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SOCIO HYDROLOGICAL OBSERVATORY FOR WATER SECURITY: CONCEPTUALIZATION AND STUDY CASE IN SÃO CARLOS, BRAZIL

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FELIPE AUGUSTO ARGUELLO DE SOUZA

SOCIO HYDROLOGICAL OBSERVATORY FOR WATER SECURITY: CONCEPTUALIZATION AND STUDY CASE IN SÃO CARLOS, BRAZIL

Master thesis presented at São Carlos School of Engineering, University of São Paulo, in partial fulfillment of the requirements for obtaining the Degree of Master in Science: Hydraulics and Sanitation Engineering.

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Statistics reveal that few Brazilians have the opportunity to be enrolled in any undergraduate course. These numbers are even lower when we analyze those who have access to public universities. Some people say I am blessed to have this opportunity, others say I am lucky and some say I had worked to be here, so it is my merit. I am not the best person to affirm why I am here at this position, but any other guy in his mid-twenties. The only thing I can say is that I am very thankful for all the opportunities I was given so far and I hope to make it worth all the time, money and expectation that the people listed below have put on me.

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ABSTRACT

SOUZA, F. A. A. **Socio Hydrological Observatory for Water Security: conceptualization and study case in São Carlos, Brazil**. 2019. 97 f. Thesis (Master) – São Carlos School of Engineering, University of São Paulo, São Carlos, 2019.

The need to better comprehend the relationship between societies and the hydrological cycle led scientists to develop sophisticated mathematical models in order to predict how these relationships will be in the future. However, some transformations might not be predicted in such socio-hydrological models, what makes necessary to search for new methods to build scenarios. In this way, the present work seeks to understand how societies will change the way they deal with water resources regarding different drivers of change, such as population growth, changes in climate, land cover, patterns of consumption and influence of governmental institutions. To do so, this work employs not only official data sets that are public available, but also information provided by citizens through citizen observatories concepts of crowdsourcing, participatory governance and environmental monitoring. Such volunteered information is based on their own experiences, knowledge and individual patterns regarding water management and sanitation aspects from the study area, São Carlos city. The conclusions reveal that the new tool presented in this work, the Socio-Hydrological Observatory for Water Security (SHOWS), makes possible to outline future trajectories of coevolution in coupled human-water system and provide assessment on water security scenarios. This work integrates the water security component facing climate changes, from INCT-MC2 (FAPESP 2014/50848-9), contributes to better comprehend socio hydrological aspects in UK Academies (FAPESP 2018/03473-0) and provides a new tool, the SHOWS, which assists decision makers in resilient cities, in the context of CEPID/CEMEAI (FAPESP 2011/51305-0) e do SPRINT-Warwick (FAPESP 2018/08413-6). At international level, it is a contribution to the activities of "Panta Rhei – Everything Flows 2013-2022", promoted by the International Association of Hydrological Sciences, which seeks to understand, estimate and predict the hydrological dynamics to support societies under change.

Keywords: Socio-Hydrology, Citizen Observatory, Water Security, Climate Change, Citizen Science, Water Footprint.

RESUMO

SOUZA, F. A. A. **Observatório Sócio Hidrológico para Segurança Hídrica: Definições e estudo de caso em São Carlos, Brasil**. 2019. 97 f. Dissertação (Mestrado) – Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2019.

A necessidade de compreender as relações entre as sociedades e o ciclo hidrológico levou cientistas a elaborarem sofisticados modelos matemáticos para prever como estas relações serão no futuro. Porém, determinadas transformações podem não ser previstas nestes modelos sócio-hidrológicos, sendo necessário recorrer a novos métodos para elaborar cenários. Desta maneira, o presente trabalho busca entender como as sociedades irão modificar a maneira que lidam com os recursos hídricos frente aos vetores de mudanças, como crescimento demográfico, alterações climáticas, mudanças do uso e ocupação do solo, influência de instituições governamentais e padrões de consumo da população. Para isto, este trabalho emprega não somente o uso de dados oficiais, disponibilizados em plataformas públicas, mas também as informações fornecidas por cidadãos através dos conceitos dos observatórios cidadãos, como crowdsourcing, governança participativa e monitoramento ambiental. Estas informações voluntárias são baseadas em suas experiências, conhecimentos e padrões individuais em relação a aspectos necessários a gestão dos recursos hídricos e dos sistemas de saneamento da área de estudo, o município de São Carlos. Ao fim, conclui-se que, a partir da ferramenta Observatório Sócio Hidrológico para Segurança Hídrica (SHOWS), é possível interpretar possíveis trajetórias de coevolução entre os sistemas sociais e naturais de maneira a avaliar os cenários de segurança hídrica. Este estudo integra a componente de segurança hídrica frente às mudanças climáticas do INCT-MC2 (FAPESP 2014/50848-9), contribui para a compreensão dos aspectos sócio hidrológicos do UK Academies (FAPESP 2018/03473-0), além de testar uma nova ferramenta, o SHOWS, que serve de auxílio à tomada de decisão em cidades resilientes, no contexto do CEPID/CEMEAI (FAPESP 2011/51305-0) e do SPRINT-Warwick (FAPESP 2018/08413-6). Em âmbito internacional, é uma contribuição às atividades da década científica "*Panta Rhei – Everything Flows 2013-2022*", promovida pela *International Association of Hydrological Sciences*, a qual busca entender, estimar e prever dinâmicas hidrológicas para apoiar sociedades sob mudanças.

Palavras-chave: Sócio Hidrologia, Observatório Cidadão, Segurança Hídrica, Mudanças Climáticas, Ciência Cidadã, Pegada Hídrica.

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LIST OF ABBREVIATIONS

ANA	–	National Water Agency
BOD	–	Biochemical Oxygen Demand
BraSIS	–	Brazilian Sanitation Information System
CETESB	–	Environmental Company of São Paulo State
CO	–	Citizen Observatory
CPI	–	Consumer Price Index
ENC	–	Environmental National Council
ERC	–	Energy Research Company
GDP	–	gross domestic product
IBGE	–	Brazilian Institute of Geography and Statistics
ICT	–	Information and Communication Technologies
MGRB	–	Mogi Guaçu River Basin
NPV	–	Net Present Value
NWRP	–	National Water Resources Policy
RCP	–	Representative Concentration Pathway
SEADE	–	*Fundação Sistema Estadual de Análise de Dados*
SHOWS	–	Socio-Hydrological Observatory for Water Security
SR	–	Situation Report
TJRB	–	Tietê-Jacaré River Basin
TJ-RBC	–	Tietê-Jacaré River Basin Committee
VGI	–	Volunteered Geographic Information
WF	–	Water Footprint

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1 GENERAL INTRODUCTION

Modern societies have observed and recognized that some vectors - such as population and economic growth, shift in rain regimes, increase in the temperature and changes in land use - may threaten water security where humans are settled. They threaten not only the availability in terms of water quantity, but also compromise the water quality. As consequence, the concern with public water supply, food production, hydropower electricity, economic activities and ecosystem conservation led scientists, practitioners and general population search for adaptive strategies. The recognition of these traditional challenges and the imminent effects caused by changes in global climate reported by the Intergovernmental Panel on Climate Change led global leaders to sign the Sustainable Development Goal, what make every country committed with tackling those effects.

Adding to this, collecting information remains a big challenge for water resources sciences and management during the last years. Despite technological advances, making prediction in river basins with little or no measurements, as well as collecting accurate data regarding water consumption, are still a common goal of many scientists in different regions of the world. This is mainly due to the lack of sensors to perform measurements, which have several reasons, such as implementation cost, maintenance complexity, risk of theft and lack of experience of operator. In this way, the transformation in computer technologies brought tools that help hydrologists to overcome the barriers imposed by the lack of measurements. These tools not only enhanced public well-being, but also enabled citizens to perform tasks that help on knowledge generation.

The procedure of engaging citizens in data gathering is worldwide recognized and defined as citizen science since early 90s. It brought important improvements to science by pushing citizens to observe and report the environment, which was improved by the advances of information and communication technologies. However, the concept of citizens goes further than describing the engagement of volunteers in knowledge creation, it is also related to public participation in governance.

By the other side, to make water governance efficient, it is necessary to think further and make predictions about possible trajectories of evolution. Understanding how humans will consume water and how water will be available is not an easy due to many arising vectors of change that were aforementioned. To make those predictions about possible trajectories, socio-hydrology proposes to understand the feedbacks between human and water systems. Several works employed feedback loops, mathematical modelling based on time series, comprehension on memories and values effects, but few have asked the citizens what they imagine it is going happen in the future.

In order to comprehend the possible trajectories and feedbacks between human and physical systems, the present study focused on developing a concept that integrate the principles of socio-hydrology to the water security assessment by employing the citizen observatory methodology. It was possible thanks to the creation of the Socio-Hydrological Observatory for Water Security (SHOWS), which comprises the three aforementioned scientific fields. The concept of this tool is worked in the following chapter and two case studies are present, one at laboratory scale the second and on the ground experiment.

This work was supported by FAPESP [grant nº 2018/08413-6], which provided a broad discussion regarding the employment of citizen observatories into water research and involved researcher from the Department of Hydraulics and Sanitation, the University of Warwick and the Institute of Mathematic Sciences and Computation; CNPq 465501/2014-1 and FAPESP 2014/50848-9 INCT-II, which aim at understanding the effects of climate change towards water security component. It was funded by CAPES PROEX [PPGSHS EESC USP] and CNPq [grant nº 165026/2018-9]. This work is also a contribution to the international Panta Rhei Decade Water & Society (MONTANARI et al., 2013) and is part of the Water Security Component of the Brazilian Institute of Science and Technology for Climate Change (INCT-MC2).

1.1 TEXT ORGANIZATION

This master thesis is organized in four chapters. The first one is this introduction, which provides an overview regarding what is the background of the working hypothesis and how it is linked to the objectives and the methodology employed. The following two chapters describe the respective methodology and results from SHOWS' experiments. Finally, the last chapter present the conclusion and lessons learned from these experiments and point out recommendations for future works.

In **chapter two**, the concept of SHOWS and all its backgrounds is developed. We link the two emerging fields – socio-hydrology and citizen observatories – to the analysis of possible trajectories in terms of water security. We employ the variables from the dynamic framework proposed by Srinivasan; Konar; Sivapalan (2017) to make quantitative assessment of such trajectories at a laboratory scale.

In **chapter three**, we follow the recommendations from previous conclusions, we run a new experiment with real citizens from São Carlos city and we propose more “touchable” variables to be measured. Once again, we prove that, even changing the water security assessment to the water footprint accounting, citizens are able to contribute on scenario building and can provide useful insights in order to make predictions regarding the interactions of human and water systems.

Finally, **chapter four** summarizes the conclusions from each experiment. It is presented what limitations, lessons could be inferred, and what are the next steps towards the use of volunteer information to make predictions about possible trajectories.

1.2 RESEARCH HYPOTHESIS

Building scenarios in order to understand how societies will consume water is not an easy task. Adding to the traditional lack of measurements and time series, mathematical models may not capture transformations regarding changes in human patterns, political shifts and economic choices. Instead of building scenarios employing “what if…” assumptions, asking citizens what they think will happen in the future can be a valuable method to provide a quantitative assessment and capture such transformations.

1.3 GOAL AND OBJECTIVES

1.3.1 Goal

Build scenarios of possible trajectories by integrating public available data sets with a socio-hydrological citizen observatory as source of information, which captures individual patterns, beliefs and transformation on society.

1.3.2 Objectives

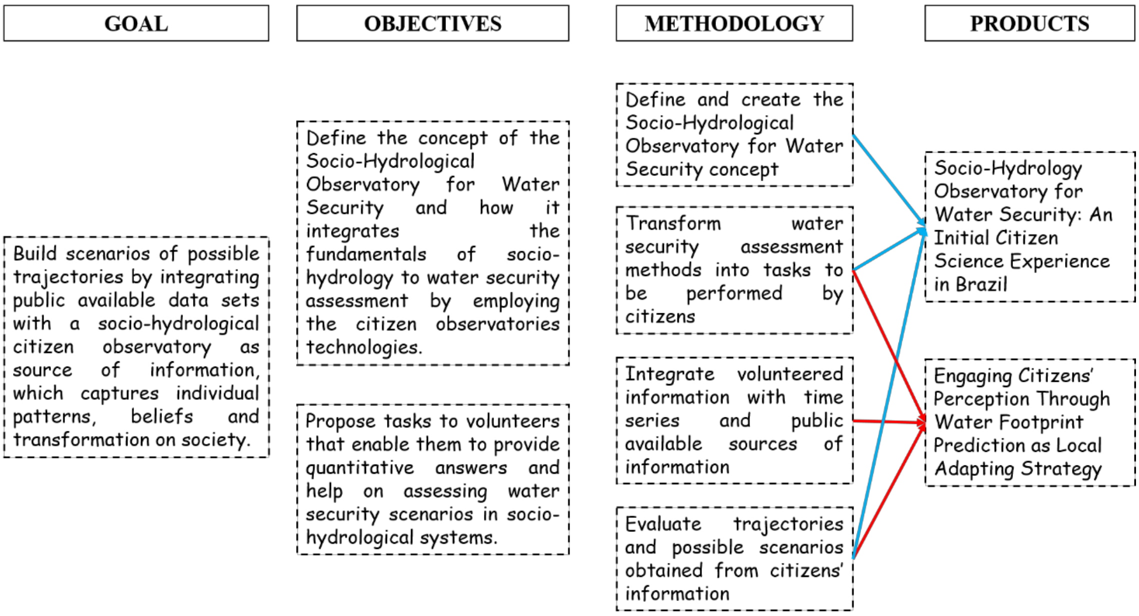
- Define the concept of the “Socio-Hydrological Observatory for Water Security” and how it integrates the fundamentals of socio-hydrology to water security assessment by employing the citizen observatories technologies.

- Propose tasks to volunteers that enable them to provide quantitative answers and help on assessing water security scenarios in socio-hydrological systems.

1.4 RELATIONSHIP BETWEEN OBJECTIVES, METHODOLOGY AND PRODUCTS

A flowchart of this study is presented in Figure 1. It correlates the specific objectives to the methodology employed and the products resulted from each experiment. The products correspond to chapters of this master thesis, which will be submitted to a journal.

Figure 1: Interconnection between goal, objectives, methodology and products



1.5 REFERENCES

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SRINIVASAN, V.; KONAR, M.; SIVAPALAN, M. A dynamic framework for water security. **Water Security**, v. 1, p. 4225, 2017.

2 SOCIO-HYDROLOGICAL OBSERVATORY FOR WATER SECURITY: AN INITIAL CITIZEN SCIENCE EXPERIENCE IN BRAZIL

A modified version of this chapter was submitted as: SOUZA, F. A. A.; DEGROSSI, L. C.; MENDIONDO, E. M.; ALBUQUERQUE, J. P.; DELBEM, A. C. B. Socio-Hydrological Observatory For Water Security: An Initial Citizen Science Experience In Brazil. **Hydrological Sciences Journal.**

Abstract: In recent years, many regions worldwide have encountered certain difficulties in predicting water availability and hydrologic hazards due to the relationship between water and human activities. Considering this, the need to better understand this interaction has led scientists to involve the general public in collecting data activities using information and communication technologies. However, the lack of methodologies for gathering data from citizens in the water security domain has led us to integrate the fundamentals of socio-hydrology, citizen science as a social innovation and a dynamic framework of water security in order to conduct a new methodology using a tool called Socio-Hydrological Observatory for Water Security (SHOWS), which acknowledges how citizen science performs quantitative assessment through interdisciplinary sciences.

Keywords: Citizen Observatory, Water Security, Socio-hydrology, citizen science

2.1 INTRODUCTION

Socio-hydrology has emerged as a new science that focuses on understanding the co-evolution of human and water systems (SIVAPALAN et al., 2012). This understanding explores the possible trajectories of this coupled system based on historical events and future changes that hydrologists and sociologists would never predict. Therefore, to better comprehend these previous and future patterns, Sivapalan et al. (2014) point out three main goals: 1) multiscale analyses of space and time and the dynamics of socio-hydrologic processes; 2) to explain, interpret and predict socio-hydrologic responses and; 3) respect and consider cultural, political and economic values related to water. To advance this new science, some studies have strongly recommended developing new models involving these interrelationships based on past events (TROY; PAVAO-ZUCKERMAN, 2015). In fact, some models and discussions concerning hydrological and social variables have already been conducted in previous studies concerning floods (Di BALDASSARRE et al., 2015; BARENDRECHT et al., 2017; LOUCKS, 2015), ancient civilizations (KUIL et al., 2016), cultural values (SANDERSON et al., 2017) and agricultural aspects (ELSHAFEI et al., 2014).

In the Brazilian context, the current national water law (law 9.433/1997) promotes the River Basin Committee as an institution for water resources management, which is responsible for developing the Water Resources Plan of its respective river basin. These committees must represent every sector of society and engage public participation. This participation aims to trigger people's attention through public consultation, technical meetings and workshops. However, some citizens have never heard about these tools for water management or are barely represented in those committees. Considering this lack of representativeness on one hand and the socio-hydrology premises on the other, we have been searching for tools that can capture people's perception, knowledge and concerns in order to interpret possible trajectories of hydrological factors and social components so as to contribute to local water governance.

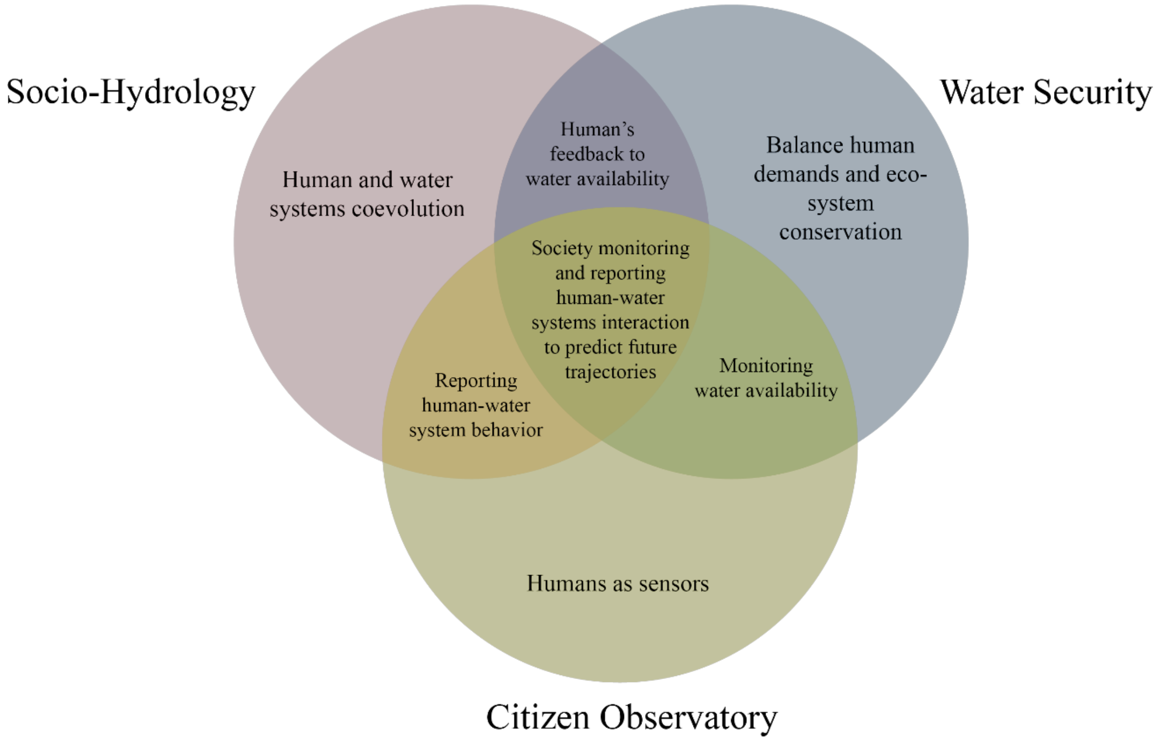
One of the available tools that can fill this gap is Citizen Observatory (CO). This type of technology aims at observing natural and social phenomenon, enabling citizens to play an active role in environmental management (WEHN et al., 2015), which is possible due to the background of the COs. They represent the next phase of citizen science (BUYTAERT et al., 2014) due to the advances in information and communication technologies. In this paper, CO is used to better understand possible trajectories of the coupled human-water systems from citizens' points of view based on the dynamic framework for water security proposed by Srinivasan et al. (2017).

The working hypothesis is that citizens can contribute to water governance by reporting their own observation and comprehension on natural and social phenomenon through the Socio-Hydrological Observatory for Water Security (SHOWS). These reports reveal important aspects regarding three variables (SRINIVASAN et al. 2017), which involve water consumption aspects and personal/collective behaviors, enabling decision makers and scientists to infer possible trajectories of coupled human-water systems. To do so, Section 2 of this paper analyzes in what way socio-hydrology, water security and COs could be integrated, what points they have in common and how the Socio-Hydrological Observatory for Water Security can help us to answer the research question. In Section 3, we describe the methodology adopting SHOWS and its first application. Then, in Section 4 we present the results, limitations and potential bias involved in this initial experiment. Finally, in Section 5 we analyze these results and describe some steps to be taken to obtain more accurate results and carry out a more in-depth analysis for future studies.

2.2 BACKGROUND

The conceptual framework we built is based on three knowledge areas, which are represented by three different circles namely Socio Hydrology, Citizen Observatories, and Water Security (Figure 2). They are fundamental components for the SHOWS conceptualization. We also discuss the knowledge gaps that emerge from the integration among these three research fields, which are underexplored and allow contributions to decision-making processes on water resources management including public participation.

Figure 2: Relationships among Socio-Hydrology fundamentals, Water Security concerns and Citizen Observatory features



2.2.1 Citizen Observatories

A vast body of literature addressing citizen observatory has defined its current definition, which is used today for scientific and governance purposes. Citizen science was the first milestone in scientific contribution that engaged citizens in tasks aiming at gathering data for scientists (BUYTAERT et al., 2014). The first projects date back to the 1990s, where citizens were asked to perform simple activities, such as observing and reporting nature. In fact, scientists noticed that engaging a considerable amount of volunteers could provide a great contribution because they played an alternative role in environmental monitoring and this could help data generation (MCKINKLEY et al., 2017). This process of inviting volunteers to carry out specific tasks in order to collect data for scientific purposes was later defined as Citizen Science (BURGESS et al., 2017; CATLIN-GROVES, 2012). Furthermore, as people have more and more cell phones and mobile applications, this led to an evolution of Information and Communication Technologies (ICT). These ICTs not only brought benefits to citizens' everyday lives, but also facilitated the way data could be gathered (McCABE et al., 2017). Mobile technologies are also responsible for encouraging more volunteers to take part in crowdsource projects due to the support to users in performing specific tasks. As a result of these advances to create online platforms for citizen science purposes, merely observational monitoring activities have been replaced by reports in mobile applications with the possibility of being in real time (PALEN; LIU, 2007).

Data provided by citizens can be useful for many purposes. Flood-related information, for instance, can be used by decision makers to identify the intensity and the location of a flood event. On the other hand, this same information can be used: i) to determine rain intensity (RESTREPO-ESTRADA et al., 2018); ii) for forecasting models (FAVA et al., 2014) and; iii) to create collaborative maps (ALBUQUERQUE et al., 2016) and iv) to identify flooded areas (HIRATA et al., 2015). When the data provided by citizens have a geographic reference, it is called Volunteered Geographic Information – VGI (GOODCHILD, 2007), which has been increasingly considered a valuable resource for natural hazard preparedness and mitigation (KLONNER et al., 2016). The aforementioned examples describe how VGI has been used in hydrological disasters and how VGI is collected by different collaborative activities (ALBUQUERQUE et al., 2016), i.e. Social Media, Collaborative Mapping and Crowd Sensing (DEGROSSI et al., 2018).

Finally, Citizen Observatories can be defined as platforms used for obtaining specific information from citizens (MIORANDI et al., 2013), which deal with volunteered geographic information, as well as big data (SEE et al., 2016). Although few hydrologists have adopted this tool in their studies (ASSUMPÇÃO et al., 2017; BUYTAERT et al., 2014), it represents a social innovation that presents different characteristics depending on the area of application, data provision and its goals (WHEN; EVERS, 2015), ranging from floods to water scarcity. This innovation concerns its capability of capturing citizens' observation and comprehension on natural or social phenomenon in order to contribute to governance.

Some specific definitions were assigned to COs. Liu et al. (2014) provide a conceptual approach on Citizen Observatories. They state that no clear definition was available at that time, but a CO supporting governance should raise public awareness and allow dialogue and data exchange among citizens, scientists and decision makers. Wehn et al. (2015) also highlight the link between data gathering and citizens' participation in decision making through data provision, and knowledge/feedback exchanges. In other state-of-art reviews on Citizen Observatories, Palacin-Silva et al. (2016) uphold that the great characteristic about COs is the capability of observing social and environmental phenomenon to support participatory governance, which deals with big data systems through different platforms, and may include websites, mobile apps and sensor networks. Grainger (2017) emphasizes that COs are the most sophisticated phase of citizen science due to the possibility of environmental management. The author describes other features of Citizen Observatories, such as bidirectional (or two-directional) information flow, multi-functions of citizen contributions, and support for governance. Finally, Gharesifard et al. (2017) provide a technique for benchmarking Citizen Observatories. The authors compare several scientific projects using COs and identify the dimensions involved. Therefore, all the reviews converge to the same definition of the CO's main aspect: its capability of capturing citizens' observation and comprehension on natural or social phenomenon in order to contribute to governance. Examples of this include WeSenseIt and SCENT, which are two large European citizen observatory projects. The former involves monitoring water to raise communities´ awareness about floods (LANFRANCHI et al., 2014), while the latter collects data about land use/land cover (ASSUMPÇÃO et al., 2017; GRAINGER, 2017). Other observatories and respective purposes are listed in Table 1.

Table 1: A Review of Scientific Projects Involving Citizen Engagement

Project	Purpose	Website
CITI-SENSE	Air Quality	http://www.citi-sense.eu
Air Quality Egg	Air Quality	https://airqualityegg.wickeddevice.com
Citclops	Air Quality	http://www.citclops.eu
OMNISCIENTIS	Air Quality	http://www.omniscientis.eu
COBWEB	Biosphere	http://cobwebproject.eu
The Open Air Laboratory	Environmental Monitoring	https://www.opalexplorenature.org
Big Butterfly Count	Butterfly Observation	http://www.bigbutterflycount.org
COMBER	Marine Biodiversity Observation	https://comber.hcmr.gr
Cyclone Center	Cyclone Monitoring	https://www.cyclonecenter.org
SCENT	Land Cover/Use Monitoring	https://scent-project.eu
SnowTweets	Snowfall monitoring	http://snowtweets.uwaterloo.ca
Observatório Cidadão	Flood Risk Observation	http://www.agora.icmc.usp.br/enchente/
WeSenseIt	Water Resources Governance	http://www.wesenseit.eu

Although there are several COs in the literature, there is a lack of a standardized approach for integrating them to the concepts of socio-hydrology and water security. Therefore, the main aim of this work is to establish an approach in order to obtain water security information from citizens based on their own relationship with water disposal and other variables from the region they live in. To do this, we propose a brief summary illustrated in Figure 2, where initially the three areas do not have any connection with each other. The yellow circle represents COs and their main objectives: a tool where citizens behave as sensors when observing important parameters of environmental variables. (GHARESIFARD et al., 2017; WEHN et al., 2015; WHEN; EVERS, 2015). In other words, a tool that allows citizens to behave as sensors.

2.2.2 Pursuing Water Security in Socio-Hydrological Systems

Simultaneously, the red circle represents socio-hydrology studies. Sivapalan et al. (2012) introduced this interdisciplinary field proposing to understand the two-way feedback in coupled human-water systems. A series of debates about how to include social variables into mathematical modelling was provided by several researchers (BALDASSARRE et al., 2015; GOBER; WHEATER, 2015; LOUCKS, 2015; MONTANARI, 2015; SIVAPALAN, 2015; TROY; PAVAO-ZUCKERMAN, 2015) and further discussions incorporated scientists from different backgrounds (SEIDL; BARTHEL, 2017; XU et al., 2018) in order to incorporate humans as agents into the hydrological circle. Although socio-hydrological modelling was able to quantify and interpret social phenomenon at different scales (GARCIA et al., 2016; GONZALES; AJAMI, 2017; KUIL et al., 2016; ROOBAVANNAN et al., 2017; SRINIVASAN et al., 2010), this science concentrates on innovative methods of gathering data to understand water security in poorly gauged places (McCABE et al., 2017; ROOBAVANNAN et al., 2018).

Water security studies have increased and evolved over the years. All these studies analyze different scales, levels and challenges in terms of spatial, temporal, economic, social and hydrologic features (BOGARDI et al., 2012; COOK; BAKKER, 2012; KUMMU et al., 2016; PEREIRA; FREITAS, 2017; SINGH, 2017). This leads to a variety of multi-faceted analyses that incorporate various and contrasting aspects (VARIS et al., 2017). Therefore, the focus we propose in this study is defined inside the blue circle. Societies have to properly manage the resources available to attend household, economic and environmental demands, but water consumed by these sectors should not affect the quality and quantity of water for future generations.

2.2.3 Citizen Observatories x Water Security x Socio-Hydrology

Analyzing the interaction among these scientific fields, there are some under explored subareas. Understanding human responses to water resource availability is a common objective of the red and blue circles. This implies in understanding people's behavior facing the risk of water scarcity. Some possible scenarios may occur, such as conscious actions seeking for optimum consumption of water resources, with or without an existing risk of scarcity. This represents a proactive scenario that can bring positive consequences in terms of security for future generations. However, another possibility is a high intensity depletion of the water available, which represents a threatening situation as a result of indifferent behaviors to the risk of scarcity due to economic choices, or simply, the lack of knowledge about the consequences of those consumption patterns. Both behaviors can be found in different regions under different conditions. However, some citizens may not distinguish whether their actions are good or not for ecosystem sustainability, this is the role of decision makers, who are responsible for implementing policies.

Another field to be explored emerges from the interaction between yellow and blue circles. People's observations can be used to obtain information and monitor the quantitative and qualitative water aspects. This possibility would be a great contribution for decision makers by involving individuals in monitoring water resources availability and providing data through the COs for water resources management purposes (FRATERNALI et al., 2012; VOINOV; BOUSQUET, 2010). Similarly, COs can be an effective tool to report people's feedback due to hydrologic processes and vice versa (the intersection between red and yellow circles). For example, rivers that cross regions where people have inefficient or even no access to sanitation systems are targets for pollution loads. Therefore, people may help monitor these sources of pollution by making reports at COs. This example illustrates how anthropological factors affect water factors. By changing perspectives, COs can also be a tool where people report the material damage they have experienced due to extreme hydrologic phenomena such as heavy rains or a severe drought (GUZMÁN et al., 2017; MOHOR; MENDIONDO, 2017). In both cases, people are able to provide required information by insurance companies and government agencies in order to evaluate what economic and social impacts disasters have caused. These cases represent the mix of socio-hydrology and citizen observatories and are quite effective by engaging volunteers for decision-making and scientific purposes.

2.2.4 Research question

Finally, joining all these possibilities, an opportunity arises to bring people together to monitor not only natural resources and their own behaviors separately, but also to perform these two tasks together. Monitoring and reporting these paradoxes allow us to better understand the goals of socio-hydrology and answer questions such as “What percentage of available resources do societies consume?”, “How do they consume this?”, “What do they do to improve this situation?” Although these questions allow us to understand present and past status of water security with information available, possible trajectories need to be estimated that traditional mathematical models are unable to predict. Thus, considering these unpredictable changes, such as climate, politics and economic choices, can citizens help delineate which directions the trajectories will probably point to, based on their knowledge and beliefs? This is the main question that emerges when we analyze the three knowledge areas in Figure 2.

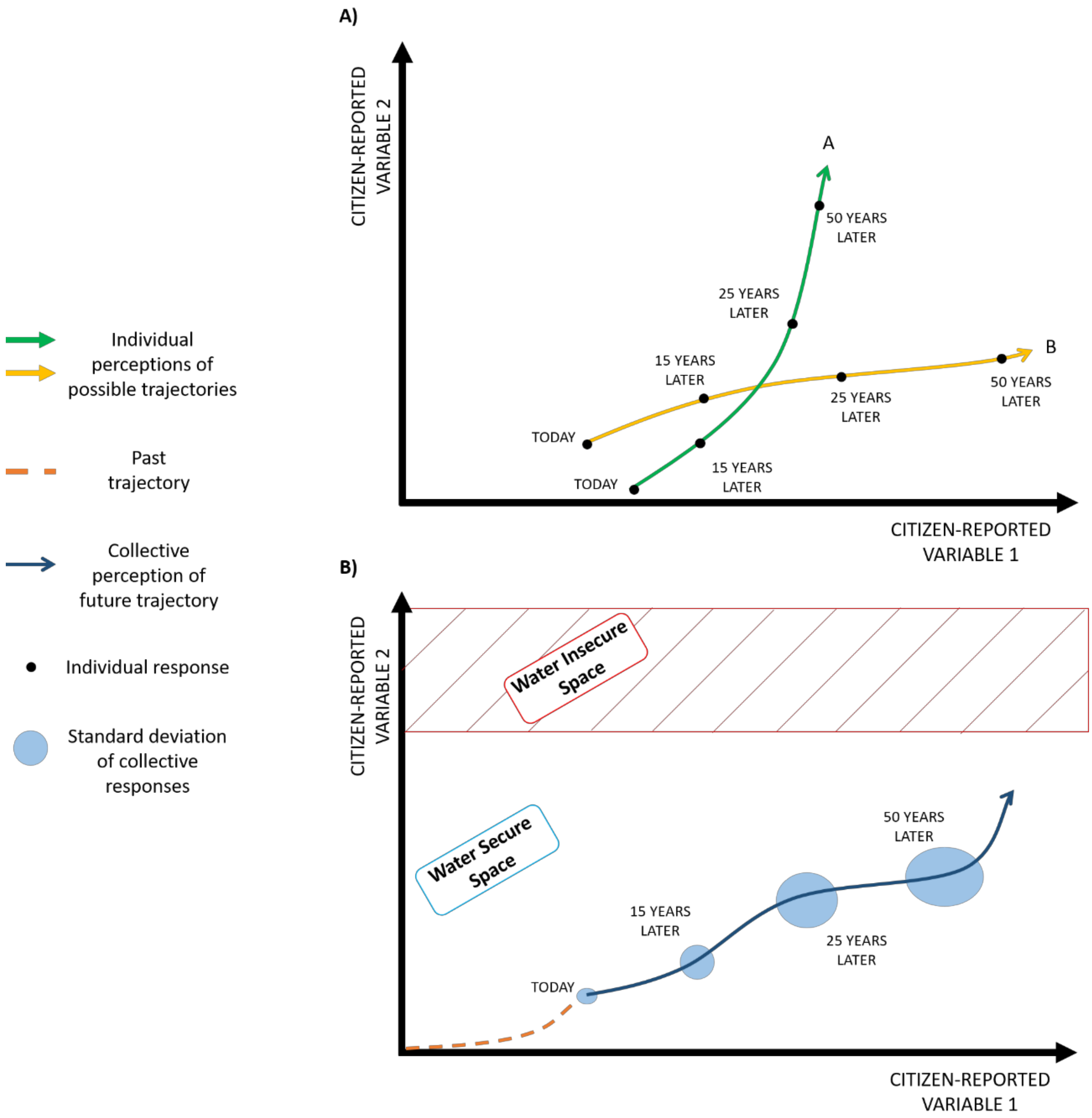
Engaging citizens to monitor the environment does not only entail quantifying water resources availability, but also how we will probably be consuming these resources under the influence of the aforementioned changes. Therefore, the lack of models that can outline possible trajectories of coevolution by inputting observational data from volunteers led us to choose the Dynamic Framework for Water Security, proposed by Srinivasan et al. (2017), to test this possibility. The authors propose a framework comprising three variables, which concerns hydrological, social and structural aspects. When plotted together, conclusions can be drawn about future trajectories of water security based on collective demands, infrastructure and economic activities. These variables are:

i) the water resource utilization intensity, which means the proportion between water consumption to produce goods and services (PW) and the available water resources (P+I). An index which can be studied as a fraction (PW/P+I) that interprets what percentage of water we have been consuming from the total amount available;

ii) the importance given to the water infrastructure to guarantee its distribution, not only for the present moment, but also in the future. This variable is denoted as the ability of society to invest in Trade and Technology (TT);

iii) the ratio of water to produce goods in the studied watershed (PW) and the water footprint of consumed goods in the studied watershed (CW). This ratio (PW/CW) illustrates what economic and consumption patterns the population presents and the water footprint fluxes (HOEKSTRA et al., 2011).

Figure 3: Illustrative description of SHOWS' first experiment, where A) is the individual responses from volunteers and B) is the water security assessment based on the collective perception of future trajectory of coupled human-water system.



Therefore, we created the SHOWS, a tool that integrates the three aforementioned fields, and we ran an initial experiment to gather information about future changes based on volunteers' knowledge and beliefs regarding these variables. Finally, we discuss how the outlined trajectories and behaviors can be interpreted and what conclusions we can infer. The framework of this first experiment is illustrated in Figure 3 as an adaptation of the framework proposed by Srinivasan et al. (2017), which represents a trajectory regarding two out of the three variables. In part A) of Figure 3, the spaghetti graph indicates possible trajectories based on individual perception, how each citizen imagine the variables will evolve in the future. These trajectories can present paradoxical behaviors since they translate individual patterns and beliefs. The part B) provides a water security assessment based on collective answers. The multiple spaghettis are replaced by only one, which represents the future trajectory based on collective perception. This trajectory might point to a secure or insecure scenario in terms of water. The uncertainty is indicated by the blue circle that accounts the standard deviation. The dotted orange line represents the trajectory of coevolution that has already happened. Since it translates a moment prior to the present, volunteers are not required to monitor them. The methodology, results and conclusion are discussed in the following sections regarding the conceptualization proposed

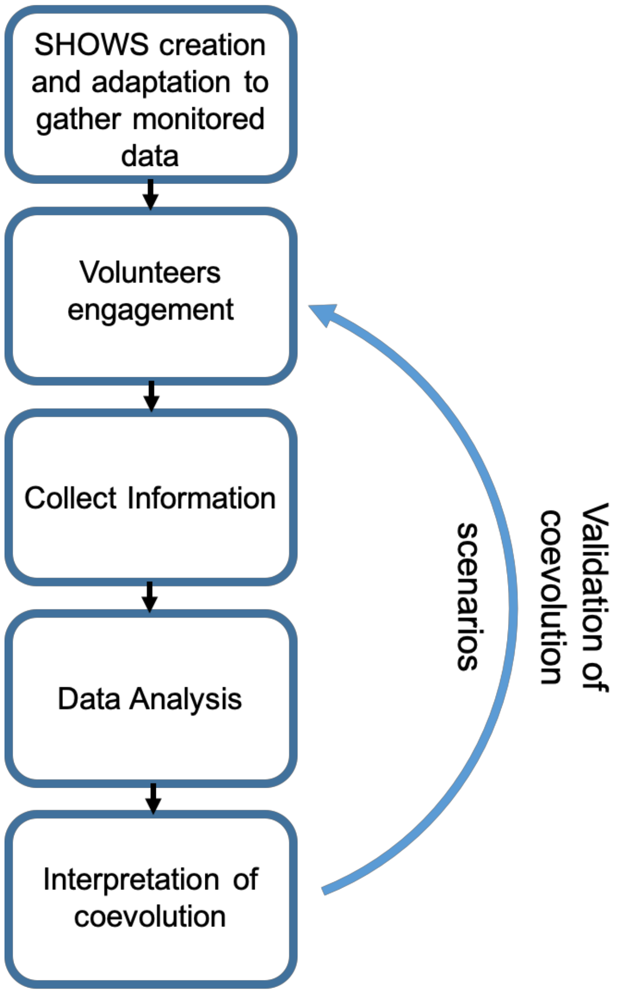
2.3 METHODOLOGY

Observing the environment from the citizens´ perspective is an experiment that must be carefully designed for two main reasons. Firstly, ordinary citizens do not know how to evaluate the current state of water resource availability in their region. In order to obtain the necessary data to calculate the variables proposed by Srinivasan et al. (2017), a questionnaire was developed to facilitate data gathering (see supplementary material). Secondly, there is a need to make the observatory platform accessible to persuade volunteers to help. This includes designing the platform interface for an audience who will perform the tasks. Other dimensions analyzed by Gharesifard et al. (2017) contribute to the good performance of this sort of experiments and they are described in detail in the Results section.

To deal with these aspects, Figure 4 (left hand side) illustrates the flowchart of this first experimental activity. The first step is to design the tasks that volunteers will perform and implement them on the CO platform. In other words, select the variables necessary to delineate trajectories, then, how volunteers can properly observe and report them. With the observatory ready to receive the reports, we need to select which candidates can participate in this experiment and consider how to engage them. This can be done using publicity, personal requests, social media, etc. Therefore, the selected groups make the reports and the CO needs to store the data with the location, answers, photographs or videos. This information needs to be processed, and reports that do not comply with the purpose of the experiment, such as wrong information, must be excluded. Finally, we input the observational data; calculate future scenarios; and finally, the output results show the trajectories that the volunteers believe will happen in the future, based on their knowledge and observations.

In order to validate the information, the observations should be compared to the real data measured by official agencies. However, it is necessary to repeat the previous steps in the future in order to confirm the predictions. A new generation of volunteers would confirm or not the trajectories indicated by the previous generation. As mentioned before, repeating the previous steps will identify how the human-water system evolved, if there were changes in human consumption patterns, if governments paid more attention to water security investments and how the economic choices influenced the resource availability and vice-versa.

Figure 4: Initial task proposed by SHOWS



1) How much of the total food you will consume **in X years**, do you believe will be produced in the city where you live?
2) How much of the total products you will buy **in X years**, do you believe will be manufactured in the city where you live?

3) How much of the total water available in your city do you think will be consumed by households **in X years**?

4) How much of the total water available in your city do you think will be used to make new products **in X years**?

5) How much of the total water available in your city do you think will be consumed by residences **in X years**?

6) How much of the total financial resources that the municipal authorities will have **in X years** will be invested to ensure that there are no shortages?

7) In what way do you think that municipal financial resources will change **in X years**?

2.3.1 Study Field

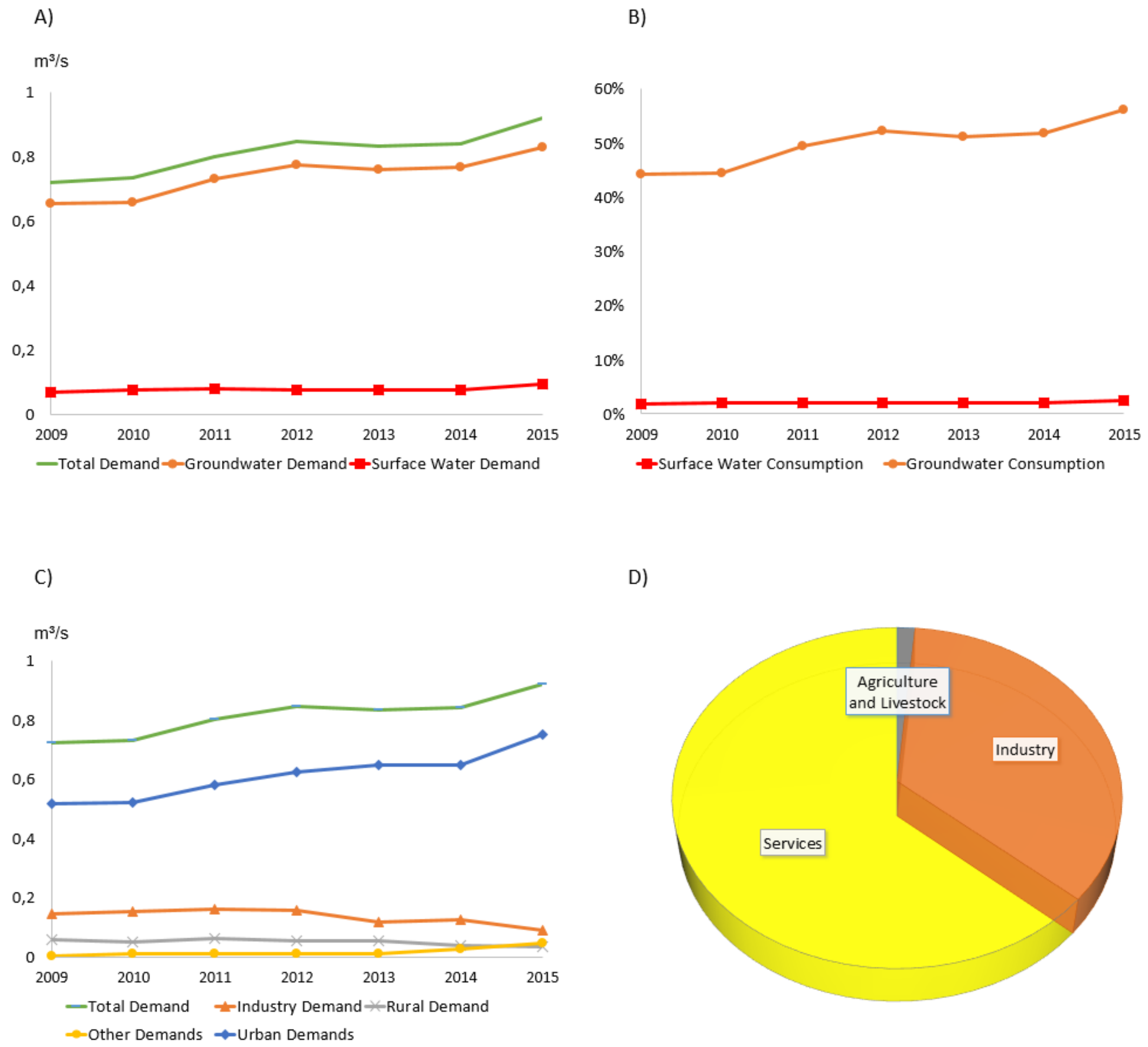
For this first experiment of the SHOWS, an urban watershed was selected. The field of study is the city of São Carlos, where the São Carlos School of Engineering at the University of São Paulo is located. According to the Brazilian Institute of Geography and Statistics (IBGE) and the Fundação Sistema Estadual de Análise de Dados (SEADE), the city has more than 238 thousand inhabitants and a population density of 210.07 inhabitants/km . Local services are responsible for almost half of the city´s gross domestic product, followed by industries, agriculture and livestock, respectively. In terms of water consumption, urban demands are responsible for most of the total demand and have been growing considerably over the years. On the other hand, the economic sectors represent less than half of the urban demands, where the agricultural, livestock and industrial sectors have decreased their demands (see Figure 5).

When analyzing the consumption charts, we conclude that groundwater is mostly responsible for urban supply. However, considering the available water, the exploitable volume of groundwater and the 10-year low-flow, 7-day statistical method (Q7,10), we realize that the depletion of groundwater threatens water availability, since this consumption has reached half of the total available.

2.3.2 Type of participants

In this experiment, anonymous volunteers from the São Carlos School of Engineering at the University of São Paulo, who were students, faculty members and staff, freely accepted to contribute to SHOWS. They were not required to have any previous knowledge about the water resource status in their city. The only requirement was that they had to be living in the city of São Carlos. Oral instructions were given to the volunteers about how to download the mobile app and/or access the SHOWS platform on their computers. All of them did this, as described in Section 3.4. At the end of this questionnaire, a question was asked about whether the volunteers would allow the researchers to post their answers without identifying them. The volunteers could take part in the questionnaire either by using mobile applications, or by the SHOWS website (https://shows.ushahidi.io).

Figure 5: Economical and water consumption aspects of the study field, where each graphic represents: a) Sources of water supply in m /s; b) Percentage of water consumption compared to the total available; c) Water supply for each sector in m /s; d) Contribution of each economical sector to the municipal gross net production in 2015



2.3.3 The observatory platform

The aim of this study was not to create a new platform, but to use an existing one to meet the objectives of the experiment. Therefore, USHAHIDI was chosen to be the online interface of SHOWS. USHAHIDI, which means testimony in Swahili, is a free and open source platform that was developed to map reports of violence in Kenya after the post-election violence in 2008, and it is a good solution due to its crowdsourcing elements that allow a bottom-up flow of information. It was used in previous studies (DEGROSSI et al., 2014) and proved to be a good solution for water related studies. In the context of observatories, USHAHIDI can be used to capture specific information and help with governance decisions in disaster responses, environmental advocacy and transportation information (MORA, 2011).

SHOWS was available on the USHAHIDI website domain and mobile application. Among all the activities offered by the developers, we selected the checkbox option, which allows volunteers to choose only one option of a predefined set of answers and the location option, enabling volunteers to share the location from where the answers were submitted. Both the application and website provide the users with flexibility and encourage more participants to perform the task from wherever and whenever they feel more comfortable to contribute to the experiment.

2.3.4 Participation of volunteers

The task proposed to the volunteers was created in order to receive answers that could reproduce the variables of the dynamic framework for water security proposed by Srinivasan et al. (2017). The task consists of the questionnaire presented on the left-hand side of Figure 4.

Before answering the questionnaire, we checked if the volunteer actually lives in the study field using the location-sharing tool available on the SHOWS website. A usual social phenomenon in the region implies that people, who live in nearby cities, travel daily from other cities to São Carlos, to work and study. At the end of the day, they return to their home town. In these cases, the questionnaire does not apply to these volunteers, because they may not be aware and concerned about the situation of the city.

Questions 1 and 2 analyzed the volunteers´ ability to identify the spatial heterogeneity in production and consumption through the proportion between products that were produced in their city (PW) and consumed products that were produced in their city (CW). The original variable (PW/CW) was suggested to evaluate each item in terms of volume. However, non-experts do not have this type of information unless they search for it. Therefore, it was expected that they could think in terms of units or amounts such as “how much of the food you eat is produced in the city you live in?” This sounds more familiar to non-experts than asking “how much water from the city you live in is consumed to produce the food you eat?”

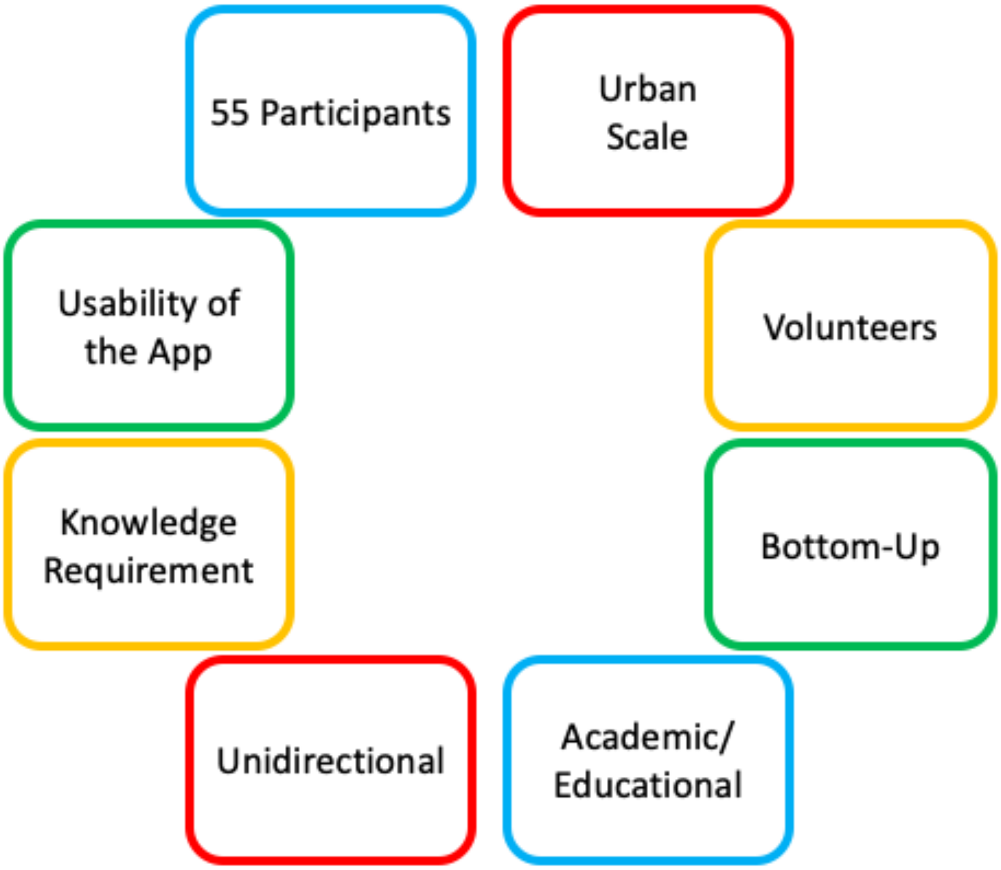
Questions 3, 4 and 5 ask citizens how much of the available resources are used to produce food, goods and how much is consumed by households. This variable is proposed to analyze the intensity of water resource utilization PW/(P+I) and can illustrate how much water each economic sector has consumed and how their consumption patterns will evolve over the years. By answering these questions, people are expected to consider not only past economic choices, but to think further, to analyze how the country's economic situation affects municipal wealth, how climate change impacts its consumption and water resource availability. Finally, Question 6 is an adaptation of the original variable “trade and technology” (TT), which evaluates the ability of societies to invest in structural and non-structural measures to ensure the distribution and access to water. In this case, people are asked to give their opinion, on a percentage scale, about how much local government funding is invested for this purpose. Adding to these questions, people are asked in Question 7 how they imagine the financial resources of their city will change in the future. In fact, this question is still related to the TT parameter, because we evaluate the importance given to this type of investment, and then we evaluate if the total amount of financial resources will vary. The TT variation for future scenarios is the product of the two previous answers.

All these questions were asked for present and future scenarios of 15, 25 and 50 years, which is shown in Figure 4 by "in X years..." At the end of this procedure, the volunteers received no feedback about their answers and we asked them if we could include their answers in this research without identifying them. They also needed to confirm their location using a map or enabling the geolocation setting on their mobile device.

2.3.5 Dimensions of SHOWS’ initial experiment

Regarding the dimensions identified by Gharesifard et al. (2017) for citizen observatories, Figure 6 shows this experimental analysis. In order to contribute to this experiment, 55 volunteers joined this initial experience. Specific knowledge nor a social status were required; all the volunteers were anonymous. In addition, a bottom-up flow of information was adopted, which means that laymen contributed to a specific purpose in a unidirectional communication way whereby people contributed with information, but they were not told whether their answers were right or wrong. As this research is funded by the Brazilian funding agencies for education and research, the income sources are classified as academic/educational. Finally, although no previous knowledge was required, the only effort necessary to accomplish the task was their own knowledge. The only support offered by the platform developers was to give instructions on how to download, access and complete SHOWS research.

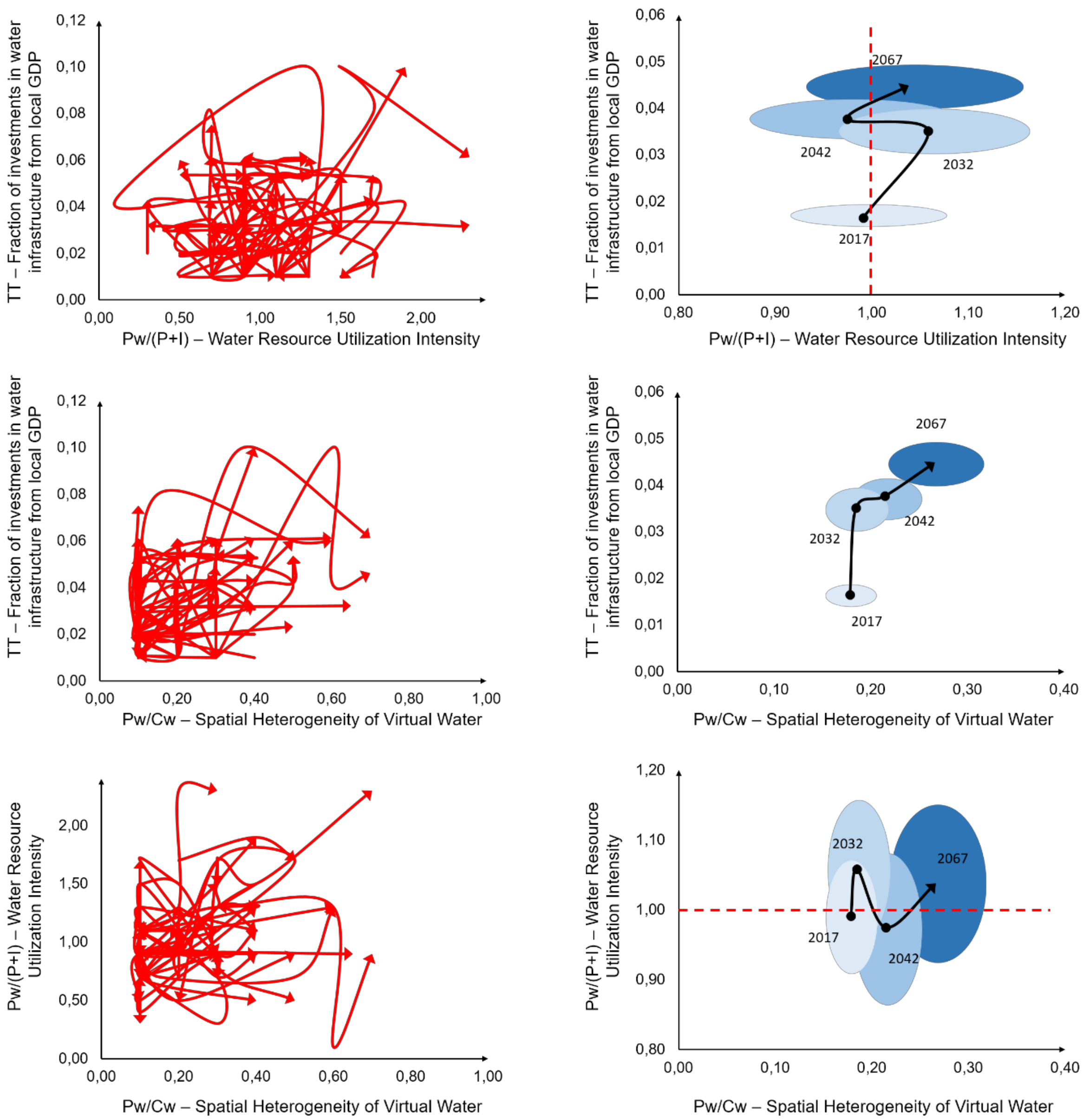
Figure 6: Dimensions and features description of SHOWS initial experiment



2.4 RESULTS AND DISCUSSION

After an exhaustive discussion about trajectories, we finally present them as a result of the experiment Figure 7 illustrates the answers of the task, where the lines that connect each scenario represent the trajectories when plotting the variables against each other. The first column of charts contains several red arrows that represent the responses from each volunteer. As can be observed, volunteers expressed different opinions about these variables regarding how they will vary over time, in terms of possible trajectories and intensity. To better interpret the first column, the second one presents the average of each variable as regards to the time scales presented in Section 3.4 rounded by the confidence interval for each scenario.

Figure 7: Trajectories pointed out by volunteers.



Analyzing the water utilization intensity variable Pw/(P+I), volunteers pointed out the trajectory towards the insecure direction of the graph (top-right). They stated that the city of São Carlos is consuming nearly all the available water resources today and this will become even worse over the next fifteen years. Only then will it diminish, before rising again after twenty-five years. This result may reflect two possibilities. On the one hand, the increasing demand of water by locals. People recognize (probably because of what they read and see on the news) that society is consuming more and more water, so the demand will possibly decrease in the future as a response due to community sensitivity (Elshafei et al., 2014). On the other hand, this variable not only illustrates the demand behavior, but also the resource availability; people may recognize that changes in rain and river regimes threaten the water available to supply society's demand, similar to what happened a few years ago in the region (Nobre et al., 2016). However, if we compare the results to data measured by governmental agencies (Figure 5), we infer that volunteers do not really know how much water we consume from the total amount available. Considering surface water consumption separately, the results are incorrect, but if we include the fraction correspondent to groundwater, their answers are almost correct.

Concerning the variable that assesses the investments made in infrastructure and technology to ensure water supply, volunteers defined a water secure trajectory (top-right). They affirmed that investments will continuously increase for all scenarios. Recognizing local administration skills to ensure water supply security or developing adaptation strategies facing the imminent changes in the hydrological cycle might translate the beliefs of volunteers. This result reveals some important findings to the socio-hydrological context, because investment in sanitation systems is a key driver of water quality and leakage control in Brazil, and it can hardly be predicted by traditional mathematical modelling since it relies on political issues.

Thirdly, we wanted to understand how people imagine the variable related to the spatial heterogeneity in consumption and production will evolve. The aim of these questions was to understand where the products they consume come from, if they are produced in the same city or if they are imported. Therefore, the answers are not expected to be the same for every volunteer because of the different habits each of them has. This is due to economic, cultural and social characteristics. Thus, the mean of the population´s responses represents this variable better. The more participants, the better representation of the society. With a ratio ranging from under 0.20 to nearly 0.30, the results showed that most of the products they consume today are produced externally. However, there is a tendency to consume more local goods in the future, which means a water insecure trajectory concerning this variable (top-right). This directly affects the field of study in terms of water security because it represents higher local water consumption instead of importing virtual water. However, this hypothesis diverges from the official data of water consumption per sector, which indicates a decrease in water consumption by industry, agriculture and livestock. Concerning all variables together, the confidence interval increases over the years. It reveals that not only for mathematical modelling, but also from the citizens' perspective, longer scenarios are followed by higher uncertainties. Volunteers perceived that investments in water infrastructures present less variance than other variables. This fact should be considered in socio-hydrological modelling, because while water demands and availability are calculated based on time series, political influence and its consequences, such as those investments, cannot be predicted in traditional modelling. Thus, asking volunteers what might happen regarding political decisions in water infrastructures is a new method to explore long-term dynamics of water governance (ROOBAVANNAN et al., 2018).

Another important aspect regarding this experiment concerns the target audience. The volunteers who performed the SHOWS task are members of a Brazilian public university, which has around 4,600 people. This number comprises students, faculty members and staff and represents less than 2% of the total inhabitants of the city. However, if we consider the total local population who has any kind of connection to public universities, we should include the population from another university in São Carlos called the Federal University of São Carlos, whose community includes more than 11,800 people. Therefore, the academic community in São Carlos represents almost 7% of the total population in São Carlos. Although our sample represents a considerable percentage of municipal inhabitants, the answers may present potential bias due to social aspects. First, many of the people who belong to the university community came to São Carlos to work or study in either of these institutions. This means that they represent a fraction of the total population who were not born in São Carlos or who have recently moved to the city. In terms of knowledge and beliefs about the region, they differ from locals who are established for a longer time. Secondly, the university community receives a great deal of information on a daily basis, while locals have access to the information they are interested in. Governance, water facilities and sustainability are frequently discussed topics in the academic environment. Despite this low representativeness of our sample, we intended to demonstrate how the questions were formulated, how they took into account the variables used and in what way the answers should be interpreted in order to help decision makers and the implementation of new policies. An “on-the-ground” experiment needs to be carried out with local citizens’ involvement, but the initial step consists of a laboratory scale, engaging volunteers who carry out scientific research.

2.5 CONCLUSIONS AND RECOMMENDATIONS

This study is a continuous effort in terms of predicting the coevolution trajectories of man and water. Moreover, it is the first approach of integrating socio-hydrology, water security and COs. This integration is an interdisciplinary approach to capture the responses of human activities and the hydrologic environment to better understand the coevolutionary trajectories through the experiences of water-related services the general public have experienced as a result of hydro-social relationships (JEPSON et al., 2017). To illustrate this possibility, the framework proposed by Srinivasan et al. (2017) and its respective variables were adapted in order to be estimated by non-experts and outline possible trajectories. Two main hypotheses were confirmed: i) it is possible to integrate the three areas and develop a tool to gather the referred type of data. This tool, SHOWS, takes advantage of the characteristics of COs to achieve its objectives and ii) SHOWS enables citizens to provide future scenarios that indicate possible trajectories of coupled water-human systems. This can be done based on their memories, experiences and knowledge acquired from the news, social networks and individual observations. Although the analysis focused on how to interpret the results in terms of possible trajectories, what they mean, what might lead volunteers to make those affirmations and how the uncertainties increases over time, we did not find any threshold that indicates which regions of each graph indicate if the trajectories reached the water insecurity threshold. This comprehension needs to be studied in-depth, compared to other place-based studies or can also be inferred by policy makers' rules and official regulatory agencies. Nevertheless, our discussion identified if the result of each variable indicated a secure or insecure trajectory in terms of water.

In order to obtain more accurate results, SHOWS could propose easier tasks. The questions asked in this initial experiment have some difficulty in being answered. Even experts may find it difficult to quantify them. Asking volunteers to monitor variables that can be observed during household activities would increase the accuracy of results. For example, instead of asking the intensity of water resource consumption ($Pw/(P+I)$), we could derive this variable into others, such as individual consumption and combine it with official measured data. It is important to note that uncertainties are drawbacks to using coupled component models (BLAIR; BUYTAERT, 2016), i.e. the influence of climate change on the model's variables (GOSLING; ARNELL, 2016). Not only human behavior, but also the hydrologic system modifications are under the influence of climatic behaviors and should be considered in volunteered information to obtain more realistic trajectories and future scenarios.

Adding to these possibilities, engaging trained volunteers and whoever does not belong to the educational community to perform these tasks would avoid potential bias. If the volunteers understood more about what, why and how they are monitoring, their work could present better results. Similarly, implementing bi-directional communication on COs platform, which means citizens obtaining feedback about their performance on the proposed tasks in real time, may help engage more volunteers. If SHOWS could provide a brief explanation about the purposes of the tasks and a comparison between the volunteers' performance and real data, they might feel more encouraged to be part of this experiment and it would raise their awareness concerning water risks (UUNVER et al., 2017).

Finally, the biggest step forward would be to include human observations in official and measured data. This process implies taking advantage of historical series of hydrological data measured by rainfall, river and groundwater gauges and analyzing official statistics about water demand per sector, economical and municipal supply. As a result, this could provide a more realistic framework about the current situation where human observations could depict how coupled human-water systems will evolve in the future. Furthermore, other variables could be aggregated into this interdisciplinary analysis in order to better represent future trajectories and scenarios. In terms of direct and indirect water consumption, or virtual water demand, qualitative water and wastewater variables can also be considered to better illustrate these future scenarios.

2.6 SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.17632/s3fz7jw5mp.3 and at the Appendix A of this work.

2.7 ACKNOWLEDGEMENTS

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3 ENGAGING CITIZENS' PERCEPTION IN THE WATER FOOTPRINT ASSESMENT AS A LOCAL ADAPTATION STRATEGY

Abstract: Under climate change scenarios, predicting water availability and human demands is still a major challenge and involves many different perspectives and holistic understandings by decision makers. Adding to the traditional uncertainties of future demands and the lack of catchment measurements, climate adaptation strategies are a matter of concern for governments, science and citizens. Although recent research has made efforts to translate social dimensions into hydrological variables, few studies involve citizens' knowledge and beliefs concerning water footprint prediction. The methodology adopted in this study integrates citizens' perceptions with time series of sanitation elements related to the municipal water footprint in order to understand scenarios of 2030 and 2050. The findings in this study area reveal that the water footprint related to human activities, such as household demands and water needed to dilute sewage and sanitary landfill leachate, are higher than the water required by economic activities. Although citizens in São Carlos, Brazil did not recognize fundamentals of sanitation systems in their city, we conclude that public knowledge can be shared to help build scenarios of the future water footprint and understand human-water coevolution.

Keywords: Citizens' perception, water footprint assessment, socio-hydrology, climate change

3.1 INTRODUCTION

Water is an essential element not only for human existence, but also for food production, economic development and environmental conservation, whose absence may undermine any of these activities. Its scarcity implies not only in the lack of available volume in determined regions, but also in not meeting quality standards of water quality. To describe the threats that any one of these activities poses due to a lack of water, the term water security is used, whose definition may vary according to the perspectives and purpose of analysis, as well as the spatial and temporal scales (BAKKER, 2012; SRINIVASAN; KONAR; SIVAPALAN, 2017; WHEATER; GOBER, 2015). The changes observed in the climate, at local and global levels, can also have an impact on water availability and, consequently, threaten the current way of life by presenting risks to food production (HANJRA; QURESHI, 2010; VARIS; KESKINEN; KUMMU, 2017), public health (WATTS et al., 2015), damage related to economic activities (GUZMÁM et al., 2017; MOHOR; MENDIONDO, 2017), household demands (QUESNEL; AJAMI, 2017) and environmental needs (Rodrigues et al., 2014; TAFFARELLO et al., 2016)

In the Brazilian context, water resources are not distributed in the same way as the population is organized in different regions of the country (GRANJA; WARNER, 2006) and are managed by a multi-layer system (PETELET-GIRAUD et al., 2017). The water resources governance milestone was the establishment of National Water Resources Policy (NWRP), instituted by Federal Law 9,433, in 1997 (BURITI; BARBOSA, 2014). Until this milestone, information regarding water resources was controlled by the electric power sector, which created the greatest demand for regulation (BORSOI; TORRES, 1997). Among the NWRP, the following was instituted: i) multiple uses of water; ii) the watershed as the territorial unit and; iii) the decentralized water resources management, including participation and representation of every user (WOLKMER; PIMENTEL, 2013). Although some watershed cases are successful in inclusive water resource governance (ENGLE et al., 2018), SOARES; THEODORO; JACOBI (2008) listed some reasons why the population´s level of involvement is low. Among the various arguments, the authors highlight the need for technical knowledge, the legitimacy of representativeness and non-recognition of water as a public good that explain citizens´ lack of representativeness in water resources governance councils.

In the context of the integrative approach of human aspects in hydrology, socio-hydrology emerges as a transdisciplinary field that aims at understanding the dynamics of human-water systems (SIVAPALAN; SAVENIJE; BLÖSCHL, 2012). To achieve this, it is proposed that new mathematical models should abandon the traditional approaches that natural systems are modeled on separately, and rather adopt a holistic perspective that integrates humans as agents within these systems, enabling them to have an impact and be impacted on by the outcomes and changes in the hydrologic cycle (BLAIR; BUYTAERT, 2016; ELSHAFEI et al., 2014). In this context, various studies have followed this guideline and have led to an understanding of the most varied hydrological processes, such as the evolution of household demands (GARCIA; PORTNEY; ISLAM, 2016; GONZALES; AJAMI, 2017), urban floods (DI BALDASSARRE et al., 2015), development in rural catchments (SANDERSON et al., 2017; VAN EMMERIK et al., 2014) and the collapse of ancient civilizations (KUIL et al., 2016). However, recent studies have questioned the applicability of these socio-hydrological models due to the difficulty of predicting change in individual behaviors and social systems (SRINIVASAN et al., 2017), the ability and creativity of modelers in predicting transformations in their models (GOBER; WHEATER, 2015) and the real interest and participation of social scientists in hydrological models (XU et al., 2018). Therefore, the Socio-Hydrological Observatory for Water Security (SHOWS) follows the precepts proposed by BUYTAERT et al. (2014) concerning the engagement of citizens in monitoring hydrologic variables and translating their knowledge, norms and beliefs (ROOBAVANNAN et al., 2018). It differs from methodologies adopted so far because it uses information provided by volunteers in order to build scenarios and assess the water security of specific places based on volunteer information (SOUZA et al., 2019).

The objective of this study is to integrate available datasets with citizens' knowledge in order to understand the evolution of water demands over the last ten years and then build scenarios to estimate direct and indirect water demands at a municipal scale. Thus, the working hypothesis in this paper is that volunteers with no technical training in water resources can use their knowledge based on their personal experiences, individual consumption patterns and beliefs in scenario building. To do so, we used the water footprint assessment method proposed by HOEKSTRA et al. (2011) to quantify different water demands. Nevertheless, we used the concept of SHOWS, defined by Souza et al. (2019), which integrates the methodologies of citizen observatories as a participative source of information in order to outline possible trajectories of coevolution of human-water systems and evaluates future scenarios in terms of water security. Thus, the next item describes the essential aspects of the study area to make it easier for readers to understand the results and conclusion. Therefore, we present the results and discuss them in detail, highlighting particularities of each scenario. Finally, we evaluate if the hypothesis was confirmed, how it influences the results and we also indicate procedures and suggestions for future studies.

3.2 STUDY AREA

River basins are usually selected as a unit of water resources management. Similarly, the federal law nº 9.433 – also known as the water law – uses the river basins as a reference unit. Due to the fact that the selected area for this study was the municipality of São Carlos, this traditional premise was changed. São Carlos is located in São Paulo State, in the Southeast region of Brazil. However, two river basins split the municipality surface area. Although most of this area is situated in the Mogi Guaçu River Basin (MGRB), the urban area is established in the Tietê-Jacaré River Basin (TJRB), and therefore the municipality is subjected to the control of the Tietê-Jacaré River Basin Committee (TJ-RBC)

The municipality of São Carlos, whose surface area corresponds to 1.136,907km , registered 234,002 inhabitants in 2016, 96% of whom lived in the urban area. It is expected that the population will decrease to 253,937 and 247,139 inhabitants in 2030 and 2050, respectively (SEADE, 2016). In the context of sanitation systems, the water supply and sewage collection service is provided by the Autonomous Water and Sewage Service. company (*Serviço Autônomo de Água e Esgoto)*. According to the Brazilian Sanitation Information System (BraSIS), during 2016, the whole population of São Carlos was served by the water supply service (SNIS, 2018), which has several pumping wells spread around the city and relies on two surface water abstraction points, one in the Feijão Creek and the another in the Espraiado Stream. Conversely, only the urban region of the municipality is attended by sewage system services, which is collected and taken to one of the three treatment plants, two of them are located close to the city and the other one is more distant. The company *São Carlos Ambiental*, who is responsible for collecting domestic waste, has provided a solid waste management service since 2013 and is responsible for collecting domestic waste. It also operates the current sanitary landfill, which started functioning in 2013. Based on 2015, the economic scenario is represented by the services sector, which has the largest share of value added with 60%, followed by industry with 30% and finally the agricultural sector, representing less than 2% (SEADE, 2018).

Figure 8: Location of study area. A) Location of São Paulo State on a map of Brazil; B) River basins' threshold in São Paulo state; C) Location of water bodies and sanitation facilities in São Carlos.

Regarding the climatic elements, the Köppen classification indicates that São Carlos' climate is Cwa, with an annual precipitation average of 1361mm and annual temperature average of 21.5ºC (EMBRAPA, 2019). According to CAVALCANTI et al. (2015), the region where the municipality is located showed an average annual temperature growth of 2ºC from 1960 to 2009, while the annual precipitation average observed increased 1mm/day. On the other hand, CAVALCANTI et al. (2015) indicate that the average temperature for some seasons will probably increase up to 4.5ºC, while precipitation records may experience a reduction of up to 10%.

In terms of water resource demands for consumptive purposes, two databases were used in this study. The first one is the Situation Report (SR) published annually by the Tietê-Jacaré River Basin Committee (TJ-RBC). Among various pieces of information, the report describes every demand according to its purpose that can be classified as urban demand, industrial demand and rural demand. Furthermore, these demands are also classified according to their origin, such as surface or groundwater. According to the latest SR, based on 2016 (CBHTJ, 2017), the urban water demand was eight times higher than the industrial demand, while the rural demand was twenty times lower than the urban demand. Regarding the origin of water, the groundwater sources provide eight times more water than the surface water abstraction points. According to the second database used, which is the BraSIS (SNIS, 2018), the water consumption per capita rose from 174 liters per day in 2009 to 223 liters per day in 2016. Moreover, the BraSIS points out that the losses in water supply due to leakages at this time was around 50%.

3.3 METHODOLOGY

In order to meet the objectives of this work, we followed the flowchart illustrated in Figure 8. The first step was to select the temporal and spatial scales to understand the processes that occur within the study area (BLOSCHL; SIVAPALAN, 1995). Due to the limitations described in item 2, we adopted the municipality limits of São Carlos, which comprise both urban and rural areas. Regarding the temporal scale, we selected the annual time interval in order to capture the climatic and hydrological variations in the region. However, this study sought not only to account for previous demands, but also to predict future demands for the scenarios regarding 2030 and 2050.

Therefore, we used the methodology proposed by HOEKSTRA et al. (2011) to quantify the direct and indirect for water demands, defined as the municipal water footprint. According to the authors, the water footprint can be split into three components in order to better quantify them. The most intuitive is the blue water footprint, which refers to direct water abstraction from the water bodies to meet human and economic demands. Differently, the gray water footprint involves the indirect water demand needed to dilute pollution loads in order to meet regulated standards of potability. Finally, the green water footprint accounts for the volume of water transferred to the hydrologic cycle because of human activities, such as evapotranspiration in crops.

Having this method at hand, the next step was to check the available data for the study area (Table 2). Some databases are publicly available but have no connection among them. Thus, we put all this information together in the same database to define which available data could be useful for water footprint accounting and which information would be needed. Afterwards, we defined the scope of the water footprint assessment and selected which elements could be quantified, observed and reported by citizens who live in the study area, based on their personal living experiences. Thus, we proposed questions based on these observations that enabled us to understand not only personal patterns of consumption from locals, but also how they imagine their water consumption and the variables involved in the indirect water demands could change in the studied scenarios.

Figure 9: Questions asked to volunteers who live in São Carlos

How long have you lived in São Carlos?

In what neighborhood do you live in?

1a) How many people lived in your house ten years ago?

1b) How many people live in your house today?

1c) How many people will live in your house in 2030?

1d) How many people will live in your house in 2050?

2a) How much did you use to pay for water bills ten years ago?

2b) How much do you pay for water bills today?

2c) How much do you think you will pay for water bills in 2030?

2d) How much will you pay for water bills in 2050?

3a) How many bags of waste did your household use to produce on a weekly basis ten years ago?

3b) How many bags of waste does your household produce on a weekly basis today?

3c) How many bags of waste will your house produce on a weekly basis in 2030?

3d) How many bags of waste will your house produce on a weekly basis in 2050?

4a) What percentage of government wealth used to be invested in water supplies and sanitation structures 10 years ago?

4b) What percentage of government wealth is invested in water supplies and sanitation structures today?

4c) What percentage of government wealth will be invested in water supplies and sanitation structures in 2030?

4d) What percentage of government wealth will be invested in water supplies and sanitation structures in 2050?

5) Where does the water you drink come from?

6) Who/Which company is responsible for bringing water into your home?

7) What happens to the sewage produced by your house?

8) Who consumes more water in your city: population, industries or farms?

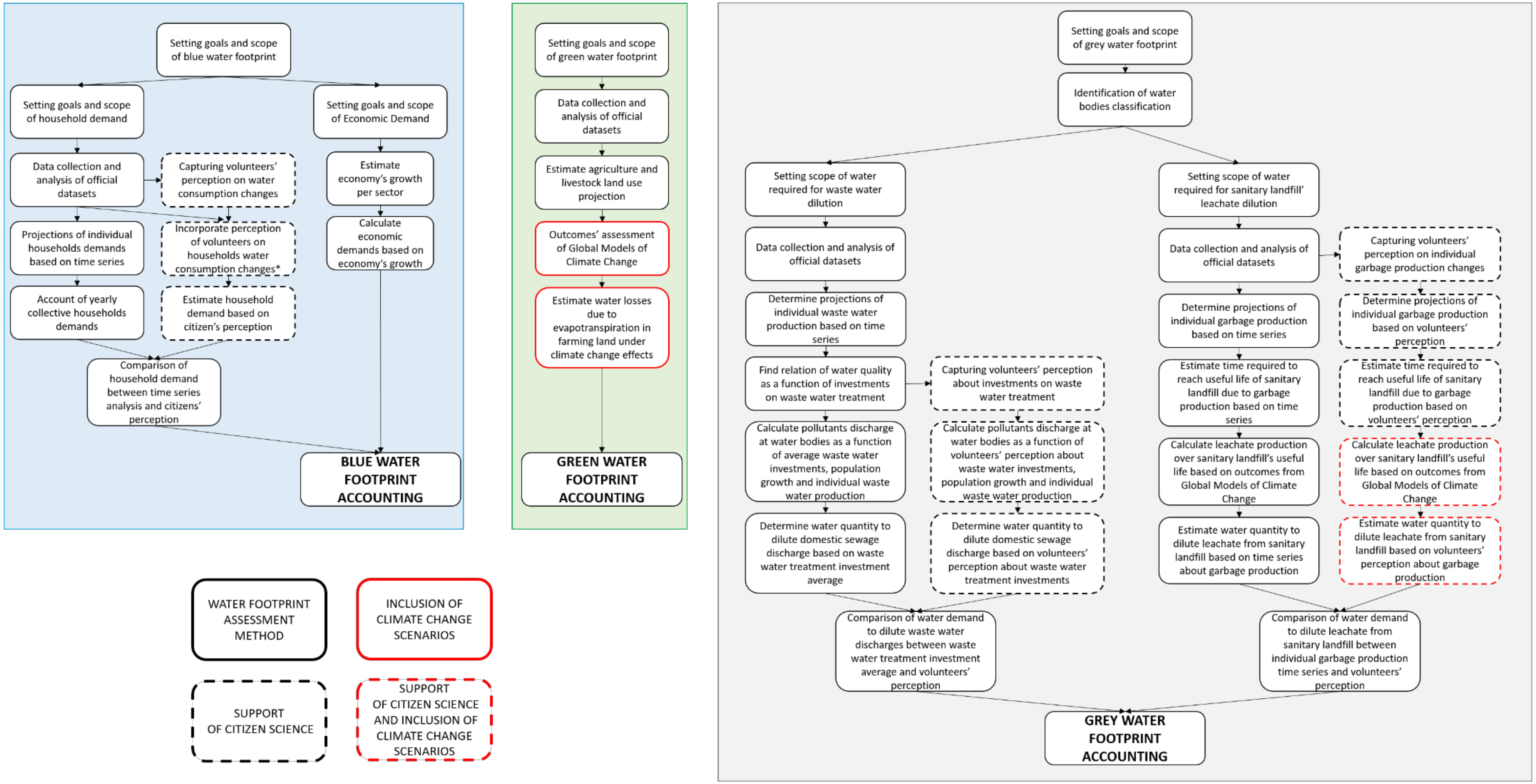
9) Are you concerned about whether or not the city you live in will have drinkable water in 2100?

Table 2**:** Publicly available information used in this study

Type of information	Unit	Source
Average daily consumption per capita	l/hab./day	
Index of losses in water networks	%	
Average water rate	R$/m	(SNIS, 2018)
Volume of sewage collected	m /year	
Average sewage rate	R$/m	
Investment made in sewage structures	R$/year	
Rural water demand	m /s	(CBHTJ, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017)
Industrial water demand	m /s	
Organic load of pollution due to domestic sewage	kg BOD/day	
Projection of index of losses in water networks	%	(PMSC, 2012)
Projections of GDP growth	U$	(PWC, 2017)
Population	inhabitants	(SEADE, 2018)
Consumer Price Index	%	(IBGE, 2018)
Projections of precipitation under climate change scenarios	mm	(PROJETA, 2019)
Projections of evapotranspiration under climate change scenarios	mm	
Participation of Agriculture in Brazilian GDP	%	(ANA, 2017; EPE, 2015)
Participation of Industry in Brazilian GDP	%	
Projection of Brazilian GDP growth	%	
Projection of population growth	inhabitants	(SEADE, 2018)
Agricultural area	ha	
GDP	R$	
Time series of precipitation	mm	(EMBRAPA, 2019)
Time series of evapotranspiration	mm	
Time series of household waste production	tons	(CETESB, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2015, 2016, 2017, 2018)

The task proposed to citizens, who voluntarily accepted to participate in this experiment, consists of quantitative and qualitative questions, illustrated in Figure 9. This experiment was submitted and reviewed by the local Ethics Committee, who announced a positive statement. Firstly, questions 1 to 4 reflect the quantitative aspect. They were used to understand personal patterns of consumption and to translate their beliefs about investment in sanitation structures ten years ago for the present and for scenarios of 2030 and 2050. The aim of questions numbered 1 is to count how many people live in the same house as the interviewee. Next, questions 2 were proposed, which indirectly enable us to understand the volume of water that was/is/will be consumed by those number of people indicated in questions 1. We can find this number through the average annual water price, in R$/m , which is available at BraSIS (SNIS, 2018). Then, questions 3 aim at understanding how household waste production has been changing over the last ten years and how the citizens think it will change in the future. To quantify this variation, we asked the volunteers how many plastic garbage bags their residences usually produce for the same period of previous questions (10 years ago, present, 2030 and 2050). This question was formulated based on a common habit in Brazilian cities, whereby people throw their household waste away in supermarket plastic bags while waiting for the garbage truck to come and pick them up (MOURA; PINHEIRO; CARMO, 2018). Therefore, we used the plastic bags as reference unit to make it easier to citizens quantify the variance of their waste production. The last quantitative question focuses on translating the importance given to sanitation infrastructure by local authorities in order to enhance water quality (DADSON et al., 2017). To do that, we proposed questions 4, which asks what fraction of municipal financial resources is allocated to sanitations systems, on a percentage scale. We intended to capture the variation of the investments made my local authorities over the years to enable us to quantify the gray water footprint. This information will be explained in detail later on in this section.

Figure 10: Flowchart showing methodology



Finally, we propose the qualitative questions from number 5 to 9. They were designed to check if citizens recognize the most fundamental elements of sanitation elements in the city and if they are concerned about not having sufficient water for future generations by the end of the century.

The considerations and hypothesis involved in water footprint accounting are described as follows.

3.3.1 Blue Water Footprint Methodology

The water footprint accounting was split into two parts. Firstly, we accounted for the household demands, which comprise domestic water consumption and the percentage of losses caused in water transportation pipes (VARRIALE, 2018). The time series for both components, from 2009 to 2016, are available at the BraSIS (SNIS, 2018). Thus, we can find the volume of losses during water distribution through Equation 1 (PMSC, 2012) and the total household demand can be obtained by Equation 2, where Q_l is the annual volume of water losses due to leakages in the water network (m /s); Q_{hh} is the annual volume of water consumed by residences (m /s), L is the index of losses in water networks (%);D_{hh} is the annual household demand (m /s).

$$Q_l = \frac{Q_{hh}}{1-L} - Q_{hh} \qquad \text{Equation 1}$$

$$D_{hh} = Q_l + Q_{hh} \qquad \text{Equation 2}$$

We used three methods to estimate the annual consumption average per capita for each scenario analyzed: a) the linear regression based on the time series available, from 2009 to 2016; b) the confidence interval for T-student distribution, using the same time series and; c) the method used in the Municipal Master Plan of São Carlos City, which adopts the daily individual water consumption of 200 liters, suggested by VON SPERLING (1996). Thus, the annual volume of water consumed by residences is obtained from the product of population projections for the study area time the individual water consumption.

The second part of the blue water footprint comprises the demands from economic activities. For previous years, we employed such information from situation reports, which describes the demands from industrial and agricultural sectors. Concerning future demands for the economic sector, we assumed that they would follow the same participation of each economic activity in the gross domestic product (GDP) projections. The Pricewater House Coopers (PWC, 2017), a multinational network of companies in the area of auditing and accounting, has recently published a report regarding the projections for the Brazilian GDP growth for 2030 and 2050. Once this report only provides the predictions for GDP, we also acquired information regarding the sectorial participation in GDP from the report published by the Energy Research Company - ERC (EPE, 2015). Lastly, we identified the types of industry established in São Carlos from report published by the National Water Agency (ANA, 2017) that classifies the use of water according to type of industries in Brazilian cities.

3.3.2 Gray Water Footprint Methodology

With respect to the gray water footprint – which is the volume of water needed to dilute pollutant loads until reaching an acceptable status determined by local resolutions – we also split it into two categories. The first one is related to the emissions from domestic effluent in the water bodies. The effluent in this work consists of sewage and it passes through one of the treatment plants in São Carlos before being discharged into the closest river. The annual volume of collected sewage was obtained from BraSIS (SNIS, 2018), while the remaining polluting load is available from the SR published by the TJ-RBC. Thus, the dilution volume could be calculated using Equation 3, adapted from (TUCCI, 2017), where: Q_p is the annual volume of domestic effluents discharged in São Carlos' water bodies (m /ano); Q_d is the annual volume needed to dilute the polluting loads, c_1 is the concentration of Biochemical Oxygen Demand (BOD) of domestic effluent discharged in São Carlos' water bodies (mg/m), c_2 is the concentration of BOD for dilution volume (1mg/l), and is the accepted concentration of BOD of the water body (mg/m), according to the classification established by the Conama resolution, number 357/2005 (BRAZIL, 2005).

$$Q_p * c_1 + Q_d * c_2 = (Q_p + Q_d) * c_3 \qquad \text{Equation 3}$$

However, to calculate the volume needed to dilute the household effluents in the future, it is necessary to have at hand the volume of sewage produced by the population and the respective polluting load. Similarly to household water demands, we used the same methods to determine the annual volume of sewage produced per capita in 2030 and 2050: a) linear regression; b) the confidence interval based on time series from 2009 to 2016 and; c) the average daily volume of sewage produced per person according to VON SPERLING (1996), which is equal to 160 liters/day.

We performed a linear regression to determine the polluting load (c_2) as a function of annual investments in sewage infrastructures (R$). To do that, the value of investments made in previous years were transformed to the Net Present Value (NPV) by using the time series of the Brazilian annual Consumer Price Index (CPI), which measures the inflation in Brazilian cities. However, we do not know how much will be invested in 2030 and 2050. Therefore, we transformed the former values of investments into a fraction of previous GDPs and performed two analyses. In the first one, we considered future investments based on the average of precedent percentages and the second one was based on questions 4 asked to the volunteers, shown in Figure 9. Based on this, we calculated the value of investment for future scenarios based on GDP projections and variance of investments as the fraction of the total GDP, indicated by the citizens. For example, if today 1% of the GDP is invested in sewage infrastructure and the average number of responses indicates that it will increase by 50% in the future, we multiply the projected GDP by 1% and by 1.5 in order to find the value that will be invested.

The second category of the gray water footprint is the volume needed to dilute the polluting load due to the leachate from the sanitary landfill, where the household waste is deposited. To perform this accounting, we consulted the State Inventories of Domestic Waste, which have been released yearly since 2003 by the Environmental Company of São Paulo State (CETESB). In these reports, the company published the daily average production of household waste over the last year (tons/day). Knowing that the current sanitary landfill started to be operated in 2013, its capacity is correspondent to 2,222,288 tons and its surface is equal to 213,234.48m , we calculated:

a) How many years would be necessary to reach its total capacity based on Equation 4, where T is the time required to reach maximum capacity of sanitary landfill (years); C_{sl} is the capacity of sanitary landfill (tons); Pop_i is the population of São Carlos municipality in year i (inhabitants) and; g_i is the production of household waste per person (tons/person*year) in the year i. The future projections were obtained based on the upper and lower limits of the confidence interval from the CETESB time series (2003 to

2017) and were compared to the responses that volunteers provided in questions 3 (Figure 9);

$$C_{sl} \geq \sum_{i=1}^{T} Pop_i * g_i \quad \text{Equation 4}$$

b) how much leachate volume from the sanitary landfill will there be over the T years based on the water balance of Equation 5, which considers that: i) the surface area set for the sanitary landfill does not receive any external surface runoff and; ii) waterproofed inner walls. Therefore, L is the volume of leachate in year i (mm); P is the precipitation incident on the sanitary landfill's surface area in year i (mm) and; ETp is the potential evapotranspiration in year i (mm). We obtained the last two items from a meteorological station operated by EMBAPA (EMBRAPA, 2019) and the outcomes of the climate change projections model HADGEM-2S for the municipality of São Carlos, concerning the scenarios Representative Concentration Pathway (RCP) 4.5 and 8.5 (CHOU et al., 2014a, 2014b; LYRA et al., 2018).

$$L_i = P_i - ETp_i \quad \text{Equation 5}$$

c) the equivalent leachate volume for each year from Equation 6, where Q_{g_i} is the equivalent leachate volume for year i (m /year); G_i is the total waste expected for year i (tons); C_{sl} is the capacity of sanitary landfill (tons) and; L_T is the sum of leachate from the beginning of the sanitary landfill operation to the end of its useful life.

$$Q_{g_i} = \frac{G_i}{C_{sl}} * \sum_{j=1}^{j=T} L_j \quad \text{Equation 6}$$

d) the gray water footprint for year i due to the dilution volume for leachate from the sanitary landfill shown in Equation 7, which is adapted from Equation 3, where Q_p assumes the meaning of Q_{g_i} and c_1 is the yearly average of BOD concentration in leachate from Sao Carlos' sanitary landfill, measured by JUSTO (2018).

$$Q_{g_i} * c_1 + Q_d * c_2 = \left(Q_{g_i} + Q_d\right) * c_3 \quad \text{Equation 7}$$

One of the limitations of this method implies that the water footprint correspondent for each year is directly correlated to the useful life of the sanitary landfill. The lower the useful life, the less volume of leachate will be computed by Equation 5 and, consequently, Equation 6 will provide less equivalent leachate for each year i. It means that the optimum in terms of the water footprint happens for a smaller surface area, less time of exposure to rain regimes and less domestic waste production. If one sanitary landfill has a large surface area, the precipitation volume will be high, but there will be a higher capacity of storage. On the other hand, if the sanitary landfill is longer, there will be more waste storage capacity, but the landfill will be exposed longer and will produce a higher volume of leachate. However, if the population produces more household waste, the useful life will be shortened and, consequently, there will be less volume of leachate.

3.3.3 Green Water Footprint Methodology

To determine the green water footprint, we have to identify changes in land use from native vegetation to agriculture. Next, we calculate the evapotranspiration in this place due to climatic conditions. Finally, we determine the water losses of the hydrologic cycle as a consequence of human intervention and classify that as the green water footprint.

For the periods up to 2017, the agriculture area in São Carlos city was obtained from the time series of the *Portal de Estatística do Estado de São Paulo* (SEADE, 2018). This database lists which crops were grown and which area was used for planting. Since it does not have projections for future scenarios, we consulted the report published by the Energy Research Company (ERC), which assesses the projections of national agricultural area growth, and we assumed the same rates for São Carlos city.

Regarding evapotranspiration, we consulted the time series recorded by the meteorological station from EMBRAPA *Pecuária Sudeste* until 2018 (EMBRAPA, 2019). This station is located in São Carlos city and uses the Penman-Monteith method to calculate evapotranspiration. For 2030 and 2050, we used the outcomes of the climate change projection model HADGEM-2S for the municipality of São Carlos, and assessed the RCP 4.5 and RCP 8.5 (CHOU et al., 2014a, 2014b; LYRA et al., 2018). Therefore, we found the green water footprint in the study area by combining projections in agriculture and possible effects of climate change

3.4 RESULTS AND DISCUSSION

The results for previous years do not present any variations since we accounted for water footprints based on the time series. However, future scenarios for the 2030 and 2050 values ranged according to the different calculation methods used. Firstly, we propose a discussion on quantitative results regarding the water footprint assessment and we put them all together in charts to better visualize what differences those methods reveal and whether the determined footprint is higher or lower compared to the other and how it differs from time series analysis to citizens´ perception. The Table 3 presents such perception, as answers of questions proposed in Figure 9, translated into numbers.

3.4.1 Blue Water Footprint Results

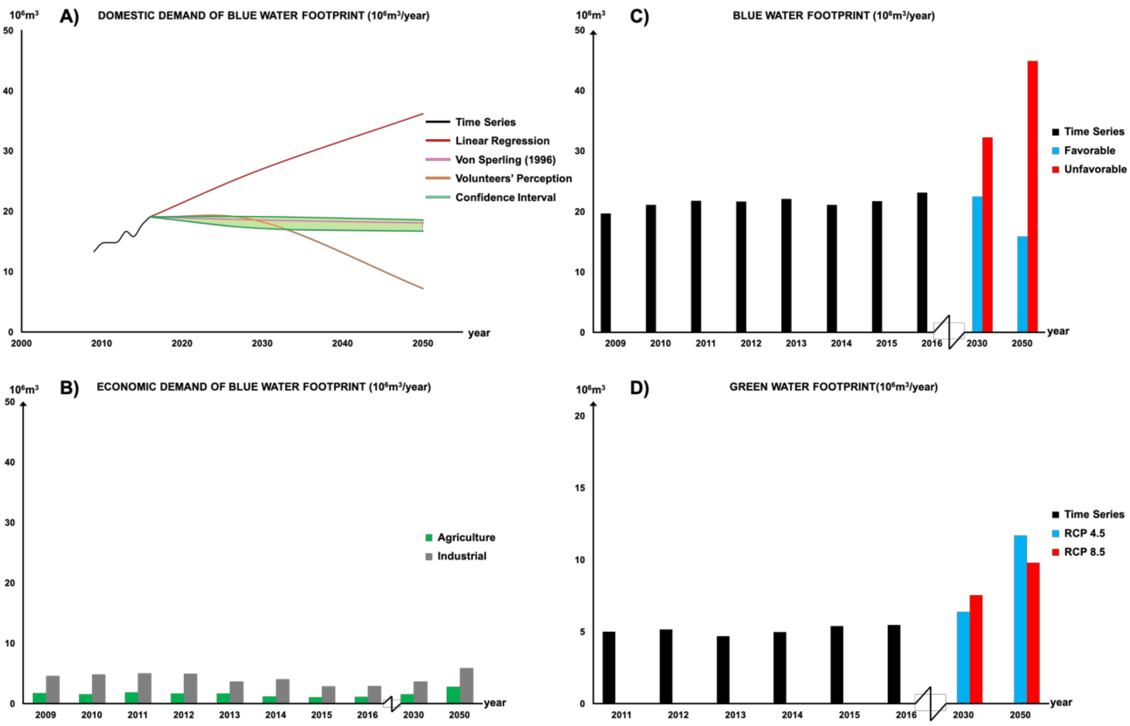
Four methods were used to determine future household demands and Figure 11 A presents their respective outcomes. The first one is the result from the linear regression, which corresponds to 0.73. It presented 291,50 and 401,13 liters per day per person for 2030 and 2050, respectively. The VON SPERLING (1996) method did not present any variations, considering a constant value of 200 liters/person. Therefore, the variance over the years depends only on demography. On the other hand, the confidence intervals show that consumption per person varies between 185.42 and 205.86 liters per day per person. Finally, the responses from the volunteers indicated that the average of their consumption: i) was 13% lower ten years ago; ii) it will decrease 12% in 2030 and; iii) in 2050 the reduction will be equivalent to 64%.

Table 3: Result of volunteers' answers to the task proposed

Variable	Average
Water bill per person ten years ago (R$/person)	13,48
Water bill per person today (R$/person)	28,51
Water bill per person in 2030 (R$/person)	52,01
Water bill per person in 2050 (R$/person)	70,57
Plastic bags of waste per person ten years ago (unit/person)	2,65
Plastic bags of waste per person today (unit/person)	3,03
Plastic bags of waste per person in 2030 (unit/person)	3,13
Plastic bags of waste per person in 2050 (unit/person)	3,41
Fraction of investments on sanitation from total resources available ten years ago (%)	22%
Fraction of investments on sanitation from total resources available today (%)	20%
Fraction of investments on sanitation from total resources available in 2030 (%)	28%
Fraction of investments on sanitation from total resources available in 2050 (%)	33%
Number of volunteers that answered correctly the origin of tap water	18
Number of volunteers that answered correctly the agency responsible to bring water to their house	46
Number of volunteers that answered correctly the destination of waste water	20
Number of volunteers that recognized citizens demand more water than other sectors	28
Number of volunteers that affirmed they are concerned about water availability in 2100	44

The other side of the blue water footprint, the economics demands, was not based on statistical methods as was explained in Item 3.1. Instead of doing that, we used projections for the Brazilian economy and assumed that São Carlos city would follow same pace of evolution, respecting each sector of economy (EPE, 2015; PWC, 2017). As a result, for the study area, the agriculture sector is expected to grow 46% in 2030 and 161% in 2050, while the industrial sector will increase 28% and 106% for the same respective years (Figure 11 B). Although agricultural growth seems to be higher than industrial growth, the latter will continue demanding more water than the former. We highlight that these projections of demands were based only on GDP growth but other factors, such as new techniques and technologies, changes in economic choice e the possibility of the future not meeting the GDP growth prediction may present different values from the results presented in Figure 11 B. However, the need to comprehend - at least compare what might happen – lead us to assume that these are the most realistic scenarios based on the information available.

Figure 11: Results for Blue and Green Water Footprints



Finally, Figure 11 C presents the total blue water footprint for previous years and what they would be for favorable or unfavorable scenarios in 2030 and 2050, from the perspective of water security. By analyzing Figure 11 A and Figure 11 C, a remarkable disparity between both scenarios can be observed, which is a consequence of linear regression outcomes. On the other hand, the method proposed by Von Sperling (1996) showed results within the lower and upper limits of the confidence interval based on the time series, which shows a good approximation in terms of predicting future demands and designing water supply structures. Finally, volunteers showed to be more concerned about the future demands for 2030 and 2050. Due to the latter method, the volunteers' perception was responsible for taking the blue water footprint in 2050 to the lowest value recorded so far. This can be a reflection of what some authors call environmental awareness (ELSHAFEI et al., 2014) as a consequence of the possibility in the reduction of water availability.

3.4.2 Gray Water Footprint

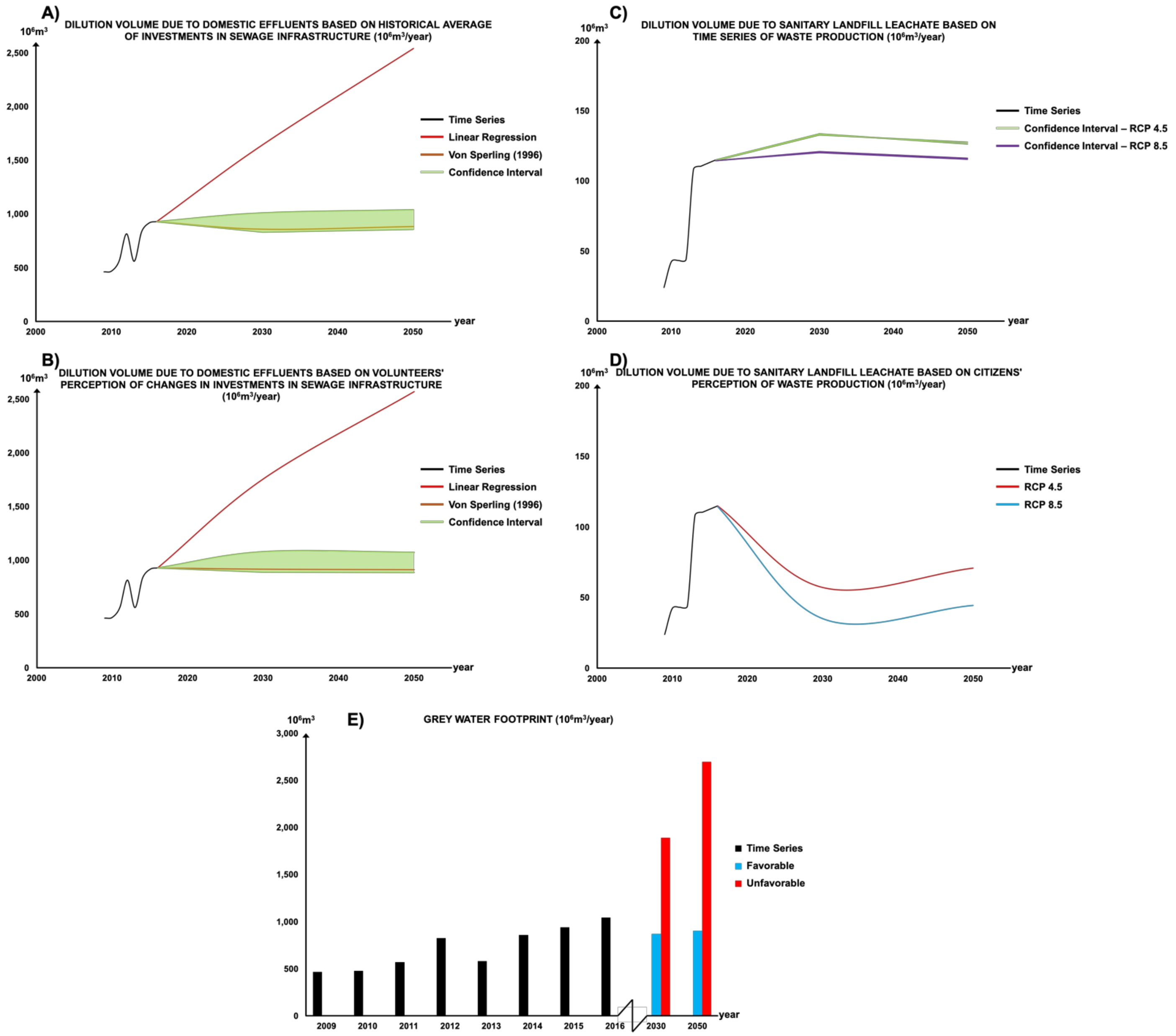
Similarly to the blue water footprint, the gray one was split into two parts. The first one accounted for the dilution volume needed as a consequence of domestic effluent discharge into water bodies; and the second regarding the volume needed to dilute the sanitary landfill leachate.

Firstly, we determined the volume of domestic sewage production per person for 2030 and 2050 using three methods as described in Item 3.2: i) the linear regression, which was equal to R 0.58, indicates 111.90 and 168.10 cubic meters per day per person for 2030 and 2050, respectively; ii) the method proposed by Von Sperling (1996), which is correspondent to 58.40 daily cubic meter per person and; iii) the confidence interval based on time series, which range from 56.70 to 68.8 cubic meter per day per person.

Next, we performed another linear regression in order to find out the relation between polluting concentration in treated domestic effluent (BOD kg/m3) as a function of investments made in sewage infrastructure (R$/year). The tendency line presented R equal to 0.67 based on the time series for São Carlos city (SNIS, 2018). The tendency line is represented by Equation 8, where x corresponds to the value of investments made in the sewage infrastructure in São Carlos city (10^6 R$) and y is the polluting concentration of treated domestic effluents discharged in water bodies (BOD kg/m^3).

$$y = -0{,}01x + 0{,}262 \qquad \text{Equation 8}$$

Figure 12: Results for Gray Water Footprint



In addition, we correlated the polluting load of treated domestic effluents with the investments made in sewage infrastructures – as a fraction of São Carlos GDP. For previous years, from 2009 to 2016, this fraction was obtained from total investments, available at SNIS (2018), by São Carlos' GDP for the corresponding years, available at SEADE (2018). However, for 2030 and 2050 we used two methods. The first one is the average of responses to questions 4 (Figure 12), asked to inhabitants from São Carlos. The volunteers affirmed that those investments would be 47% and 33% higher in 2030 and 2050, respectively, in comparison to the present. The second one considers the historical fraction of GDP based on the time series from 2009 to 2016 and GDP projections for 2030 and 2050 (EPE, 2015) – that represent almost 0.04% of municipal GDP (SEADE, 2018; SNIS, 2018). Thus, to determine the gray water footprint, correspondent to the dilution volume for treated domestic effluents, we used Equation 3. The outcomes for these two methods – volunteers' perception and time series' analysis – are presented in Figure A and Figure 12 B, respectively. The results indicate little difference between them, where citizens indicated an unfavorable scenario from the water security perspective, corresponding to 6% higher in 2030 and 3% higher in 2050 compared to the time series analysis.

On the other hand, Figure 12 C and B presents the annual volumes of water needed to dilute the leachate from São Carlos' sanitary landfill. As the company responsible for operating the sanitary landfill began operating in 2013, and the time series of daily domestic waste production have surprisingly increased since 2013, we decided to establish the confidence interval after 2013. Adding to these aspects, the confidence interval presented values ranging from 0.89 to 0.90 daily kg/person. The immediate consequence of this fact is that the dilution factor presented almost no variation within the confidence interval. Alternatively, as the time series may not be able to prepare predictions about possible changes in solid waste generation, we used the volunteers' responses to perform this projection. According to the volunteers, individual household waste production will probably increase to 47% and 33% when comparing 2030 and 2050 to the present, respectively.

The high production of domestic waste leads to the reduction of the sanitary landfill's useful life. Nevertheless, at some point there will be an inflection: although the shortening time of the sanitary landfill operation leads to less volume of leachate, the weighing factor in Equation 6 ($\frac{G_i}{C_{sl}}$) may be large enough to overcome the benefit of having a landfill exposed for a short period of time. This is what happened with the outcomes from the volunteers' perception. Although the growth in waste production leads to a reduction in the sanitary landfill's useful life, the corresponding leachate for each year i Q_{g_i} is higher than the analysis based on the time series. It is also interesting to note that scenarios RCP 4.5 for both methods – volunteers' perception and statistical analysis - presented higher volumes of leachate than scenarios RCP 8.5. This is because the volume of precipitation exceeded the volume of evapotranspiration.

Finally, the total gray water footprint is presented in Figure 12 D, which joins the annual dilution volumes for domestic effluents and sanitary landfill leachate. The same happened to the blue water footprint case, in which linear regressions led to very large values in unfavorable scenarios, while the favorable scenarios for 2030 and 2050 corresponded to $867*10^6$ m and $901*10^6$ m , respectively.

3.4.3 Green Water Footprint

The scope of the green water footprint in this study considers the product of the agricultural land area by the expected annual evapotranspiration for São Carlos city. For previous years, the areas are available at SEADE (2018), while we adopted the expansion for future years based on the projection at EPE (2015). On the basis of 2013, an expansion of 13%, 36%, 63% and 90% is expected in lands occupied by agriculture in 2020, 2030, 2040 and 2050, respectively. The time series of evapotranspiration values are available at EMBRAPA (2019) and we used the outcomes of scenarios RCP 4.5 and RCP 8.5 from HadGEM-2s climate model for the Southeast region of Brazil (CHOU et al., 2014a, 2014b; LYRA et al., 2018).

Figure 11 D presents the result of the green water footprint for the study area. As can be seen, the green WF represents the lower demand when compared to the blue and gray water footprint. This is because of the economic aspect of the study area described in Item 4 of this paper. Adding to this, scenarios RCP 4.5 and RCP 8.5 alternate as favorable and unfavorable predictions in terms of water security. In 2030, it is expected that scenario RCP 8.5 will demand more water, while in 2050, RCP 4.5 evapotranspiration rates will probably be higher. There are some reasons that can possibly explain this fact, such as the changes in precipitation regimes, the moment when global weather will reach maximum temperatures and variations in the resultant radiative forcing.

3.4.4 Volunteers´ knowledge of sanitation systems

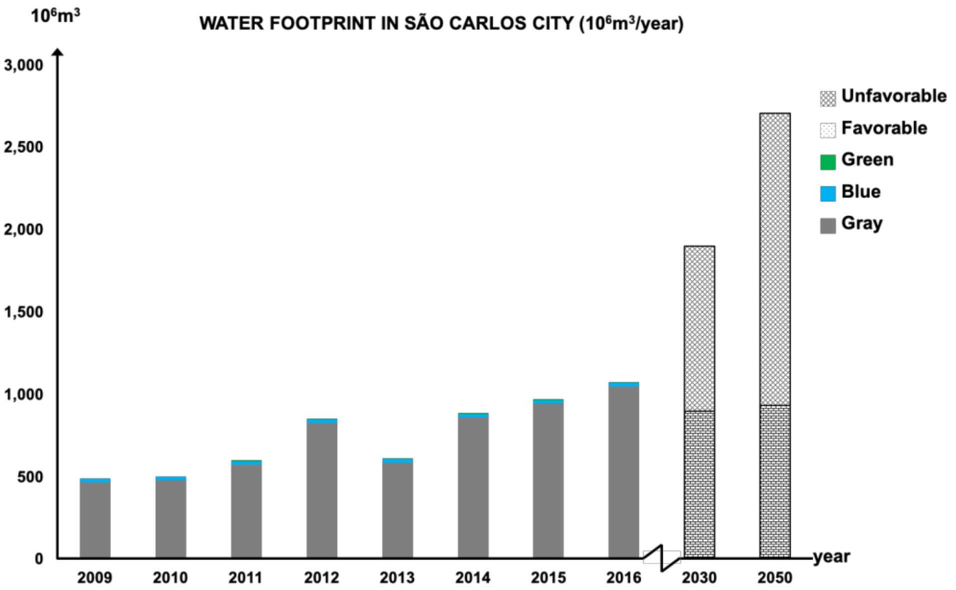
In addition to the questions regarding the quantitative aspects of consumption patterns, we also checked if volunteers recognize key elements of the sanitation processes that have some relation to water quality and quantity in the city where they live. These questions are numbered from 5 to 9 in Figure 9. The results – illustrated in Figure 14 – reveal that their knowledge is limited.

Although most of them know which company is responsible for supplying water to their house, almost one third does not know where the water comes from. It is even surprising that forty percent of the group of volunteers do not know that domestic effluents that leave their houses every day go to one of the treatment plants and then they are discharged into water bodies. Some of them answered that they believe it is treated and then goes back to their house for consumption, while others have no idea about what happens to the sewage. This fact reinforces the need to disseminate environmental education to the whole population in order to raise awareness about environmental conservation. If the population knew where the water comes from and the final destination of sewage, they could develop better attitudes towards water conservation and water use efficiency (GUNDA et al., 2019), increase pressure on local authorities in order to protect water bodies and make investments in sewage treatment.

The results also revealed that the residence time of volunteers in the city does not have such a big impact on their knowledge about sanitation elements and environmental awareness. While 21% of citizens who have lived in São Carlos for less than 20 years were able to answer positively/correctly all the questions, no volunteers who have lived in the city between 20 and 30 years were able to respond to the five questions positively/correctly. However, almost 60% of the volunteers who have lived in the city for more than 30 years answered four or five questions positively/correctly, while 16% of citizens who have lived in the city between 20 and 30 years and 35% of those who have resided there for less than 20 years had the same performance. It means that another factor, such as education, income or age might have a different impact and should be considered in the case of engaging volunteers to help decision-making processes of water resources.

Figure 13: Water security assessment on possible scenarios. A) Breakdowns water footprint for previous year and provides favorable and unfavorable scenarios for 2030 and 2050 and B) compares blue and total water demands versus water availability.

A)



B)

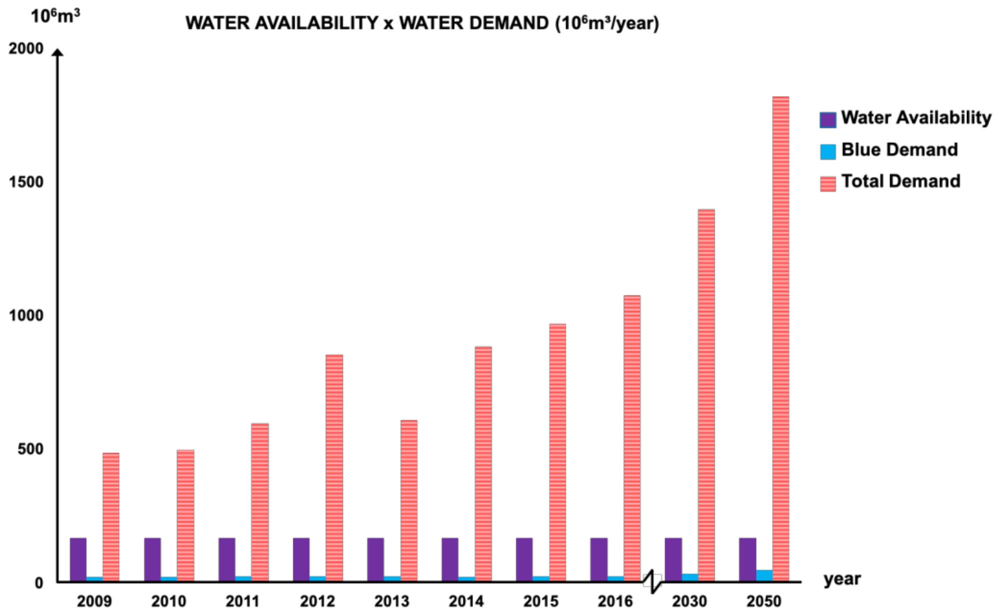
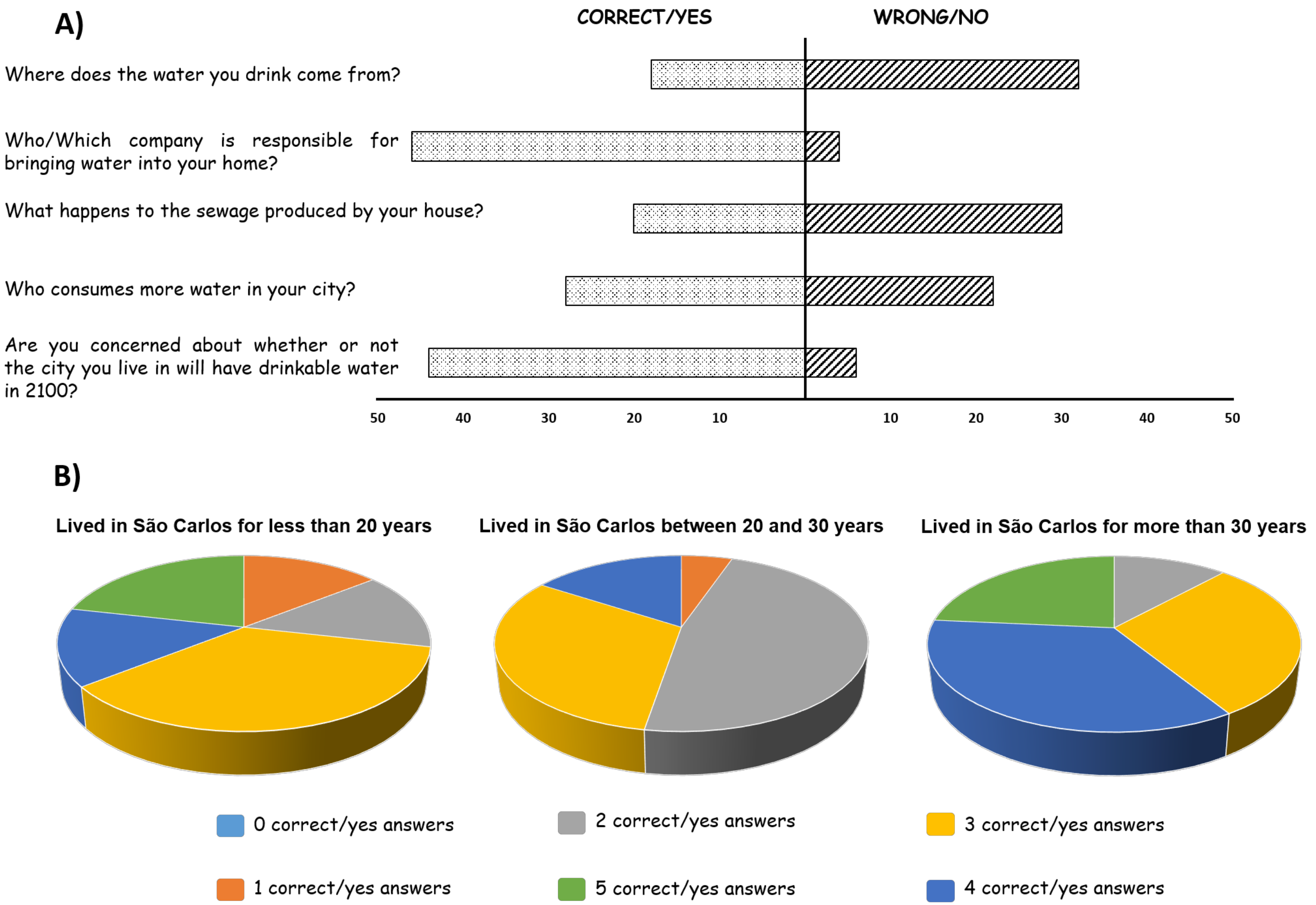


Figure 14: Responses from citizens to qualitative questions, where A) represents the answers from all volunteers and B) evaluates the number of answers according to their residence time in São Carlos city



3.5 CONCLUSIONS AND RECOMMENDATIONS

The present work incorporates a socio-hydrological methodology in order to understand water use evolution (KONAR et al., 2016). According to the results obtained from different methods to estimate the water resources demands at a municipal scale, we were able to draw some conclusions concerning the attempt to understand the possible trajectories of human-water interactions. Splitting water demands into blue, gray and green enabled us to depict how human activities demand water. All the methods used here converged to the same conclusion, gray water, or the water needed to dilute pollutants, is the highest demand and, unfortunately, it is not accounted for as a demand by situation reports. The case of São Carlos municipality, where we analyzed not only the urban area, but rural area as well, revealed that gray water footprint was twenty-five times higher than direct demands for water – blue WF – and almost fifty times higher than water lost to the hydrologic cycle through evapotranspiration in agricultural lands. Policy makers responsible for accounting water demands should take into consideration these results, which could be included in official reports to assess the water security context at municipal or river basin scales.

In addition, the short time series available for several items incorporated into the water footprint assessment performed in this work led to disparities of results varying according to each method used. Such cases were observed by comparing the confidence intervals for water consumption and sewage production for the trend line for 2030 and 2050. It reveals that short time series might not be adequate to assess long-term scenarios. On the other hand, we concluded that the method proposed by Von Sperling (1996) are adequate for São Carlos, because it was comprised within the upper and lower limits of the confidence interval for both water consumption and sewage production.

Regarding the volunteered information used to capture physical, societal and cultural behaviors (WADA et al., 2017), the results revealed that citizens are concerned about the water availability for future generations and are optimistic in terms of the local authorities paying more attention to investments in sanitation in São Carlos. The numbers show this concern. Almost 90% of the volunteers affirmed they are concerned about water availability at the end of this century, they believe their water consumption average will reach more than 50% of savings in 2050 and the fraction of GDP might increase up to a third compared to the present, according to volunteers. However, it is remarkable that citizens cannot recognize essential elements of sanitation processes within the city they live in despite affirming that they are concerned about water availability. This is alarming, because being familiar with the place we live in can be a key aspect in terms of raising environmental awareness. On the other hand, despite this lack of familiarity, the task proposed in this work successfully captured what citizens believe will happen in the future and their personal patterns of consumption, which makes us consider the most valuable conclusion in this work in terms of engaging public knowledge in order to understand possible trajectories of coevolution in socio-hydrological systems.

Since the gray water footprint was responsible for the highest demands, we recommend a better understanding regarding the processes in future studies, such as capturing the variation in the quality and quantity of sanitary landfill leachate throughout the year, the effect of self-depuration of treated effluent discharge in water bodies and the inclusion of industrial effluents in gray WF accounting. These elements can provide more accurate results and a better view of real human demands. In terms of green WF, real evapotranspiration for different types of crops can also lead to better results. Finally, the inclusion of virtual water transfers would be the key element to complete the water footprint at a municipal scale.

3.6 ACKNOWLEDGEMENTS

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4 GENERAL CONCLUSION

The conclusion will be presented as answers to the objectives. In the next topic it is presented recommendation for future works based on lessons learned, limitations in methodology and possibilities to obtain more accurate results.

4.1 CONCLUSIONS

The first objective is: "*Define the concept of the "Socio-Hydrological Observatory for Water Security" and how it integrates the fundamentals of socio-hydrology to water security assessment by employing the citizen observatories technologies*".

The Socio-Hydrological Observatory for Water Security – SHOWS – was conceptualized in second chapter as an innovative tool that enable scientists to gather information from citizens who have no technical instruction regarding neither water nor social sciences. The ease of accessing SHOWS through information and communication technologies permits volunteers to perform tasks in order to monitor the environment around them. Such tasks, in this study, were questions asked to volunteers, which enabled us to capture individual and collective patterns of consumption and their beliefs regarding transformations in water availability and society's demands feedbacks at municipal scale. It represents an alternative approach to traditional socio-hydrological modelling processes by addressing the uncertainties of possible trajectories to the people who live within the river basins analyzed.

However, asking volunteers about the future is not such a simple experiment. Before asking what will happen, it is necessary to select properly which method of water security assessment are better transformed into variables that can be monitored and reported by citizens. In this study, we presented two methods that citizens could provide answers in two different ways and translate the interactions between humans and water. The first one was inspired in the Dynamic Framework for Water Security proposed by SRINIVASAN; KONAR; SIVAPALAN (2017), while the second was an adaptation from the Water Footprint Assessment Manual (HOEKSTRA et al., 2011). The former analyzes the trajectories of societies in terms of water security by employing only three variables. Although questions could be adapted in order to help volunteers translate such variables, we consider that they are not as simple as the second experiment, because the later aims at understanding individual patterns of consumption.

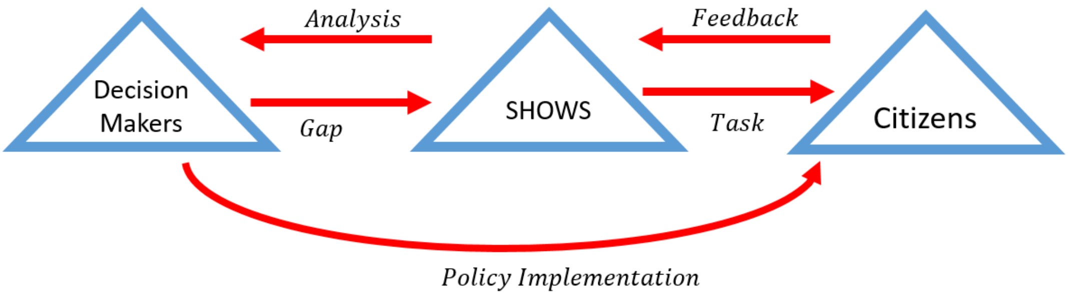
The second objective is: "*Propose tasks to volunteers that enable them to provide quantitative answers and help on assessing water security scenarios in socio-hydrological systems*".

The conclusions around this specific objective was partially presented in previous paragraph and was covered by both experiments. The first experience reveals that volunteers from academic environment believe that investments from local governments in water infrastructures will continuously increase until next fifty years and water utilization intensity will be lower than today for the same period. It means they have positive perspectives in terms of water security. By the other side, volunteers affirmed that virtual water fluxes, or the difference between water embedded in products produced locally by those produced externally the city, is going to increase in future years and it is not a good perspective regarding the dynamic framework for water security.

The second experiment provided different insights. The methodology allowed us to quantify direct and indirect demands in the future. The results revealed that water needed to dilute the loads of pollution due to sewage discharged into water bodies and leachate from sanitary landfill are much higher than water consumed for domestic and economic activities. For this reason, we believe it should be considered in water management reports. Furthermore, the answers from this experiment presented the same behavior regarding the variable that translate such investments for future years. Local citizens confirmed the predictions from previous experiment by affirming that it will continuously increase, which reveals the trust in local authorities' capacity to ameliorate the sanitation systems or it might be the environmental awareness that local population have concerning the uncertainties

Lastly, the main conclusion in this work is the role that SHOWS can play in the context of helping on policy implementation as illustrated in Figure 15. In situations such as the citizen science experiments in this study, decision makers can identify gaps regarding the interaction between human and water systems. So, SHOWS can transform this gaps into variables and tasks that can be monitored by citizens. After performing such tasks, the SHOWS provides analyses based on the feedbacks from citizens. With these analyses on hands, decision makers can implement new policies regarding the former gap and propose new monitoring activities to SHOWS in order to evaluate those new policies. This loop can help not only on identifying future demands of water, but it is also a valuable to the context of floods and water quality monitoring.

Figure 15: Role of SHOWS in policy implementation



4.2 RECOMMENDATIONS FOR FUTURE WORKS

In order to have more accurate results and better capture the knowledge and beliefs from population, it is recommended to attend the following suggestions in future works:

a. Develop a platform exclusively for the SHOWS. It would make the observatory even easier to be accessed by those who want to contribute in future experiments. USHAHIDI was a good solution to the objectives proposed in the first experiment. However, if citizens could search on internet for “SHOWS” and they were able to find the platform, they could feel more persuaded to take part in the project just like other good examples of citizen observatories in Europe.

b. Find a way that do not require citizens to provide a physical signature in a consent form. This requirement from the ethics committee interfered on public engagement. Some volunteers did not intend to participate in the experiment because their signature was required. As an alternative, it was suggested to create a check box option at the platform where citizens could have access to the same consent form and their agreement to the terms would be checking the box.

c. The questions proposed in the first experiment was not so easy to answer and they were proposed to volunteers without any explanation about the purposes of the questions. Alternatively, a future experiment could consist on, firstly, provide an explanation about the context of the experiment, what is expected from each question and how they could imagine the future before answering.

d. Adding to the recommendation “c”, we suggest to future works that they invite different groups of volunteers, clustering them according to different social position, in order to comprehend how it influences on their perception of possible scenarios and how it changes the consumption patterns

e. The original paper which inspired the first experiment also presented a threshold that divides water insecure from water secure regions in the graph. Nevertheless, this threshold was not present in the results of chapter two because it was focused on understanding the answers and describing the to what direction the trajectories pointed to. Thus, in future studies it is suggested to propose these limits in order to establish if such trajectories will or will not reach water insecure scenarios.

f. The blue water footprint from household demands was accounted by comparing data series to citizens’ responses based on their water bill. Instead of doing this indirect measurement, future works could ask volunteers to count how many minutes tap was used, how many flushes was used during the day, how often do they water the garden and other monitoring activities that make possible to account water consumption.

g. The relation between water quality indicators of sewage after receiving local treatment and investments in sanitation infrastructure was obtained from a short time series from only one city. It is suggested that future studies focus on the comprehension of this relation and also break down those investments in topics like infrastructure, technology, acquisition of chemical reagents, and so on. It would enable a better understanding on what type of investments definitely impacts on treated sewage quality indicators in Brazilian cities.

h. The quality indicator of leachate employed in chapter three was the Biochemical Oxygen Demand (BOD). However, we assumed the corresponding values as an average of observations made in a previous work along the year. In order to obtain accurate result, it is recommended to better understand what impacts the shift in the rain regime cause in BOD.

i. In future studies, add a question to the survey regarding the “willingness to pay” for more sophisticated technologies that increases the availability of water in the future, such as water reuse from sewage treatment plants and desalinization plants. These technologies increase the resilience of cities, but they require more financial resources.

APPENDIX A: SUPPLEMENTARY MATERIAL FROM CHAPTER 02

This document provides a broad description regarding the paper Socio-Hydrology Observatory for Water Security: An initial citizen Science Experience in Brazil (Souza et al., 2019). First, a description of the employed variables allows readers to understand how the task in this experiment was developed and how each question quantifies respective variables. Then, a table with results is provided.

01) VARIABLES

In this experiment, the variables that were reported by volunteers were adapted from the paper A Dynamic Framework for Water Security (SRINIVASAN; KONAR; SIVAPALAN, 2017). The variable are explained as follows:

i) **Water Resources Utilization Intensity (PW/P+I):** It represents the proportion between water consumption to produce goods and services (PW) and the available water resources (P+I). Srinivasan et al. (2017) propose to study this index as a fraction in terms of volume for both variables.

ii) **Trade and Technology (TT):** Investments on infrastructures to ensure access to safe water or capability to import water or virtual water embedded in commodities. Srinivasan et al. (2017) suggest to evaluate this variable through GDP/capita index.

iii) **Spatial Heterogeneity in Production and Consumption of Virtual Water (PW/CW):** the ratio between water consumed to produce goods (PW) and the water embedded in consumed products (CW). This index (PW/CW) allow us to evaluate if the study field is exporting or importing water. Similarly to the first variable, it was no unit since both factors should be accounted in volumetric units.

02) THE TASK

The task proposed within the context of the initial experiment of SHOWS (Souza et al., 2019) consist on asking volunteers questions that allow us to quantify the aforementioned variables for the present and for 15, 25 and 50 years in advance. The questionnaire is illustrated in Figure 16, where letter "X" symbolize the scenarios. It is available at https://shows.ushahidi.io.

Therefore, the task is based upon principles, attitudes and actions related to multidisciplinary options of sustainable water resources practices, with respective norms and values of socio-hydrological models (ELSHAFEI et al., 2014; MENDIONDO; VALDÉS, 2002; ROOBAVANNAN et al., 2018; SIVAPALAN; SAVENIJE; BLÖSCHL, 2012; SRINIVASAN et al., 2018) By underpinning sustainability development, open principles arise like: “What lessons could be learned”? “In what way multi-finality responses should be approached robustly”? “How these socio-hydrological principles offer linking tracks through integrated water management”?

In order to establish a quantitative assessment of possible trajectories, we proposed the checkbox answers, so volunteers can choose which option better reflects what they think will happen in the future. The checkbox was employed to avoid possible mistakes such as values that might present a meaning unconnected with the reality and answers that cannot be quantified (without numbers).

To calculate the result, we adopted the following equations:

- **Present**

$$\frac{PW}{P+I}_{present} = \frac{Q_1 + Q_2}{2}$$

$$\frac{PW}{CW}_{present} = Q_3 + Q_4 + Q_5$$

$$TT_{present} = Q_6$$

- **15 years later**

$$\frac{PW}{P+I}_{15} = \frac{Q_7 + Q_8}{2}$$

$$\frac{PW}{CW}_{15} = Q_9 + Q_{10} + Q_{11}$$

$$TT_{15} = (1 + Q_{13})Q_{12}$$

Figure 16: Questions of SHOWS' initial experiment

01) How much of the total food you consume **today**, do you believe is produced in the city where you live?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

02) How much of the total products you buy **today**, do you believe is manufactured in the city where you live?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

03) How much of the total water available in your city do you believe is used to produce food **today**?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

04) How much of the total water available in your city do you believe is used to make new products **today**?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

05) How much of the total water available in your city do you believe is consumed by the residences **today**?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

06) How much of the total financial resources that the municipal authorities have **today** is invested to ensure that there is no shortages?

☐ 0 – 1% ☐ 1 – 2% ☐ 2 – 3% ☐ 3 – 4% ☐ 4 – 5%

07) How much of the total food you will consume **in x years**, do you believe will be produced in the city where you live?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

08) How much of the total products you will buy **in X years** do you believe will be manufactured in the city where you live?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

09) How much of the total water available in your city do you believe will be used to produce food **in X years**?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

10) How much of the total water available in your city do you believe will be used to make new products **in x years**?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

11) How much of the total water available in your city do you believe will be consumed by the residences **in x years**?

☐ 0 – 20% ☐ 21 – 40% ☐ 41 – 60% ☐ 61 – 80% ☐ 81– 100%

12) How much of the total financial resources that the municipal authorities will have **in x years** do you believe will invest to ensure there is no shortage?

☐ 0 – 1% ☐ 1 – 2% ☐ 2 – 3% ☐ 3 – 4% ☐ 4 – 5%

13) How much do you think the financial resources of your city will vary **in x years**?

☐ Raise 0 – 5% ☐ Raise 5 – 10% ☐ It will be the same ☐ Decrease 0 – 5% ☐ Decrease 5 – 10%

- **25 years later**

$$\frac{PW}{P+I_{25}} = \frac{Q_7 + Q_8}{2}$$

$$\frac{PW}{CW_{25}} = Q_9 + Q_{10} + Q_{11}$$

$$TT_{25} = (1 + Q_{13})Q_{12}$$

- **50 years later**

$$\frac{PW}{P+I_{50}} = \frac{Q_7 + Q_8}{2}$$

$$\frac{PW}{CW_{50}} = Q_9 + Q_{10} + Q_{11}$$

$$TT_{50} = (1 + Q_{13})Q_{12}$$

where $\frac{PW}{P+I}$ is Water Resources Utilization Intensity, $\frac{PW}{CW}$ is Spatial Heterogeneity in Production and Consumption of Virtual Water, TT is Trade and Technology, $Q_1$is the answer of question 1, Q_2 is the answer of question 2, Q_3 is the answer of question 3, Q_4 the answer of question 4, Q_5 is the answer of question 4, Q_5 is the answer of question 5, Q_6 is the answer of question 6, Q_7 is the answer of question 7 regarding the correspondent time scale, Q_8 is the answer of question 8 regarding the correspondent time scale, Q_9 is the answer of question 9 regarding the correspondent time scale, Q_{10} is the answer of question 10 regarding the correspondent time scale, Q_{11} is the answer of question 11 regarding the correspondent time scale, Q_{12} is the answer of question 12 regarding the correspondent time scale, Q_{13} is the answer of question 13 regarding the correspondent time scale.

03) RESULT

Fifty-five volunteers performed this experiment and answered such questions illustrated in Figure 16. The answers were calculated according to the equations formulated in previous section and the result is presented in Table 4.

Section 2.4 of chapter 2 provides a discussion concerning the results, as well as Figure 7 in paper illustrates trajectories according to individual and collective perspectives. The trajectories were outlined when plotting the variables against each other.

Table 4: Result of SHOWS first experiment

Volunteer ID	Today			15 Years			25 Years			50 Years		
	Pw/(P+I)	TT	Pw/Cw	Pw/(P+I)	TT	Pw/Cw	Pw/(P+I)	TT	Pw/Cw	Pw/(P+I)	TT	Pw/Cw
1	0,90	0,03	0,20	0,90	0,01	0,20	0,70	0,01	0,10	1,10	0,02	0,10
2	1,10	0,02	0,10	0,90	0,02	0,10	0,70	0,05	0,10	0,70	0,06	0,10
3	0,70	0,02	0,10	1,10	0,05	0,20	0,90	0,06	0,20	1,30	0,06	0,20
4	0,90	0,02	0,20	0,90	0,02	0,30	0,70	0,02	0,10	0,70	0,08	0,10
5	0,30	0,02	0,10	0,30	0,03	0,10	0,30	0,04	0,10	0,30	0,04	0,10
6	1,10	0,04	0,10	1,10	0,05	0,20	1,10	0,05	0,20	1,10	0,05	0,20
7	0,50	0,02	0,10	0,70	0,02	0,10	0,90	0,02	0,10	1,10	0,04	0,30
8	1,10	0,03	0,20	0,70	0,02	0,10	0,50	0,03	0,40	0,50	0,03	0,40
9	0,90	0,02	0,20	1,10	0,03	0,10	0,90	0,04	0,20	0,90	0,04	0,30
10	1,10	0,01	0,30	0,90	0,02	0,20	0,90	0,03	0,10	1,10	0,04	0,10
11	0,90	0,02	0,20	0,90	0,03	0,10	0,90	0,03	0,10	0,70	0,06	0,10
12	0,70	0,03	0,20	0,40	0,03	0,10	0,70	0,03	0,10	0,70	0,02	0,10
13	1,10	0,02	0,20	1,10	0,02	0,20	0,90	0,03	0,20	0,90	0,04	0,20
14	1,10	0,01	0,10	1,10	0,02	0,10	1,30	0,02	0,10	1,10	0,03	0,10
15	1,10	0,01	0,10	1,10	0,02	0,10	1,10	0,03	0,10	0,90	0,05	0,10
16	0,90	0,02	0,10	0,90	0,06	0,10	0,90	0,03	0,20	0,90	0,05	0,40
17	1,10	0,03	0,10	1,10	0,03	0,10	1,30	0,04	0,30	1,10	0,04	0,40
18	1,30	0,01	0,30	1,30	0,10	0,60	0,10	0,04	0,60	0,90	0,05	0,70
19	0,70	0,01	0,10	0,70	0,03	0,10	0,50	0,03	0,10	1,30	0,03	0,40
20	0,90	0,01	0,20	0,70	0,03	0,20	0,90	0,03	0,20	0,90	0,03	0,65
21	0,70	0,01	0,10	0,90	0,04	0,10	0,90	0,04	0,10	0,90	0,05	0,20
22	0,90	0,01	0,20	1,70	0,08	0,30	1,50	0,10	0,40	2,30	0,06	0,70
23	0,90	0,02	0,40	0,90	0,02	0,10	0,50	0,02	0,10	0,50	0,03	0,10
24	1,10	0,01	0,10	1,30	0,03	0,10	0,90	0,02	0,10	1,50	0,03	0,30
25	0,50	0,01	0,10	0,90	0,02	0,10	0,90	0,02	0,10	1,10	0,02	0,10

26	0,90	0,01	0,20	0,90	0,02	0,10	0,50	0,02	0,20	0,90	0,02	0,50
27	1,10	0,01	0,40	1,30	0,02	0,10	1,10	0,02	0,10	0,70	0,03	0,10
28	0,50	0,02	0,10	0,70	0,02	0,10	0,50	0,01	0,10	1,10	0,01	0,10
29	1,70	0,01	0,30	1,70	0,02	0,30	1,50	0,01	0,30	1,50	0,01	0,30
30	0,90	0,01	0,10	0,90	0,05	0,10	0,90	0,05	0,10	0,90	0,05	0,10
31	1,10	0,01	0,10	1,30	0,03	0,10	1,10	0,06	0,20	1,30	0,06	0,60
32	0,90	0,01	0,10	0,70	0,08	0,15	0,70	0,06	0,50	1,30	0,06	0,60
33	0,70	0,02	0,10	0,90	0,02	0,20	0,90	0,01	0,20	0,90	0,01	0,10
34	1,50	0,02	0,30	1,70	0,04	0,30	0,80	0,03	0,30	0,50	0,06	0,50
35	1,50	0,03	0,10	1,50	0,05	0,10	1,50	0,05	0,20	0,90	0,06	0,30
36	0,70	0,02	0,30	0,70	0,02	0,30	0,90	0,03	0,30	0,90	0,06	0,30
37	1,30	0,01	0,30	0,90	0,05	0,20	1,30	0,05	0,30	1,30	0,06	0,40
38	0,90	0,01	0,10	1,10	0,05	0,10	1,10	0,05	0,10	1,10	0,05	0,10
39	0,70	0,02	0,10	0,50	0,03	0,10	0,30	0,03	0,10	0,30	0,03	0,10
40	1,50	0,04	0,50	1,50	0,05	0,50	1,50	0,05	0,50	1,50	0,05	0,50
41	1,10	0,01	0,30	1,70	0,04	0,50	1,70	0,05	0,30	0,50	0,05	0,20
42	0,90	0,01	0,10	0,90	0,04	0,20	0,90	0,05	0,10	0,90	0,05	0,10
43	0,70	0,01	0,20	0,70	0,03	0,20	0,90	0,05	0,30	0,70	0,05	0,30
44	0,70	0,01	0,10	0,30	0,04	0,30	0,70	0,04	0,30	1,10	0,04	0,10
45	1,10	0,01	0,30	1,30	0,01	0,20	1,30	0,01	0,20	1,10	0,01	0,10
46	1,30	0,01	0,10	1,10	0,05	0,10	1,30	0,05	0,40	1,30	0,05	0,30
47	1,10	0,02	0,20	1,30	0,03	0,30	1,50	0,05	0,30	1,90	0,10	0,40
48	0,90	0,01	0,10	1,10	0,03	0,10	1,10	0,03	0,10	1,70	0,04	0,10
49	1,70	0,02	0,20	1,90	0,04	0,40	1,70	0,04	0,50	1,70	0,05	0,50
50	0,90	0,01	0,20	1,10	0,04	0,20	0,70	0,05	0,30	0,90	0,05	0,40
51	1,10	0,01	0,10	1,30	0,03	0,20	2,30	0,03	0,20	2,30	0,03	0,30
52	0,70	0,01	0,10	0,90	0,03	0,10	0,70	0,03	0,10	0,70	0,04	0,10
53	1,30	0,04	0,30	1,50	0,03	0,40	1,30	0,04	0,30	0,70	0,03	0,10

54	1,50	0,01	0,20	1,70	0,02	0,10	0,90	0,04	0,30	1,10	0,05	0,40
55	1,10	0,01	0,10	1,50	0,05	0,10	1,10	0,05	0,20	0,90	0,06	0,20

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APPENDIX B: SUPPLEMENTARY MATERIAL FROM CHAPTER 03

This appendix provides a broad description regarding the third chapter: "Engaging Citizens' Perception in the Water Footprint Assessment as A Local Adaptation Strategy". We breakdown each part of the total water footprint in order to facilitate the readers' comprehension of each step. We also provide some examples to illustrate the hypothesis we took into consideration and how we employed different datasets in our calculation.

1. Blue Water Footprint.

We split the blue water footprint into two parts, domestic and economic demands. The domestic demand is the combination of individual consumption and water losses in pipelines, while the economic demands regard the volume consumed and registered by industries and farm fields in São Carlos

1.1 Domestic demand

We obtained the domestic demand from Equation 1 and 2, as follows:

$$Q_l = \frac{Q_{hh}}{1-L} - Q_{hh} \qquad \text{Equation 1}$$

$$D_{hh} = Q_l + Q_{hh} \qquad \text{Equation 2}$$

Example 01: In 2013 the population in São Carlos was equal to 226,987 inhabitants (SEADE, 2018), the average of individual water consumption was 201.30 liters*inhabitant^{-1}*day^{-1} (SNIS, 2018) and the water losses index was equal to 44.76% (SNIS, 2018). What was the domestic demand of water in 2013?

According to Equation 1, the volume of water losses was equal to:

$$Q_l = \frac{Q_{hh}}{1-L} - Q_{hh}$$

$$Q_l = \frac{201.30}{1-0.4476} - 201.30 = 163.11 \frac{liters}{inhabitant * day}$$

The demand of each citizen is equal to:

$$D_{hh} = Q_l + Q_{hh}$$

$$D_{hh} = 201.30 + 164.7 = 364.41 \frac{liters}{inhabitant * day} = 133.01 \frac{m^3}{inhabitant * year}$$

The municipal domestic consumption is equal to:

$$D_{hh} = D_{hh} * Population$$

$$D_{hh} = 133.49 * 226{,}987 = 30.2 * 10^6 \frac{m^3}{year}$$

1.2 Economic sector's demand

We obtained the demands from the economic sector for previous years from Situation Reports, issued by the *Tietê-Jacaré River Basin Committee*. For future scenarios, we considered that water demand for each sector (industrial and agricultural) would follow the same growth of participation in municipal GDP.

Example 02: The transforming industries are the main responsible for industrial production in São Carlos city. According to the report "*The long view: how will the global economic order change by 2050*" (PwC, 2017), the Brazilian GDP, at Purchasing Power Parity, was equal to U$ 3135 billion, in 2016, and it is expected to reach U$ 4439 billion, in 2030. However, according to the report "*Cenário Econômico 2050*" (EPE, 2015), the projections on the participation of industrial activities at the national GDP corresponds to 27.2%, 25.9% and 26.7% for 2013, 2020 and 2030, respectively. In addition, the same report presents a projection on how participation of transforming industries at the total industrial activities. The prediction reveals that it corresponds to 56.4%, 52.7% and 51.5% for 2013, 2020 and 2030 respectively. Consider that industrial water demand in São Carlos corresponds to $2.87 * 10^6 m^3$ in 2016 and assume the hypothesis that water demands will follow the same patterns of economic sector growth, what will be the water demand from local industries in 2030?

Step 01: Calculating the GDP growth rate in percentage.

$$GDP\ growth_{2016-2030} = \frac{GDP_{2030} - GDP_{2016}}{GDP_{2016}}$$

$$GDP\ growth_{2016-2030} = \frac{4439 - 3135}{3135} = 41.49\%$$

Step 02: Determining the industrial sector growth in percentage

$$Ind\ Part_{2016} = \frac{(Ind\ Part_{2020} - Ind\ Part_{2013}) * (2016 - 2013)}{(2020 - 2013)} + Ind\ Part_{2013}$$

$$Ind\ Part_{2016} = \frac{(25{,}9\% - 27{,}2\%) * (2016 - 2013)}{(2020 - 2013)} + 27{,}2\% = 26{,}64\%$$

Step 03: Determining the participation of transforming industry in percentage of GDP

$$Transf\ \ Ind_{2016} = \frac{(Transf\ \ Ind_{2020} - Transf\ \ Ind_{2013}) * (2016 - 2013)}{(2020 - 2013)} + Transf\ \ Ind_{2013}$$

$$Transf\ \ Ind_{2016} = \frac{(52{,}7\% - 56{,}4\%) * (2016 - 2013)}{(2020 - 2013)} + 56{,}4\% = 54{,}81\%$$

Step 03: Determining the participation of transforming industry in U$ billion.

$$Transf\ \ Ind_{2016} = 3135 * 26{,}64\% * 54{,}81\% = 457{,}75$$

$$Transf\ \ Ind_{2030} = 4439 * 25{,}7\% * 51{,}5\% = 587{,}52$$

Step 04: Determining the transforming participation growth on economy.

$$Transf\ \ Ind\ Growth_{2016-2030} = \frac{587{,}52 - 457{,}75}{457{,}7533} = 28{,}35\%$$

Step 05: Determining the water demand from industrial activities

$$Water\ Demand_{2016-2030} = Water\ Demand_{2016} * (1 + Transf\ \ Ind\ Growth_{2016-2030})$$

$$Water\ Demand_{2016-2030} = 2.87 * 10^6 m^3/year * (1 + 28.35\%) = 3.68 * 10^6 m^3/year$$

2. Gray Water Footprint.

We split the gray water footprint into two parts according to the origin of pollutants. The first one refers to the discharges of domestic wastewater into water bodies after the treatment of sewage plants. The second one concerns the leachate produced at the municipal sanitary landfill, which receives domestic solid waste. In this section, we present how we calculated the volume of pollutants and its respective index of water quality, the biological demand of oxygen.

2.1 Effluents from sewage treatment.

The wastewater collected from houses in São Carlos goes to one of the sewage treatment plants located within the municipal territory. Our main hypothesis on this processes considered that the water quality index is a function of investments in such sewage treatment systems. Based on the available time series on volume of sewage collected (SNIS, 2018), Organic load of treated sewage that is discharged into local water bodies (CBHTJ, 2010 to 2018) and investments made in sewage systems (SNIS, 2018), we got the following linear regression:

$$\frac{Biological\ Demand\ of\ Oxygen\ kg}{m^3} = -0.01(Investments\ 10^6 R\$) + 0.262$$

Next, we wanted to find what would be the volume required to dilute such effluents (Q_d) based on Equation 3 (TUCCI, 2017). In this equation, we got the volume of effluents (Q_p) from statistical analysis on time series and the recommendation from Von Sperling (1996). The index of water quality (c_1) based on such investments was obtained from the previous function, where investments are considered fraction of municipal GDP. We built two scenarios, *a)* considering the average of such fraction of all previous years and *b)* considering the answers of volunteers regarding how these investments will change in the future. Then, we assumed the BDO of diluting water would be equal to 1mg/liter. Lastly, according to local water bodies classification, established by the CONAMA resolution number 357/2005 (Brazil, 2005), we determine the water quality index desired (c_3).

$$Q_p * c_1 + Q_d + c_2 = (Q_p + Q_d)c_3 \qquad \text{Equation 3}$$

Example 03: Considering that, the BDO limit of a water body next to the sewage treatment plant is equal to 5mg/l, what is the volume of water required to dilute wastewater discharged into this water body in 2030?

Assume that:

a) Municipal GDP in 2016 is equal to R$10.06*$10^9$;

b) The GDP growth rate for this period is equal to 41.49%;

c) The interest rate used to calculate the Net Present Value corresponds to 6.5%/year;

d) Investments in sanitation systems corresponded to R$126,167.86 in 2016;

e) Historically, the investments' average in sanitation systems in São Carlos city corresponds to 0.04% of municipal GDP;

f) Volunteers believe that such fraction of GDP will increase 47.43% in 2030;

g) The number of São Carlos' citizens in 2030 will be equal to 253,937;

h) The Von Sperling's recommendation affirms that each citizen produces 160 liters of sewage per day;

i) Time series of individual's yearly sewage production ranges from 56.67 to 68.79 liters;

<u>Step 01:</u> Determining volume of sewage production in 2030 – Von Sperling's recommendation

$$Sew_{VS_{2030}} = Population_{2030} * Ind.Daily\ Prod. * 365\ days$$

$$Sew_{VS_{2030}} = 253{,}937 * 160\ liters * 365\ days = 14{,}829{,}920.80\ m^3$$

<u>Step 02:</u> Determining volume of sewage production in 2030 – time series confidence interval

$$Sew_{upper\ limit_{2030}} = Population_{2030} * Ind.Yearly\ Prod.$$

$$Sew_{upper\ limit_{2030}} = 253{,}937 * 68.79 = 17.468.326{,}23\ m^3$$

$$Sew_{lower\ limit_{2030}} = Population_{2030} * Ind.Yearly\ Prod.$$

$$Sew_{lower\ limit_{2030}} = 253{,}937 * 56.67 = 14{,}390{,}609.79 m^3$$

<u>Step 03:</u> Determining municipal GDP in 2030

$$GDP_{2030} = (1 + GDP\ growth\ rate_{2016-2030}) * GDP_{2016}$$

$$GDP_{2030} = (1 + 47.43\%) * \text{R\$}10{,}06 * 10^9 = \text{R\$}14{,}24 * 10^9$$

From this point, we split the scenarios according to the investments in sanitation infrastructure. Firstly, we consider as an average of previous years. Latter, as a perception from volunteers on how such investments, as a fraction of municipal GDP, will change in 2030 according to their beliefs.

AVERAGE OF PREVIOUS YEARS

Step 04A: Determining investments in sanitation systems in 2030 – average of previous years

$$Value\ of\ Investments_{2030_{average}} = fraction\ of\ GDP_{average} * GDP_{2030}$$

$$Value\ of\ Investments_{2030_{average}} = 0.04\% * \text{R\$}14.24 * 10^9 = \text{R\$}5.69 * 10^6$$

$$Net\ Present\ Value_{2030_{average}} = \left(\frac{Value\ of\ Investments_{2030_{average}}}{(1 + r)^{(2030-2016)}}\right)$$

$$Net\ Present\ Value_{2030_{average}} = \left(\frac{\text{R\$}5.69 * 10^6}{(1 + 6{,}5\%)^{(2030-2016)}}\right) = \text{R\$}2.95 * 10^6$$

Step 05A: Calculating wastewater quality parameter (BDO) – average of previous years

$$\frac{BDO\ kg}{m^3} = -0.01(Investments\ 10^6 R\$) + 0.262$$

$$\frac{BDO\ kg}{m^3} = -0.01(2.95) + 0.262 = 0{,}23\ \frac{BDO\ kg}{m^3}$$

Step 06A: Determining water needed to dilute pollutants from wastewater discharge – average of previous years

Von Sperling recommendation:

$$Q_p * c_1 + Q_d * c_2 = \left(Q_p + Q_d\right) * c_3$$

$$14{,}829{,}920.80\ m^3 * 0{,}23\ \frac{BDO\ kg}{m^3} + Q_d * 1 * 10^{-3}\ \frac{BDO\ kg}{m^3} = (14{,}829{,}920.80\ m^3 + Q_d) * 5 * 10^{-3}\ \frac{BDO\ kg}{m^3}$$

$$Q_d = 842.24 * 10^6 m^3$$

Confidence Interval

Upper Limit:

$$Q_p * c_1 + Q_d * c_2 = (Q_p + Q_d) * c_3$$

$$17.468.326,23\ m^3 * 0,23\ \frac{BDO\ kg}{m^3} + Q_d * 1 * 10^{-3}\ \frac{BDO\ kg}{m^3} = (17.468.326,23\ m^3 + Q_d) * 5 * 10^{-3}\ \frac{BDO\ kg}{m^3}$$

$$Q_d = 992.09 * 10^6 m^3$$

Lower Limit:

$$Q_p * c_1 + Q_d * c_2 = (Q_p + Q_d) * c_3$$

$$14{,}390{,}609.79 m^3 * 0,23\ \frac{BDO\ kg}{m^3} + Q_d * 1 * 10^{-3}\ \frac{BDO\ kg}{m^3} = (14{,}390{,}609.79 m^3 + Q_d) * 5 * 10^{-3}\ \frac{BDO\ kg}{m^3}$$

$$Q_d = 817.29 * 10^6 m^3$$

PERCEPTION OF VOLUNTEERS

Step 04B: Determining investments in sanitation systems in 2030 – perception of volunteers

$$Value\ of\ Investments_{2030_{volunteers}} = fraction\ of\ GDP_{2016} * \left(1 + growth\ rate_{2016-2030_{volunteers}}\right) * GDP_{2030}$$

$$Value\ of\ Investments_{2030_{volunteers}} = 0.01\% * (1 + 47.43\%) * \text{R\$}14,24 * 10^9 = \text{R\$ } 2.10 * 10^6$$

$$Net\ Present\ Value_{2030_{volunteers}} = \left(\frac{Value\ of\ Investments_{2030_{volunteers}}}{(1+r)^{(2030-2016)}}\right)$$

$$Net\ Present\ Value_{2030_{volunteers}} = \left(\frac{\text{R\$ } 2.10 * 10^6}{(1 + 6.5\%)^{(2030-2016)}}\right) = \text{R\$}0.87 * 10^6$$

<u>Step 05B:</u> Calculating wastewater quality parameter (BDO) – perception of volunteers

$$\frac{BDO\ kg}{m^3} = -0.01(Investments\ 10^6 R\$) + 0.262$$

$$\frac{BDO\ kg}{m^3} = -0.01(0.87) + 0.262 = 0{,}25\ \frac{BDO\ kg}{m^3}$$

<u>Step 06B:</u> Determining water needed to dilute pollutants from wastewater discharge – perception of volunteers

<u>Von Sperling recommendation:</u>

$$Q_p * c_1 + Q_d * c_2 = (Q_p + Q_d) * c_3$$

$$14{,}829{,}920.80\ m^3 * 0{,}25\ \frac{BDO\ kg}{m^3} + Q_d * 1 * 10^{-3}\ \frac{BDO\ kg}{m^3} = (14{,}829{,}920.80\ m^3 + Q_d) * 5 * 10^{-3}\ \frac{BDO\ kg}{m^3}$$

$$Q_d = 920.28 * 10^6 m^3$$

<u>Confidence Interval</u>

<u>Upper Limit:</u>

$$Q_p * c_1 + Q_d * c_2 = (Q_p + Q_d) * c_3$$

$$17.468.326{,}23\ m^3 * 0{,}25\ \frac{BDO\ kg}{m^3} + Q_d * 1 * 10^{-3}\ \frac{BDO\ kg}{m^3} = (17.468.326{,}23\ m^3 + Q_d) * 5 * 10^{-3}\ \frac{BDO\ kg}{m^3}$$

$$Q_d = 1{,}084.01 * 10^6 m^3$$

<u>Lower Limit:</u>

$$Q_p * c_1 + Q_d * c_2 = (Q_p + Q_d) * c_3$$

$$14{,}390{,}609.79m^3 * 0{,}25\ \frac{BDO\ kg}{m^3} + Q_d * 1 * 10^{-3}\ \frac{BDO\ kg}{m^3} = (14{,}390{,}609.79m^3 + Q_d) * 5 * 10^{-3}\ \frac{BDO\ kg}{m^3}$$

$$Q_d = 893.02 * 10^6 m^3$$

2.2 Leachate from sanitary landfill

The first step to determine the water needed to dilute the leachate from sanitary landfill consists on finding the volume of leachate yearly produced. It can be calculated by employing the equations 4 to 7, described in section 3.3.2. We demonstrate how we performed such method by filling the Table 5.

$$C_{sl} \geq \sum_{i=1}^{T} Pop_i * g_i \quad \text{Equation 9}$$

$$L_i = P_i - ETp_i \quad \text{Equation 10}$$

$$Q_{g_i} = \frac{G_i}{C_{sl}} * \sum_{j=1}^{j=T} L_j \quad \text{Equation 11}$$

$$Q_{g_i} * c_1 + Q_d * c_2 = \left(Q_{g_i} + Q_d\right) * c_3 \quad \text{Equation 12}$$

Initially, we found how many years (t) would be necessary to reach the landfill's capacity (C_{sl}). We added the yearly production of domestic waste in column 2, which is obtained from the product of population (Pop_i) by individual production of waste (g_i) in year i. We built two scenarios and compared the results from such level of domestic production according to a) the confidence interval based on time series of domestic waste production in São Carlos (CETESB, 2004 to 2010) and; b) the citizens' perspectives on their own future production. Then, we calculated the column [3], which is the yearly correspondent contribution to reach the total capacity, by dividing column [2] byC_{sl}.

Next, we determined what the correspondent production of leachate for each year is (column [7]). First, we found the production of leachate in column [6], as the difference from precipitation (column [4]) and evapotranspiration (column [5]). These hydrological data is a result of PROJETA (2018) for scenarios RCP 4.5 and RCP 8.5 for the region of São Carlos city. The total volume of leachate produced during landfill's service life (VOL) is the sum of each cell in column [6]. Finally, we determined the correspondent production of each year (column [7]), by multiplying column [2] by column [6].

Once we had the volume of leachate for each year, we employed the results of Justo (2018), which provides the BDO of municipal sanitary landfill. Thus, we are able to account the total volume of water required to the dilute leachate production.

Table 5: Procedure to determine the correspondent volume of leachate for each year

[1] Year	[2] Domestic Waste Production (tons)	[3] Percentage Capacity (%)	[4] P	[5] Et_p	[6] Leachate (m)	[7] Leachate as a function of capacity (m)
1	G_1	$\%_1$	P_1	ETp_1	L_1	Vol_1
2	G_2	$\%_2$	P_2	ETp_2	L_2	Vol_2
3	G_3	$\%_3$	P_3	ETp_3	L_3	Vol_3
⋮	⋮	⋮	⋮	⋮	⋮	⋮
t	G_t	$\%_t$	P_t	ETp_t	L_t	Vol_t
Σ	C_{sl}	100%			Vol	

3. Green Water Footprint.

The green water footprint is the only part of this work that did not employ volunteered information. We considered it as the product of agricultural area by the potential evapotranspiration. The current area occupied by farming fields in São Carlos city was obtained from SEADE (2018) and growth of these areas was assumed the same from the predictions of EPE (2015), which provides a prediction on agriculture and agricultural area growth for the whole country. The evapotranspiration data is the result from the PROJETA (2018) for scenarios RCP 4.5 and RCP 8.5.

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APPENDIX C: ETHICS COMMITTEE DECISION

The following pages are the final decision from the ethics committee of the "*Escola de Artes, Ciências e Humanidades"* regarding the second experiment, presented in chapter 3, which involved general citizens in data gathering.

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: MULTIDADOS DE RESILIÊNCIA URBANA VIA OBSERVATÓRIO CIDADÃO SÓCIO HIDROLÓGICO EM CIDADES SUSTENTÁVEIS

Pesquisador: FELIPE AUGUSTO ARGUELLO DE SOUZA

Área Temática:

Versão: 2

CAAE: 02911818.2.0000.5390

Instituição Proponente: UNIVERSIDADE DE SAO PAULO

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 3.079.239

Apresentação do Projeto:

Trata-se de pesquisa que visa avaliar a percepção dos cidadãos, que são os usuários finais dos recursos hídricos, de uma bacia hidrográfica no processo de gestão e governança.Trata-se de pesquisa qualitativa e quantitativa, para avaliar a percepção dos cidadãos, que são os usuários para isto, será feita a avaliação quantitativa utilizando a pegada hídrica. Assim, será possível verificar se os dados fornecidos pelos voluntários estão dentro do intervalo de cenários elaborados com base em dados oficiais e modelos existentes de segurança hídrica.

Objetivo da Pesquisa:

O objetivo de estudo deste projeto consiste na integração de dados existentes de demandas de água, com resultados dos modelos de mudanças climáticas desenvolvidos por outros projetos existentes e com a percepção dos cidadãos frente a estas transformações, com a finalidade de compreender como serão as demandas futuras pelos recursos hídricos. A integração de todas estas informações se dará pela quantificação das séries históricas e projeções oficiais, impactos possíveis das alterações climáticas e parecer dos voluntários com base em seus conhecimentos e padrões de consumo.

Avaliação dos Riscos e Benefícios:

Benefícios

O benefício deste experimento está relacionado à possibilidade da minha contribuição no processo

de governança dos recursos hídricos da região onde eu vivo. Este benefício trata-se da oportunidade de poder exprimir suas crenças, conhecimentos, opinião nas tomadas de decisão que impactarão meu cotidiano e o futuro das minhas gerações.
Riscos
Riscos mínimos, como desconforto moral, ético ou físico.

Comentários e Considerações sobre a Pesquisa:

Pesquisa relevante para a área de Gestão ambiental.

Considerações sobre os Termos de apresentação obrigatória:

Todos os termos estão de acordo com A Resolução 466/2012 relacionada à Ética em Pesquisa com Seres Humanos e estão inseridos na Plataforma Brasil.

Recomendações:

Não há recomendações.

Conclusões ou Pendências e Lista de Inadequações:

Parecer aprovado, pois está de acordo com A Resolução 466/2012 relacionada à Ética em Pesquisa com Seres Humanos.

Considerações Finais a critério do CEP:

Parecer aprovado, pois está de acordo com A Resolução 466/2012 relacionada à Ética em Pesquisa com Seres Humanos.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1231309.pdf	12/12/2018 11:47:46		Aceito
Parecer Anterior	Carta_resposta_pendencia.pdf	12/12/2018 11:46:07	FELIPE AUGUSTO ARGUELLO DE SOUZA	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_revisado.pdf	12/12/2018 11:45:50	FELIPE AUGUSTO ARGUELLO DE SOUZA	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_revisado.pdf	12/12/2018 11:45:28	FELIPE AUGUSTO ARGUELLO DE SOUZA	Aceito
Declaração de Pesquisadores	DeclaracaoDoPesquisador.pdf	03/10/2018 15:49:31	FELIPE AUGUSTO ARGUELLO DE	Aceito

Declaração de Pesquisadores	DeclaracaoDoPesquisador.pdf	03/10/2018 15:49:31	SOUZA	Aceito
Declaração de Instituição e Infraestrutura	INFRAESTRUTURA.pdf	03/10/2018 15:44:22	FELIPE AUGUSTO ARGUELLO DE SOUZA	Aceito
Folha de Rosto	FolhaDeRosto.pdf	03/10/2018 15:42:34	FELIPE AUGUSTO ARGUELLO DE SOUZA	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

SAO PAULO, 13 de Dezembro de 2018

Assinado por:
Beatriz Aparecida Ozello Gutierrez
(Coordenador(a))