Participants were limited to individuals aged 18 years or older, with one adult per household chosen for interviews. With the assistance of the community water and sanitation management organizations Fecoser and Aquacol, eight water supply systems (WSSs) were selected, with four located in the peri-urban area of Cali and the remaining in the rural area of Restrepo. The random route method was used to select households, and in cases where WSSs were divided into sectors, all sectors were considered for inclusion (Haslam & McGarty, 2019). The sample size was determined using 'Gpower' software, which calculates sample size and statistical power. For this study, a small effect size ($f2 = 0.07$), a significance level (α) of 0.05, and a statistical power of 0.9 were set (Erdfelder et al., 2009). Initially, the dataset included 923 entries. After removing missing and erroneous data, the final sample size comprised 793 households.

The sample consisted of 66% women and 34% men, with an age between 41-50 years old. Approximately half of the participants had completed secondary education. Of the

respondents, 48% were employed, while 38% were engaged in household duties. On average, there were 3.5 inhabitants per household. The majority of households were situated at altitudes ranging from 990 to 1,173 masl.

5.2.3. Dataset and questionnaire

The dataset contained socio-economic (SEC) variables and psychological variables that assess participants' perceptions regarding the environmental values, beliefs and norms, and practices concerning water use (Millock & Nauges, 2010).

Water use was assessed by examining both structural and non-structural behaviour aimed at reducing water use within households. Two determinants were employed to gauge household water use: maximum water saving potential (*SP*) and showering duration (*SD*). *SP* pertains to installation of water saving devices and appliances, including considerations such as the installation of washing machines, dual-flush toilets, and water-saving showerheads. On the other hand, *SD* is associated with curtailment, such as taking shorter showers. Showering duration was provided in minutes, and frequency of showering was recorded in times per day (Addo et al., 2018; Koop et al., 2019; Russell & Fielding, 2010; Savari et al., 2022).

The survey predominantly employed a Likert-scale response format ranging from 1 to 5, encompassing both numeric and categorical variables. The survey was comprised of two main sections. The first section addressed contextual factors, wherein participants responded to SEC questions. These questions covered aspects such as household size, age, education level, gender, occupation, altitude, and zone. Age, education level, and altitude were rated on a scale of 1 to 5, while gender and zone were represented as binary variables (0-1), (See Supplementary material). Only 50% of the participants provided information about their income level, whereas 80% disclosed their education level. We utilized education level as an indicator of the income level, operating under the assumption that higher levels of education are associated with higher incomes (Baker, 2014). The second section included VBN factors. Each factor consisted of one or more items, with each item corresponding to a specific variable such as biospheric, altruistic or egoistic value. Participants responded on a scale from 1 to 5, ranging from "never" to "always," "very unimportant" to "very important," "very unconcerned" to "very concerned," and "strongly disagree" to "strongly agree" in relation to statements about water use and water conservation concerns. These factors are listed in the supplementary material. Beliefs included AC and AR, and norms exclusively addressed personal norms.

The questionnaire, as presented in the supplementary material, was designed based on a literature review and further adapted for water use at household level. Values were assessed by adapting and utilizing previous questionnaires (Bouman et al., 2018; Russell & Fielding, 2010; Russell & Knoeri, 2020; Steg et al., 2005). Biospheric values were measured with three

items, altruistic values with five items, and egoistic values with two items. Participants were presented with the list of values and asked to rate level of agreement, concern, or importance. General environmental beliefs were measured using eight items from the revised NEP scale (Klöckner, 2013). Participants were asked to rate their agreement with each on a 5-point scale ranging from 'strongly disagree' (1) to 'strongly agree' (5). AR was measured using five items, while AC was measured using three items. Personal norms were measured using four items, a sense of morality (2 items), feelings of guilt (1 item), and the desire to be a better person (1 item), with responses ranging from 'strongly disagree' (1) to 'strongly agree' (5). Participants were asked to indicate their level of agreement with each statement on a 5-point scale, varying from 'totally disagree' (1) to 'totally agree' (5) (See Supplementary Material).

5.2.4. Estimation of dependent variables SP and SD

For *SP*, the water flux values for conventional and water-saving devices and appliances were obtained from existing literature (Kunitsuka, 2015; García & Brown, 2009; Restrepo, 2010). Additionally, the type of device (td) was gathered through self-reported responses from the survey. Participants were surveyed to determine whether they had installed various water-saving devices and appliances in their homes, such as low-flow showerheads, dual-flush toilets, flow restrictors in taps and faucets, and water-efficient washing machines.

To estimate *SP* the contribution of the volume of water used by the device td was considered in relation to the overall saving volume of the entire household, see Equations 1-3. Equations 1, 2, and 3 were proposed based on previous studies that employed similar variables and equations to assess the potential for water savings at the household level, considering factors such as flow rates and device usage (Mourad et al, 2011; Vieira et al, 2017). Our analysis accounted for both water saving and non-water-saving showers. Furthermore, we assumed continuous water supply and sufficient pressure in the distribution system during showering activities.

Equations for estimation of dependent variables (DV)

	Equation	Variables
Equation 1	$SP = \frac{W_d}{V_e}$	W_d: weighing to contribution of the volume of water used by the device V_e: overall saving volume.
Equation 2	$W_d = \sum_{i=1}^{n} V_i \text{ x } td$	td: type of device or appliance; 0: conventional; 1: saving

		V_i: difference between the volume of conventional and saving device or appliance per each individual water use, I (shower, toilet flushing, tap, washing machine, hose). W_d: weighing to contribution of the volume of water used by the device
Equation 3	$V_e = \sum_{i=1}^{n} V_i$	V_i: difference between the flow of conventional and saving device or appliance per each individual water use, i V_e: overall saving volume
Equation 4	$SD = f \text{ x } t$	f: daily frequency of using shower (times per day) t: the length of each shower (min) SD: shower duration (min/day)

5.2.5. Statistical analysis

The collected survey responses were statistically analysed using a multiple regression model with the forced entry method to examine the relationship between water use and the variables proposed by the VBN theory. Equation 5 defines multiple regression, wherein Y represents the dependent variable, X_1, X_2, X_n denote the independent variables and Ɛ represents unexplained portion of Y. The coefficient β_0 represents the intercept, while β_1, β_2, β_n represent the effects corresponding to X_1, X_2, and X_n, respectively (Doane & Seward, 2013; Soetewey, 2023).

Equation 5 $$Y= \beta_0+\beta_1X_1+ \beta_2 X_2+\cdots+\beta_nX_n+ Ɛ$$

In our study, two dependent variables were considered: *SP* and *SD*, while the group of independent variables comprised contextual and psychological factors. Contextual factors included household size, age, education level, gender, occupation, altitude and zone variables, psychological included values, beliefs and norms variables. The regression model aimed to determine which independent variables account for a significant variance in dependent variables (Bolin, 2023; Lewis, 2007). The forced entry method was employed, wherein all independent variables are entered simultaneously into the equation, and the overall contribution of all variables as a set is determined (Lester et al, 2014). Statistical significance was analysed by testing linearity, independence, normality, and homoscedasticity using Python (version 3.10.12). One way to detect multicollinearity is to check for high correlations between independent variables. A correlation value greater than 0.8 is considered to indicate a high correlation, while values below this threshold correspond to a low correlation. Therefore, since no factor reached a correlation value greater than 0.8, we can conclude that the factors in this study are not strongly correlated (Arias, D., 2024). In the results and discussion section, only the p-values ($p < 0.05$) were displayed.

5.3. Results and Discussion

In Table 5.1. two groups of factors–contextual and psychological– are presented with their respective categories: socioeconomic and environmental values, beliefs, and norms. The "regression 1" column shows the results for *SP*, and "regression 2" column shows the results of *SD*.

5.3.1. Maximum water saving potential (SP)

he multiple regression model's variables explained 31% of the variance in *SP* (R^2_{adj} = 0.31). Attainment of a higher level of education and residing in rural areas were positively

associated with *SP* (β = 0.028, *p-value<0.001* and β = -0.249, *p-value<0.001*), respectively. Associations were also found between psychological factors and *SP*. Altruistic (positive) and egoistic (negative) values, as well as personal norms (positive and negative), all significantly contributed to explain *SP*. Respondents who indicated that reducing water use is important because it contributes to the well-being of other communities reported a higher *SP* (Altruistic, item 4, β = 0.062). In contrast to those who strongly agreed that water use should be unlimited reported a lower *SP* (Egoistic, item 9, β = -0.014). Households that strongly agreed that they feel guilty when they do not reduce water use also had a lower *SP* (Norms, item 21, β = -0.021). However, those who strongly agreed that they feel like a better person if they save water, reported a higher *SP* (Norms, item 24, β = 0.021).

5.3.2. Showering duration (SD)

In the multiple regression model for *SD*, the independent variables accounted for 16% of variance (R^2_{adj} =0.16). Like *SP*, education level and zone of residence were linked to *SD*. However, unlike *SP*, individuals residing in peri-urban areas and those with higher education levels tended to spend more minutes per shower *SD* (β = 3.53, *p-value<0.001*, β = 1.57, *p-value<0.001*). Households that infrequently reduce water use during household tasks (Biospheric, item 1, β = -1.09, *p-value<0.001*) and do not agree that saving water is a moral obligation (Norms, item 19, β = -0.76, *p-value<0.001*) were observed to take longer showers.

The most remarkable result arising from our data is that contextual and psychological factors collectively contribute to explain *SP* and *SD*. However, the combined effect of all environmental values, including biospheric, altruistic, and egoistic values, along with beliefs, was found to be non-significant (p-value > 0.05). Contrary to expectations, the causal chain among VBN factors was not identified. However, it was observed that personal norms are indeed rooted in values, as proposed by VBN theory (Steg, 2016). Despite non-significance of beliefs, the current results suggest that the VBN theory effectively explains *SP* and *SD* when considering environmental values and personal norms.

Further our findings indicate that education level, zone, and personal norms contribute significantly to explaining both *SP* and *SD*. (See Table 5.1).

Table 5.1. Summary of socio-economic and psychological factors of VBN associated with SP and SD.

		Maximum saving potential (SP)	Shower duration (SD)
Contextual		Education level Zone	Education level Zone
Psychological	Biospheric values		Frequency of limit or reduce your water use while performing household tasks
	Altruistic values	Limit water use for others' present and future	
	Egoistic values	Water use should be unlimited.	
	Personal norms	Feeling guilty when I do not rationally use water.	Feeling morally obliged to save water, regardless of what others do
		Feeling like a better person if I save water	

Source: Adapted from: Arias, D., 2024

Our results on curtailment behaviour reveal that individuals with higher levels of education spend more minutes per shower, suggesting increased water use. This finding is consistent with the work of Russell & Knoeri (2020), who observed correlation of higher incomes with more elevated water bills and supposably, indicative of larger water consumption. Furthermore, our results corroborate the findings of Fielding et al. (2012), who found a relationship between households that exhibit water conservation behaviours and lower income levels.

Households that consider saving water as a moral obligation (personal norms) tend to take shorter showers (item 19, Table 5.2.). This finding is consistent with the research of Savari et al., (2022), who identified moral norms as a psychological factor which explains water curtailment behaviour in rural households.

Our results on installation of water saving devices and appliances also shows a relationship between contextual factors, environmental values and personal norms, and SP. Regarding biospheric values, our findings did not reveal a significant relationship with SP. This is not in accordance with the work of Fielding et al. (2012) who identified a connection between the installation of water efficiency appliances and intentions toward water conservation. Although, Fielding et al. (2012) emphasized that certain appliances, such as pool covers, irrigation systems, and washing machines, even though they are designed for water

efficiency, were associated with increased water use. Conversely, rainwater tanks, efficient water taps, dishwashers, water-saving showerheads and toilets were found to be correlated with decreased water use.

Further, in our study, biospheric, altruistic, and egoistic values preceded personal norms following the VBN chain of factors, except for beliefs (Table 5.1.). With the use of the VBN theory to explore behaviours related to sustainable water consumption and other environmental behaviours, our results align with prior research. (Karakaş, 2023b; Lind et al., 2015; Yildirim & Semiz, 2019). Similar to Lind et al. (2015), our findings suggest that biospheric values play a more important role in promoting sustainable behaviour, e.g. *SD*, compared to altruistic values. Additionally, biospheric values influence personal norms as well with further impact on *SD*. Altruistic values were associated with *SP*. There is also a relationship between altruistic and egoistic values, and *SP*. These findings align with prior research by Karakaş (2023b), and Yildirim & Semiz, (2019). Though our results did not reveal a predictive relationship between environmental values and beliefs, we noted that the VBN theory remains effective in explaining environmental values and personal norms.

Biospheric, altruistic, and personal norms served as indicators of water conservation awareness. We identified a positive relationship between biospheric values and the feeling of moral obligation to save water with *SD* (items 1, 19, Table 5.2.). Furthermore, our results indicate a positive relationship between altruistic value and the feeling of being a better person when saving water by increasing the *SP* (items 4, 24, Table 5.2.). These results regarding awareness of water savings are in line with the findings of Singha et al.'s (2022) study, which emphasize individuals' concerns about water-related issues and their optimistic outlook and sense of duty in addressing them. This assertion is further supported by Van Valkengoed et al.'s (2022) findings, which indicate that individuals with stronger altruistic values, and particularly those with stronger biospheric values, tend to exhibit a greater propensity for engaging in sustainable behaviour. This inclination stems from the understanding that such behaviours often result in benefits for others, nature, and the environment. It is commonly observed that people worldwide strongly support biospheric values, indicating a fundamental motivation for sustainable actions. Adhering to biospheric values is frequently seen as meaningful and brings about a sense of fulfilment (Steg, 2016).

Our results affirm that education level stands out as one of the most significant socio-economic variables to explain water use and conservation behaviours. Despite the diversity of approaches in studying these behaviours, certain comparisons can be drawn. For instance, moral norms can be compared with personal norms, risk perception regarding awareness and consequences of environmental issues can be compared with biospheric values, and attitudes towards cost-benefits can be contrasted with egoistic values. Steg (2016) asserts that individuals who strongly support biospheric values (and have weaker egoistic values) tend to be more cognizant of the adverse environmental impacts of their actions. They also feel

more capable of mitigating these issues through pro-environmental behaviour, consequently, reinforcing personal norms. Ultimately, this heightened awareness and commitment increase the likelihood of engaging in pro-environmental actions.

Table 5.2. Multiple Linear Regression output for variables associated with water use.

					Regression 1			**Regression 2**		
					Dependent variable (DV)	**Maximum saving potential (SP)**		**Dependent variable (DV)**	**Shower duration (SD)**	
						β	**Pr (>|t|)**		**β**	**Pr (>|t|)**
					Intercept			**Intercept**		
	Factors									
	Category			Survey item	Variable code			Variable code		
Contextual	Socio-economic (SEC)									
				Education level	Q15_sec11	0.028	0.000	Q15_sec11	1.57	0.000
				zone	zone	-0.249	0.000	zone	3.53	0.001
Psychological	Enviromental values	Biospheric	1	How frequently do you limit or reduce your water use while performing household tasks?				Q79_beh_v_bi1	-1.09	0.001
		Altruistic	4	How important is it for you to reduce water use, keeping in mind that this helps the short- and long-term well-being of the rural community?	Q84_1_beh_v_alt1	0.062	0.000			
		Egoistic	9	Please indicate your level of agreement with the statement: Humans have the right to use water according to their needs; therefore, water use should be unlimited.	Q88_1_beh_v_eg1	-0.014	0.001			
	Norms	Personal Norms	19	Please indicate your level of agreement with the statement: You feel morally obliged to save				Q93_1_beh_v_n1	-0.76	0.02

		water, regardless of what others do.				
	21	Please indicate your level of agreement with the statement: You experience a sense of guilt when you do not use water in a rational manner.	Q93_3_beh_v_n1	-0.021	0.022	
	24	Please indicate your level of agreement with the statement: You would feel like a better person if you saved water	Q93_6_beh_v_n1	0.021	0.02	
			R^2	0.33	R^2	0.19
			R^2_{Adj}	0.31	R^2_{Adj}	0.16

Some approaches consider different types of norms such as social and descriptive. However, in this case, we compare norms within the same category. An earlier study used Risk, Attitudes, Norms, Abilities, Self-Regulation, Trust (RANASt) model to study both *SP* and *SD* (Callejas M., et al., 2024 under review). Although our results slightly differ from those of RANASt, both the RANASt and the VBN show few similarities.

Households who indicated that reducing water use is important (altruistic value item 4, Table 2) showed a higher *SP.* Similarly, results from the RANASt model indicated that households who highly believe that use water efficiency is a priority (attitude - affective), also had higher *SP*. Outcomes from RANASt did not include any personal norm as a variable to explain *SD* or *SP*. However, we found that personal norms, as explained by the VBN theory, do account for both *SD* and *SP*.

Egoistic values pertaining to the right to use water because it is unlimited are found to be negatively correlated with *SP* (item 9, Table 2). From this, we can infer that households that reported this egoistic value do not concern themselves with water conflicts. Contrarily, the outcomes from the RANASt model indicate that households concerned about water conflicts reported a shorter *SD*. This suggests a correlation between egoistic values and water use efficiency behaviours related to *SP,* and biospheric values with behaviours related to *SD*.

The moderate to low significance of beliefs in our study may be linked to a limited understanding of the consequences of water shortages and scarcity. This lack of awareness impacts perceptions of the threats posed by environmental conditions and the implications of inefficient water use.

An increasing number of studies have shown that the VBN theory is an effective model for exploring and explaining various environmental behaviours. Researchers suggest that the VBN theory can be applied to different areas of environmental behaviour. The results consistently indicate that biospheric values and personal norms are significant factors, and the causal link from stable values to personal norms has been confirmed using this theory (Razzaghi Borkhani et al., 2023; Seymour et al., 2010; Steg et al., 2005).

5.4.Conclusions

The aim of the presented study it to understand the contextual and psychological factors that explain the installation of saving devices and curtailment behaviours at household level applying the values, beliefs and norms (VBN) theory.

Two variables were employed to gauge household water use: maximum water-saving potential (*SP)* and showering duration (*SD*) to identify variables that could be targeted in

water use reduction initiatives. *SP* was estimated using the number of saving devices and their water use, and *SD* was estimated based on information on minutes per shower and frequency in times per day.

The results, based on self-reports, reveal that *SP* and *SD* were associated with different sets of factors. *SP* was linked to altruistic and egoistic values, along with two personal norms. In contrast, *SD* was associated with biospheric values and a personal norm regarding the moral obligation to save water. Although both dependent variables were influenced by distinct psychological factors, they both exhibited a positive relationship with a socio-economic factor, education level.

These results suggest that environmental values precede personal norms in influencing water use. Specifically, biospheric values were found to precede personal norms regarding the feeling of moral obligation to save water, which correlates to *SD*, a form of curtailment behaviour. Altruistic and egoistic values were shown to precede personal norms that relate to feelings of guilt. However, this did not result in the adoption of saving devices, and the desire to self-improvement and moral enhancement by *SP*. The current study contributes to our understanding of intrinsic psychological factors related to water use, with potential implication for extending these insights to sociohydrological models, as well as for further cases studies, and decision-making aimed at reducing water use.

The study findings indicate that household water conservation efforts, such as shortening shower times, can be bolstered by emphasising biospheric values and individual norms concerning sustainable water use. Additionally, the study reveals that fostering altruistic values may contribute to improved water use efficiency through measures such as the installation of water-saving devices. As we can see both shortening shower time and installation of water-saving devices are connected to psychological factors, it might help to prevent the occurrence of rebound effect.

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Author contributions

DC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. DA: Conducted statistical

analysis in Phyton. SP: Conceptualization, Formal analysis, Supervision, Writing – review & editing. JR: Conceptualization, Supervision, Writing review & editing. LR: Conceptualization, Formal analysis, Supervision, Writing – review & editing.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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Ethical considerations

This study received ethical approval from the Human Research Ethics Committee of Delft University of Technology, under approval number 1896.

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Chapter 6

6. Conclusions

6.1. Specific conclusions

Through an assessment of water use and of the behaviour of water users across rural and peri-urban water supply systems in Colombia, this thesis contributes to the understanding of factors that drive the decisions of individuals to adopt (or not) water-saving devices or curtailment behaviours within the water supply system. To design effective policy targets, react to existing water policy, build measures and find effective strategies that promote the mid- and long-term reduction of water use and overuse through adopting water reduction measures, it is necessary to identify and understand the behaviours of water users. Below, based on the research questions formulated in Chapter 1 of the thesis, specific conclusions are formulated.

What are the current approaches used and knowledge gaps in water use behaviour underlying water use efficiency?

Numerous approaches are available to interpret water use efficiency (WUE). Previous research in the fields of agronomy, sustainability, water management, and other technical domains, has defined and interpreted WUE in different ways. We conclude that each approach depends on the specific domain. For example, in agronomy, WUE typically refers to increasing production with less water, rather than focusing on water sustainability as the main objective, which has implications for WUE knowledge and how WUE is estimated. However, sustainability approaches, such as cleaner production and water footprint, focus on water demand reduction and reduction of overuse.

We identified a variety of contextual and psychological factors underlying water use behaviour. A conceptual, multi-level model was proposed, integrating contextual and psychological factors, and including water users and managers responsible for water utilities to understand (in)efficient water use based on existing models and theories.

What are the contextual factors that influence water use considering household and water supply levels?

Two dependent variables were employed to gauge household water usage: the maximum water-saving potential (*SP*) and showering duration (*SD*). *SP* was estimated using the number of saving devices and their water use, and *SD* was estimated based on information in minutes per shower and frequency per day.

Our study showed that the water supply was higher in rural areas when compared to peri-urban areas, even though the perceived water use was higher in peri-urban areas. Compared with water supply systems in peri-urban areas, water supply systems in rural areas have larger

losses because of ancient utilities, lack of technology and poor maintenance. Socio-economic factors and distance from the capital cities can explain these findings. For example, most WUA members in isolated rural areas are part-time volunteers, which suggests that this group of water managers is generally small. Additionally, given that this region has a low prevalence of technical and professional education, water managers in rural areas lack the time, money, and water literacy necessary to support full-time water management.

Household size, education level, age, and occupation were found to be critical contextual factors that influence households' perceptions of water use. People with higher education levels use more water, probably because of their higher income, which allows them to afford a house with various toilets, showers, big backyards, and sometimes a swimming pool. In peri-urban areas, people perceive their water use as more efficient, but they use more water per capita, because they have, on average, more appliances.

From the perspective of the risk, attitudes, norms, abilities, and self-regulation (RANAS) approach, what contextual and psychological factors are associated with the adoption of water-saving devices and curtailment behaviour at the household level and how are these relationships related to the rebound effect?

From our study it could be concluded that both the *SP* and *SD* variables exhibited associations with contextual factors, such as education level and location. Among the psychological factors, our findings indicate that *SD* was connected to attitudes, abilities, and self-regulation, while *SP* was connected to risks, attitudes, social norms, and abilities factors.

We found that *SD* was negatively associated with attitudes, particularly among users who believed that high investments are needed for efficient water use. Thus, the more convinced respondents were about the high investments in water-saving devices, the more inclined they were to shorten showering. This tendency may be linked to the cost-benefit assessment conducted by individuals. Thus, if costs are a concern for these individuals, they may opt to engage in curtailing behaviour rather than invest in water-saving devices. Additionally, abilities and knowledge (e.g. knowing how to check for water leaks at home) played a crucial role, because repairing a leak might be cheaper than investing in a saving device.

The results obtained from peri-urban Cali and rural Restrepo suggest that the RANAS + trust, also including trust as a factor, could be valuable in exploring the psychological and contextual factors influencing water use. Although trust is a moderately significant factor, adding this factor to the RANAS approach provided insight into the importance of this factor in terms of studying water users' perceptions.

From the perspective of values, beliefs and norms (VBN) theory, what are the contextual and psychological factors that explain the efficient use of water and curtailment behaviour at the household level?

Based on self-reports, the results revealed that the *SP* and *SD* variables were associated with different sets of value laden factors. These results suggest that environmental values preceding personal norms in influencing the use of water. Specifically, biospheric values were found to precede personal norms regarding the feeling of moral obligation to save water, which correlates with *SD*, a form of curtailment behaviour. Altruistic and egoistic values preceded personal norms that relate to feelings of guilt due to inefficient water use and the desire for self-improvement and moral enhancement by *SP*.

The results of this study support the idea that initiatives aimed at conserving household water, such as shortening shower times, can be bolstered by emphasizing biospheric values and individual norms concerning sustainable water usage. Additionally, the study stressed that encouraging altruistic values may contribute to improved water use efficiency by implementing strategies, such as the installation of water-saving devices.

6.2. Overall conclusion

The overall objective of the thesis was:

To identify contextual and behavioural factors underlying unsustainable water use related to domestic water use for applications in water supply systems using a systematic approach.

One cause behind higher than expected water demand is the failure to account for inefficient water use driven by human behaviour. This stems from the lack of an integrated assessment of behavioural and contextual factors that influence water use behaviour.

Our results indicate differences in SEC and water usage between peri-urban and rural systems. When referring to the SEC, we aim to emphasize that the contextual factors such as household size, education level and age, are relevant to assessing water usage at the household level. Factors from the RANASt model, specifically, cost-benefit assessment, social norms, abilities, and trust, are involved in individuals´ attitudes and perceptions about water use. This research supports the idea that a cost-benefit analysis influences the decision to install water-saving devices or take shorter showers. The findings suggest that actions requiring less investment are linked to water-saving behaviours, whereas actions that demand financial investment but involve less effort are linked to the installation of water-saving devices. *SP* was linked to altruistic and egoistic values, along with two personal norms. In contrast, *SD* was associated with biospheric values and a personal norm regarding the moral

obligation to save water. Although both dependent variables were influenced by distinct psychological factors, they both exhibited a positive relationship with a socio-economic factor, education level.

The most remarkable result to emerge from our data is that water use efficiency behaviour represented by *SP* is aligned with egoistic values, which reflect choices based on analysis made by water users about the individual costs and benefits. In this case, even though users perhaps were not concerned about environmental problems for water overuse, they considered reducing the water bill by installing saving devices and appliances. Even though egoistic values are not aligned with environmental awareness, making decisions from an egoistic point of view could thus reduce water use, and positively affect the environment.

Most of the previous studies have emphasized the role of socio-economic factors in the (in)efficiency of end water use in water supply systems. The findings of this study, however, also suggest that policymakers, when making decisions about water use reductions, typically give little consideration to the fact that water supply systems distant from urban areas are organized and managed differently from those closer to urban areas.

Distance has implications for water management skills, as people in remote areas often face limited incomes, restricted access to technical outreach, and challenges in managing water use at the system level. Therefore, distance and its implications impact the operation and maintenance of the water supply system, and as a result, they influence water use efficiency.

The beliefs outlined in VBN theory are connected to an understanding of environmental conditions that threaten the things that people value. In the RANAS model, the risk factor represents an individual's subjective perception of vulnerability to environmental threats and their consequences. Since the risk factor in the RANAS model was found to be of moderate to low significance, it may connect with the beliefs in the VBN and help to explain why the beliefs in the VBN theory were also not significant.

The results further support the idea that when measures to reduce water use and overuse solely consider installing water-saving devices without integrating curtailment actions, those measures might fail, because they could generate a rebound effect in the mid- and long-term. This effect occurs when people use more water than before the installation of water-savings devices, because people’s mindsets consider water use reduction to occur only by installing a water-saving device without curtailment actions.

To study efficient use of water, various models have been proposed, and existing theories have chosen different factors. Unlike existing models, the proposed new model is a behavioural model that integrates the RANAS model and the VBN theory. Various experts and researchers have employed the RANAS approach to study the water, sanitation and

hygiene behaviours in Global South countries and have effectively implemented it to enhance handwashing practices in water-scarce regions of Africa. Theoretical bases of the RANAS model are similar to those used to study environmental behaviours such as perceptions, attitudes and social norms. Researchers have primarily applied the RANAS approach in developing countries and the water sector, making this model suitable for testing water use efficiency. Previous studies agree that the VBN helps elucidate different pro-environmental actions, including the use of alternative fuel vehicles, support for smart energy systems, efforts in biodiversity conservation, and the promotion of sustainable water practices.

This new model extends existing models to incorporate a trust factor, which is essential for investigating how water users perceive trust in water authorities. In this study, we used trust to specifically examine how users perceive water associations and their implications for water use management. Additionally, in Chapter 3, this research presents a methodology for measuring unmetered water use; this methodology can be extended to other case studies and may be standardised to facilitate water measurement at the household level in the absence of metering devices. Knowledge and data on per capita water use are crucial to developing effective household demand management programs. In addition to psychological variables, this model includes socioeconomic factors that are crucial to analyse multiple groups and comparisons between water systems.

In the thesis we could identify factors affecting water use by applying behavioural science and using existing environmental approaches and theories from environmental psychology. Therefore, given the necessity of changing the direction of (un)sustainable water use, understanding how households use water and their perceptions about it presents an opportunity to strengthen policymaking about water use. The application of behavioural science in water use, in this way, built a bridge between water management and social sciences. Novel and interdisciplinary approaches, such as combining engineering and social sciences are thus necessary to transition from unsustainable to sustainable water supply systems and move forward to water sustainable actions.

Limitations

In this study, we identified that the lack of information and unplanned infrastructure in at least 50% of the examined water supplies, particularly in rural areas, is a challenge. It limits the enhancement of water use in water supply systems. The unavailability of data and the difficulties in obtaining it have profound implications for accurately estimating water balance, demand, and losses. The absence of data and effective measures hinders the development of tailored interventions and decision-making aimed at improving water management.

The sampling methods used in this thesis, had four key limitations. First, the questionnaire did not differentiate between water use on weekdays and weekends. The reason is that the goal was to estimate average perceptions of water use rather than daily usage patterns. Second, we assumed that all household members used water, as reported by the respondent, because it helped to simplify the survey process and ensure that all potential water users were represented. While we inquired about the number of people living in each household, we did not ask about their specific composition, such as the number of children, young adults, older adults, or the gender distribution, as we could not accurately capture their perceptions. Third, we did not collect information about outdoor water use because perceptions related to this aspect might not be reliably estimated based on secondary data. Fourth, the surveys were conducted in only one season, despite the bimodal hydroclimatic regime in Valle del Cauca. The first three limitations arose from the framework of this study, which focused on capturing household-level perceptions of water use rather than individual ones. In addition, constraints related to time, finances, and logistics, particularly due to the pandemic, also contributed to these limitations.

Contributions

Climate variability presents water challenges that require existing and innovative, integrated solutions. This study goes beyond previous studies by showing that initiatives aimed at reducing water use must consider both technical and behavioural aspects. Water managers often prioritise technical solutions and may overlook the importance of understanding user behaviour. However, individuals, organisations, and industries are all water users and are part of the solution. By increasing awareness and influencing social norms, they can promote changes in water user behaviours. Integrating technical solutions with behavioural insights provides a holistic view of the water supply system, facilitating a transition to more sustainable water use practices. The study also illuminates the contextual and behavioural factors that influence the efficient use of water, particularly the installation of water-saving devices at the household level and behaviours aimed at reducing water use.

This study is one step towards enhancing our understanding of intrinsic psychological factors related to water use, with potential implication for extending these insights to socio-hydrology models, as well as for further cases studies. According to our literature review, this study is the first to apply the RANAS model to examine the relationship between behavioural factors and water use efficiency at the household level. Furthermore, it extends the RANASt approach by incorporating a trust factor. In addition, the VBN theory, the approach used in this study, has the potential to be applied to other models, due to the importance of environmental values and personal norms in understanding water use. This approach enhances the typical analysis methods used in water supply systems and can assist researchers in the field of water sustainability. Ultimately, this model may enhance informed decision-making related to water use efficiency, future regulations, and implications for promoting water use efficiency.

Rural and peri-urban water supply systems are different from the urban ones. Water use and contextual and technical factors can influence water supply and water use. Research on water use reductions often focuses on urban areas, resulting in fewer studies conducted in rural and peri-urban areas. This lack of research leads to an inadequate understanding of water challenges in these regions. To effectively promote water sustainability, it is essential to assess how water use efficiency projects will influence water usage and the overall well-being of communities. Our findings suggest that water users are influenced by contextual factors, particularly the distance from major cities, which indicate differences in socio-economic levels between rural and peri-urban areas. The study reveals differences in perceptions of water use between rural and peri-urban areas. In rural water supply systems, the perception of water use is generally lower, whereas it tends to be higher in peri-urban areas. The infrastructure and water management aspects in peri-urban water systems are more akin to those found in urban systems. In contrast, rural systems often have outdated infrastructure, which can lead to inefficiencies. This may explain why water supply levels are usually higher in rural areas compared to those in peri-urban areas.

Research on the contextual and psychological factors that influence water use is predominantly conducted in countries of the Global North, which can lead to bias related to countries in the Global South. This thesis aims to provide insights into the relationship between these factors and their impact on water use in two municipalities in Colombia. By doing so, it also seeks to expand knowledge in regions like Colombia, which are often overlooked in existing studies.

6.3. Outlook

Understanding contextual and behavioural factors enables water managers to design more targeted interventions that complement conventional methods aimed at reducing water demand. Future analyses might include exploring three main aspects in designing interventions. First, factors that influence the acceptability of technology and infrastructure implementation; second, developing environmental education campaigns tailored to the specific contexts and needs of the target audience; and third, examining the factors that affect the willingness to pay for water supply services.

Other regions in the world that are also struggling with high water use and overuse, could benefit from this approach by incorporating human factors into the analysis of water use across water supply systems.

The organizational setting is related to the decision-making process. In this thesis, the focus has been on the relationship between water use and the contextual and psychological factors

of households. However, researchers should further consider the links with the administrative and organizational systems to improve the understanding of how information on this relationship can influence water resources management decisions. Administrative and organizational assessment allows us to understand how water managers and policymakers behave and make decisions about water use. This is relevant to understand how they engage and commit to reducing water use and how it might influence water systems operations and water uses.

By including a set of factors, such as in the RANAS model, the significance level improved. Similar to previous studies, this study illustrates that behaviour results from various psychological and contextual factors, and that sustainable water use does not depend solely on awareness or environmental education. The findings demonstrate the practical application of RANASt and VBN theory in water supply systems.

We have shown that RANASt and VBN are useful approaches to understanding water use behaviour that allow systematic analyses of contextual and psychological factors that influence water use behaviour. Researchers can potentially use these approaches to analyze other behaviours that affect water use across water supply systems, such as willingness to pay for water supply services, as well as awareness of the need to implement routine maintenance of these systems.

A better understanding of the factors influencing water use efficiency and the conservation of water management policies is essential for policymakers. This knowledge can positively impact water sustainability, as well-designed public policies can simultaneously affect the behaviours of many individuals. The results of this study suggest that support for water conservation policies can be strengthened by emphasizing education levels and distinguishing between rural and peri-urban contexts, which are crucial for understanding water use. Attitudes towards cost-benefit evaluations—considering both effort and money, along with social norms related to how others use water and trust in the water supply system —play a substantial role in the decision to install water-saving devices. Additionally, the ability to improve water use efficiency and knowledge of low-cost alternatives can encourage behaviours such as taking shorter showers. Moreover, altruistic, egoistic, and personal values can heighten awareness about the importance of installing water-saving devices, while biospheric and personal norms may contribute to reducing shower times.

This study not only supports the application of the RANAS model and VBN theory in water supply systems but also enhances our understanding of the factors that influence users' water use behaviour. This knowledge can assist water management policymakers and decision-makers in developing more effective policies for sustainable water use by providing a better understanding of users' decisions and behaviours. The current findings can help design pilot interventions that promote water knowledge. A good starting point would be schools,

universities, and institutes providing courses to water professionals, where a course could be introduced to educate students about water usage and water systems. This course can inform students and practitioners about water conservation actions, such as installing water-saving devices and taking short showers.

It is essential not only to teach individuals about water conservation alternatives but also to explain how to implement these options and their implications. Knowledge and understanding also include discussing the benefits and costs of such behaviour as installing water-saving devices, taking shorter showers, and repairing leaks. Furthermore, promoting biospheric values can encourage people to change their negative environmental behaviours. The aim is to raise awareness and foster a sense of responsibility for conserving water. Knowledge, understanding and implications for water use behaviour are crucial elements that can help motivate behaviour change.

Appendix A1

Supplementary material Chapter 3

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2024.1389648/ full#supplementary-material.

A.1.1 Codebook - Survey socio-economic (SEC) factors and water habits

Factors		Levels	Explanation	Reference
	Zone	0: rural 1: peri-urban		
Socio-economic	Number of people per household	1 - 6 people	Household size influences per capita water consumption.	Hussien et al., 2016
	Age	18 - 30 -> 24 31 - 40 -> 35 41 - 50 -> 45 51 - 60 -> 55 61- 70 -> 65 Older than 70 -> 70 *Aligned with generation	Previous studies showed that in rural areas older people use water more efficiently than younger people. They have more experience in droughts and traditional ways to use water efficiently [ref]. On the contrary, in urban zones, Newton&Meyer (2012) say "Older age groups tend to be higher consumers across the board of dwelling-centred resources—a reflection of the fact that the 60 plus group exhibit significant levels of under occupancy of housing in Australia".	Newton&Meyer, 2012
	Gender	0: female 1: male	Role of women. Usually, women stay at home all day, that's the way they have more ability to use water efficiently.	
	Education level	1: None 2: primary incompleted 3: primary completed 4: secondary incompleted 5: secondary completed 6: technician incompleted 7: technician completed	Education level influences knowledge, abilities and capacity to use water (or overuse).	A.J. Dean, 2016; S.M. Khair et al., 2019

		8: bachelor's degree 9: postgraduate degree		
	Occupation	1: employed full time 2: employed part-time 3: freelance 4: study only 5: studying and working 6: housework 7: volunteer work and other e.g. social leader 8: retired 9: unemployed 10: option 7 and other	Combined with other basic demographic information may be useful.	
	Income	180 euros 200 312 602 803	The measure of the influence of income on the purchase of saving appliances and fixtures.	S.M. Khair et al., 2019
Technical	Type of appliances and fixtures at home	1: I don't have it 2: Conventional 3: saving	An attempt to understand how people use water, and why they used it. It contributes to the monitoring of changes in consumption across time and space.	Adeyeye, K., 2015; Jorgensen, et al., 2009
End water use and habits	Frequency of daily water uses	0 - 5 times per day		
	a. brush teeth			
	b. wash hands			
	c. take a shower			
	d. hand wash dishes			
	e. cook			
	f. flush toilet*			
	Frequency of weekly water uses	0-7 times per week		
	a. wash clothes (washing machine)			
	b. clean house			
	c. water plants			

	shower duration	3: 1 - 5 minutes 8: 6 -10 minutes 13: 11- 15 minutes 15: more than 15

A.1.2 Linear regression socio-economic factors and water use perceived by users

Variables		Estimate	Standard error	t value	Pr (> |t|)	
	Intercept	161.58	28.8	5.6	2.72E-08	***
Q8_sec3	Number of people per household	-16.28	2.64	-6.16	1.07E-09	***
Q9_sec4	Age	-3.18	3.03	-1.05	0.293	
Q10_sec5	Gender	17.35	7.8	2.22	0.0264	
Q12_rt	Residence time	0.03	0.18	0.17	0.8603	
Q15_sec11	Education level	17.33	4.22	4.106	4.40E-05	***
Q16_sec12	Occupation	-3.4	2.94	-1.156	0.2478	
Zone	Zone	48.59	10.02	4.84	1.48E-06	***
Significant codes:		0 '***'	0.001 '**'	0.01 '*'	0.05'·'	0.1 ' ' 1
R^2	0.102					
Adjusted R^2	0.09					
p-value	<2.2e-16					
Residual standard error	107.1 on 887 degrees of freedom					
(31 observations deleted due to missingness)						

Appendix A2

Supplementary material Chapter 4

A.2.1 Codebook of variables- Section a

Factors		Variable name	Variable label	Values
		Q9 _sec4	Age	1: 18-30 2: 31-40 3: 41-50 4: 51-60 5: >60
Contextual	Socio-economic	Q10_sec5	Gender	0: female; 1: male
		Q15_sec11	Education Level	1: none 2: elementary 3: secondary 4: technical degree 5: bachelor degree
		Q16_sec12	Occupation	1: employed 2: student 3: engagement in home duties 4: unemployed 5: retired
		Zone	Location	0: rural; 1: peri - urban
		Altitude3	Elevation	>1173 – 1381 masl[2]
Behavioural	Risk	Q55_1_beh_r_r1 - Q59_beh_r_4	Examples	1-5
	Attitudes	Q60_beh_r_at1 - Q65_beh_r_at5		1-5
	Norms	Q67_beh_r_n1 - Q72_beh_r_n5		1-5
	Abilities	Q73_1_beh_r_ab1 - Q75_beh_r_ab3		1-5
	Self - Regulation	Q76_1_beh_r_sr1 - Q77_6_beh_r_sr4		1-5
	Trust	Q78_1_beh_r_tr1 - Q78_3_beh_r_tr1		1-5

Codebook variables - Section b

Factors	Independent variables	
	Item	Variable code
Contextual		
Socio-economic	1. Age	Q9_sec4
	2. Gender	Q10_sec51
	3. Education level	Q15_sec11
	4. Occupation	Q16_sec12
	5. Location	zone1
Psychological		
Risk	6. Not using water efficiently causes droughts?	Q55_1_beh_r_r1
	7. Not using water efficiently causes conflicts?	Q55_2_beh_r_r1
	8. Not using water efficiently causes interruptions in the water supply service?	Q55_5_beh_r_r1
	9. How often are you affected by price increase?	Q57_3_beh_r_r3
	10. If you do not have water for a week, how does that affect your wellbeing?	Q59_beh_r_r4
Attitudes	11. How much effort/physical labour is required to use water properly, rationally or efficiently?	Q60_beh_r_at1
	12. How much time is needed to use water efficiently?	Q61_beh_r_at2
	13. How much money is needed to use water efficiently?	Q62_beh_r_at3
	14. How sure are you that efficient use of water helps to reduce additional costs?	Q64_4_beh_r_at4
	15. How much of a priority is efficient use of water?	Q65_beh_r_at5
Norms	16. How likely is it that elderly use water efficiently?	Q68_4_beh_r_n2
	17. How likely is it that the agriculture uses water efficiently?	Q69_2_beh_r_n3
	18. How likely is it that livestock supply uses water efficiently?	Q69_3_beh_r_n3
	19. How likely is it that tourists use water efficiently?	Q69_4_beh_r_n3
	20. How likely is it that the industry use water efficiently?	Q69_5_beh_r_n3
Abilities	21. Do you know how to check your house for water losses?	Q73_5_beh_r_ab1
	22. Do you know that you can recycle water that comes out of the washing machine?	Q73_6_beh_r_ab1
Self-regulation	23. With which frequency do you find alternatives to use water efficiently?	Q76_2_beh_r_sr2
Trust	24. How much do you agree that the community aqueduct has a good reputation?	Q78_2_beh_r_tr1
	25. How much do you agree that the community aqueduct provides the water supply service and therefore can be trusted?	Q78_3_beh_r_tr1

A.2.2 Water flow for end water use for saving and non-saving devices

End water use (domestic)	Units	Min	Max
		Saving	Conventional
Toilet (lpf)	Litres/flushing	5	10
Wash teeth	Litres/min	3.5	8
Wash hands	Litres/min	4	4
Shower	Litres/min	9	15
Cooking	Litres/person.day	2	5
Hand wash dishes	Litres/min	3	15
Use washing machine	Litres/load	95	150
Cleaning house	Litres/person.day	4	4
Water plants weekly	Litres/min	8	8

Appendix A3

Supplementary material Chapter 5

A.3.1 Codebook contextual and psychological factors

Factors	Category			Survey item	Variable code	Point scale
Contextual	Socio- economic (SEC)			Household size	Q8_sec3	1 - 5 1: person 5: persons or more
				Age	Q9_sec4	1: 18-30 2: 31-40 3: 41-50 4: 51-60 5: >60
				Education level	Q15_sec11	1: none 2: elementary 3: secondary 4: technical degree 5: bachelor degree or higher degree
				Gender	Q10_sec5	0: female 1: male
				Occupation	Q16_sec12	1: Employee 2: Student 3: engagement in home duties - housewife 4: unemployed 5: retired
				Altitude	Altitude	1: <= 989 2: 990 <= 1173 3: 1174 <= 1381 4: 1382 <= 1612 5: > 1612
				Zone	Zone	0: rural 1: peri-urban
Psychological	Enviromental values	Biospheric	1	How frequently do you limit or reduce your water use while performing household tasks?	Q79_beh_v_bi1	1 - 5 1: never - 5: always
			2	How important is water conservation to you?	Q80_beh_v_bi2	1-5 1: very

					unimportant 5: very important
		3	Please indicate your level of agreement with the following sentence: I use water efficiently to conserve and protect water resources	Q81_beh_v_bi3	1 - 5 1: never - 5: always
		4	How important is it for you to reduce water use, keeping in mind that this helps the short- and long-term well-being of the rural community?	Q84_1_beh_v_alt1	1-5 1: very unimportant 5: very important
		5	Is the rational use of water important to ensure access to water for the whole community?	Q84_2_beh_v_alt1	1-5 1: very unimportant 5: very important
		6	Please indicate the level of importance you attribute to the following statement: Using water efficiently helps to conserve water.	Q84_3_beh_v_alt1	1-5 1: very unimportant 5: very important
	Altruistic	7	How concerned are you about water supply, especially for people who are more vulnerable?	Q85_beh_v_alt2	1-5 1: very unconcerned 2: very concerned
		8	Do you believe there are conflicts related to water use in your region?	Q86_beh_v_alt3	0 : yes 1 : no
		9	Please indicate your level of agreement with the statement: Humans have the right to use water according to their needs, therefore, water use should be unlimited.	Q88_1_beh_v_eg1	1-5 1: strongly disagree 5: strongly agree
	Egoistic	10	Please indicate your level of agreement with the statement: My only concern regarding water is that my home is supplied for my basic needs	Q88_2_beh_v_eg1	1-5 1: strongly disagree 5: strongly agree
Beliefs	Ascription of Responsibility (AR)	11	Please indicate your level of agreement with the statement: Each	Q90_1_beh_v_bf1	1-5 1: strongly disagree

				person is responsible for the problems related to water use.		5: strongly agree
			12	Please indicate your level of agreement with the statement: The water company is responsible for the problems related to water use.	Q90_2_beh_v_bf1	1-5 1: strongly disagree 5: strongly agree
			13	Please indicate your level of agreement with the statement: The local, regional, and national governments are responsible for the problems related to water use.	Q90_3_beh_v_bf1	1-5 1: strongly disagree 5: strongly agree
			14	Please indicate your level of agreement with the statement: The regional environmental authority is responsible for the problems related to water use.	Q90_4_beh_v_bf1	1-5 1: strongly disagree 5: strongly agree
			15	Please indicate your level of agreement with the statement: The economic sector in the region is responsible for the problems related to water use.	Q90_5_beh_v_bf1	1-5 1: strongly disagree 5: strongly agree
		Awareness of Consequences (AC)	16	Please indicate your level of agreement with the statement: In my area water scarcity is a problem.	Q92_1_beh_v_bf3	1-5 1: strongly disagree 5: strongly agree
			17	Please indicate your level of agreement with the statement: Water scarcity is a problem that only affects my property.	Q92_2_beh_v_bf3	1-5 1: strongly disagree 5: strongly agree
			18	Please indicate your level of agreement with the statement: In this region, water is overused.	Q92_3_beh_v_bf3	1-5 1: strongly disagree 5: strongly agree
	Norms	Personal Norms	19	Please indicate your level of agreement with the statement: You feel morally obliged to save water, regardless of what others do.	Q93_1_beh_v_n1	1-5 1: strongly disagree 5: strongly agree

	20	Please indicate your level of agreement with the statement: Anyone could do any action in order to use water efficiently.	Q93_2_beh_v_n1	1-5 1: strongly disagree 5: strongly agree
	21	Please indicate your level of agreement with the statement: You experience a sense of guilt when you do not use water in a conservative manner.	Q93_3_beh_v_n1	1-5 1: strongly disagree 5: strongly agree
	22	Please indicate your level of agreement with the statement: If you had the economic means to buy a new water efficient appliance (e.g. dishwasher or washing machine), you would feel morally obliged to do so.	Q93_4_beh_v_n1	1-5 1: strongly disagree 5: strongly agree
	23	Please indicate your level of agreement with the statement: you feel obligated to save water in your daily activities.	Q93_5_beh_v_n1	1-5 1: strongly disagree 5: strongly agree
	24	Please indicate your level of agreement with the statement: You would feel like a better person if you saved water.	Q93_6_beh_v_n1	1-5 1: strongly disagree 5: strongly agree

Professional acknowledgments

The PhD has been an incredible journey and sometimes I thought I was alone, but this was not true. My community was part of this journey and without them I could not be resilient, enjoy and finish this journey. All of you put a grain of sand in this thesis and contributed to enrich my personal and professional life. Today, I am finishing this journey, and I would like to express my deepest gratitude to all of you.

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After a long journey in which I have grown professionally and in a personal manner, I feel extremely excited about all the people who accompanied me during this journey, my lovely family and friends. For me, a PhD was like a trip on a roller coaster with ups and downs. Despite that, my family and friends support me, and it is invaluable for me.

Words cannot express my gratitude to my Parents, Jorge Albeiro Callejas Gómez and Zoraida Moncaleano Sierra, and my grandmom Hilda María Sierra; I could not have undertaken this journey without them. They have always believed in me, in each milestone of my professional life. Thank you for your moral and emotional support, and for your lovely and kind words during more difficult moments, and I thank Balti, Lulu and Niki for their emotional support; I love all of you.

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About the author

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I am an international Latin American professional from Bogotá, Colombia, with over 12 years of experience in Latin America in the Integrated Water Resources Management (IWRM) sector. My passion for environmental and water sustainability in Latin America goes back to my childhood in Bogotá. I used to go to rural areas during holidays, where I swam in rivers and hiked through the mountains, animals, and forests. Later, I witnessed through my teen years how fast human activities polluted the rivers, mainly in capital cities. These two stages of my life inspired me to pursue an Environmental Engineering career and later a Master's degree in IWRM at the Department of Civil and Environmental Engineering at the Universidad de Los Andes in Bogotá, Colombia.

As a practitioner, I began my professional career working in a consultancy where I was responsible for the environmental management (air quality, emissions control, solid waste management) and water sustainability component of the environmental studies for the public transportation of Bogotá (Transmilenio) and oil and mining coal industries in Colombia. I gained strong fieldwork experience, directly measuring water quality and quantity in surface and groundwater. Then, when I got a position in the IWRM Division in the Ministry of Environment and Sustainable Development (Minambiente), I deepened my institutional relations experience and stakeholder facilitation by working very closely with ministries, environmental authorities, national and international organizations, economic sectors, universities, water user's associations for drinking and irrigation users', to name a few. One of my main tasks was discussing and securing water regulations and guidelines agreements which are connected with all sectors, e.g. energy and agriculture. I also worked on various projects across and outside of Colombia, such as water and sanitation in Minambiente and water management in urban and rural contexts. In 2018, I contributed technical assistance to the development of the "Estudio Nacional del Agua", prepared by the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) of Colombia. Specifically, I provided

expertise on water uses, which were included in Chapter 5. I coordinated, led teamwork and supported the administrative and technical supervision of projects in consultancies, Minambiente and for my PhD.

My experience as a water professional in Minambiente allowed me to work with diverse sectors and their stakeholders, such as water supply systems, agriculture, hydropower, and water, sanitation and hygiene (WASH). I had the opportunity to participate in various meetings and negotiations to define public policies, write guidelines, and design economic disincentives, mainly to reduce the overuse of water and pollution on rivers and promote water reuse. I realized that even technical and economic measures are necessary; behavioral change is also relevant to changing unsustainable behaviour and making informed decisions. Then, an interdisciplinary approach is required. It motivated me to pursue a PhD in a multidisciplinary field, sanitary engineering and behavioral science, to study and understand people's water use behaviors. Along my PhD journey, I have felt more enthusiastic about learning and investigating behavioral science and applying this knowledge to improve environmental sustainability.

I started my PhD to explore recent findings in water management, water sustainability and water security fields to understand human behaviour and perception in the context of sustainability, mainly in water and how this approach can be integrated into existing water strategies such as policies and engineering solutions focusing on improving water demand, drinking water supply systems, and water sustainability. My research is on households' behaviour from water supply systems to understand the factors that influence the efficient use of water. The main aim is to understand the relationship between humans and water. I focus on domestic water use in the rural and peri-urban areas of Valle del Cauca, Colombia. These results aim to contribute to end water use knowledge and household behaviour in peri-urban and rural areas in Colombia and give insights to water managers of WUA and decision-makers to design more tailored interventions aiming to reduce water use and improve water demand across drinking water supply systems, and sustainability of its natural water sources. My project aligns with the priorities of research ecosystems established by the Colombian government within the "Pasaporte a la Ciencia programme" promoted by ICETEX, with the goal of the WWB- Colombia Foundation "work on promoting the development of women's personal; on closing inequality gaps for women; and on encouraging their active participation in economic development ", and the UN-Sustainable Development Goal 6.4. "Increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity".

Besides my expertise in consultancy, public policy and academic research, all related to water resources management, my cross-cultural communication skills are an asset for this position. My previous roles have enabled me to experience and work in international environments in Latin America and Europe alongside people with multicultural and multidisciplinary backgrounds. My strong leadership, strategic decision-making, negotiation skills, creative problem solving and organizational skills have contributed to successful outcomes.

I have always wanted to invest my time, energy, and knowledge in contributing to improving the living standards of Colombian, Latin American, and worldwide populations. Having a strong belief in the continuously growing potential of the global south region and its inhabitants.

List of publications

Peer reviewed journal publications

Callejas M., D., C., Pande, S., Rietveld, L. (2021): Water Use Efficiency: A Review of Contextual and Behavioural Factors. Frontiers in Water. (3) doi: 10.3389/frwa.2021.685650. Cited by 35 publications (Frontiers, accessed October 10, 2025)

Callejas M., D., C., Pande, S., Haeffner, M., Rodríguez, J., P., Rietveld, L. (2024): Inefficiencies in water supply and perceptions of water use in peri-urban and rural water supply systems: A case study of Cali, Colombia. Journal Frontiers in Water. Frontiers in Water. (6) Sec. Water and Human Systems. doi.org/10.3389/frwa.2024.1389648.

Callejas M., D., C., Pande, S., Rodríguez, J., P., Rietveld, L. (*Under Review*). Curtailing water use and adopting water saving devices: rebound effect in domestic water use in Colombia. Advances in hydrological science in Latin America. Special issue of the Hydrological Sciences Journal.

Callejas M., D., C., Arias, D., Pande, S., Rodríguez, J., P., Rietveld, L. (*Under Review*) Applying the Values – Beliefs – Norms Theory to Identify Psychological Factors Associated with Water Use Efficiency and Curtailments Behaviours. Environment, Development and Sustainability.

Conference presentations

XXXI Latin American Congress of Hydraulics. Factores de contexto y de comportamiento que se relacionan con el uso eficiente del agua en acueductos peri-urbanos y rurales. Universidad de Medellín. Medellín, Colombia. October, 2024. Speaker.

International meeting of Riverhood and River Commons projects "Ríos en Movimiento". Water supply for domestic use as an environmental service provided by rivers and user behaviour. Wageningen University & Research. Water Resource Management. Manizales, Colombia. March, 2024. Speaker.

1st Latin American Research Day, Mexico – Colombia. Understanding the (in)efficient water use behaviour in peri-urban and rural zones in Colombia. LATITUD-TUDelft. Delft, The Netherlands. June, 2023. Speaker.

The Water and WASH Futures Conference 2023 (WaWF): Achieving SDG6 in a Changing Climate. The water use efficiency (WUE) in peri-urban and rural water supply systems based on socio and economic (SEC) factors. Griffith University, IWC, Water for Women, Australian Aid, ADB. Brisbane, Australia. February, 2023. Speaker (Online).

Water, WASH & Climate Virtual Symposium. Water use efficiency in water supply systems in rural Colombia. Griffith University, IWC, Water for Women, Australian Aid, ADB. Australia. June, 2022. Speaker (Online).

11th Scientific Assembly of the International Association of Hydrological Sciences (IAHS). Water use efficiency in water supply systems in rural Colombia. Montpellier, France. June, 2022. Speaker.

Amsterdam International Water Week (AIWW). The water use efficiency (WUE) in peri-urban and rural water supply systems – water use and behaviour. Amsterdam, The Netherlands. November,2021. Poster presentation.

15th Delft Institute for Water Education (IHE) PhD Symposium. Collaborative Water Resource Management for a Water Secure World. “Human water behaviour: a socio-hydrology approach to improve the efficiency use of water". Delft, The Netherlands (online). October, 2021. Speaker.

1st Sociohydrology Conference – Delft 2021. Understanding the (in)efficient water use behaviour of users in rural areas of Valle del Cauca province, Colombia. Delft, The Netherlands. September, 2021. Speaker.

European Geosciences Union (EGU) General Assembly. Meta-analysis of human water behaviour underlying water use efficiency. Vienna, Austria (Online). May, 2020. Speaker.

Protocol io

Adla, S., Pande, S., **Callejas M. Diana C**. (2023): Guidelines to conduct socio-hydrological surveys to understand human behaviour. Protocol integer ID: 75802. March 15th, 2023. https://www.protocols.io/view/guidelines-to-conduct-socio-hydrological-surveys-t-cm92u98e

Ethical approval

Date 03-May-2022
Contact person Dr. Cath Cotton, Policy Advisor Academic Integrity
E-mail c.m.cotton@tudelft.nl

Human Research Ethics Committee
TU Delft
(http://hrec.tudelft.nl/)

Visiting address
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P.O. Box 5015 2600 GA Delft
The Netherlands

Ethics Approval Application: Understand water use to increase water use efficiency for water sustainability
Applicant: Callejas Moncaleano, Diana

Dear Diana Callejas Moncaleano,

It is a pleasure to inform you that your application mentioned above has been approved.

Please note that this approval is subject to your ensuring that the following condition is fulfilled: please include in the opening statement more information on what is expected from the participants, issues about privacy, and how data will be managed, used and published. Additionally, please make it available in the local language.

Good luck with your research!

Sincerely,

Dr. Ir. U. Pesch
Chair HREC
Faculty of Technology, Policy and Management



TU Delft

